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Forages in Southeast Asian and South Pacific Agriculture

Proceedings of an international workshop held at
Cisarua, Indonesia, 19–23 August 1985

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Foreword

RUMINANT animals are an important component of the economic development of the Southeast Asian and South Pacific regions. In many countries they are major contributors to draught power, and are increasingly important as a source of meat, milk and and other livestock products.

As the population increases and general economic development proceeds, consumption of meat derived from small and large ruminants is rising. This increase in consumption, together with increased demand for draught power resulting from crop intensification, poses a major challenge for national and international research agencies to improve the quality and quantity of the forage resources needed to provide for this increase in the animal population.

Australia is making a significant contribution to overcoming these problems in Indonesia through the ADAB-sponsored Forage Research Project (FRP) which is located within the Animal Husbandry Research Institute (Balai Penelitian Ternak – BPT). This program, in addition to research is training Indonesian researchers in various aspects of forage production and utilisation.

The complementary nature of the Forage Research Project and ACIAR's interests in the region enabled the Australian agencies, together with the Agency for Agricultural Research and Development (AARD) in Indonesia, to bring together scientists from Southeast Asia and the South Pacific to focus on past, present and future forage research activities in the region.

ACIAR wishes to thank Professor Dr. J. H. Hutasoit, Junior Minister for Development of Livestock and Fisheries Production, Professor Dr Ir Gunawan Satari, Director-General of AARD, Drh Jan Nari, Director, Central Research Institute for Animal Science (CRIAS) and Drh Putu Kompiang, Director, BPT, for their support. Thanks are also extended to the participants who presented papers and contributed to the valuable discussion sessions, and to Mrs Janet Lawrence for her technical editing of this volume and supervision of its production. The support provided by FRP staff in Indonesia and at the University of New England, Armidale, deserves special mention. Without it the meeting would not have been possible.

The meeting provided a valuable forum for scientists in the region to share experiences, and to identify areas of high priority in forage research that will contribute to the continuing development of forage as an important component of the farming systems throughout the region.

J.R. McWilliam
Director
ACIAR

Welcoming Address

It is indeed a pleasure to welcome participants to this seminar on Forages in Southeast Asian and South Pacific Agriculture. The topic is an extremely important one. Indonesia, like many other countries in this region, is in need of substantial research on all aspects of forage production. There is the need to study integrated pasture and livestock systems, to understand and develop methods of improving the vast areas of low quality pastures, particularly in the eastern parts of this country, and the management of these pastures. There is also the need to produce forages to maintain livestock through the dry season, which in some parts of Indonesia may last for seven months. In this regard shrubs and trees make a substantial contribution to the feed base. The identification of suitable forage species and the production of viable pasture and legume seeds all need considerable research.

The Indonesian/Australian project on forage research located at Ciawi and Gowa in South Sulawesi, is establishing a firm basis for the development of forage research programs. The exchange of scientists in both countries is not only useful for research purposes but also it strengthens the links between our two nations.

This seminar is supported by the Australian Centre for International Agricultural Research and the Australian Development Assistance Bureau, and we thank these organisations, the Central Research Institute for Animal Science and the Research Institute for Animal Production for their assistance and organisation of this seminar. Seminars of this nature are not only useful in that they are a forum for the presentation of formal scientific papers. There is also exchange of information, discussion and the opportunity to meet with scientists with common interests from many parts of the world. It is this personal contact that is so often the most important benefit of international meetings such as this one.

I sincerely hope that all of you will enjoy your stay here in Indonesia, even though it is very short, and that you will find the seminar both useful and memorable.

It is now my pleasure to declare this seminar officially open.

Gunawan Satari
Director General
Agency for Agricultural Research
and Development, Indonesia

Keynote Address

THIS is a conference on the production and utilisation of forages. Forage production, whether it be from cultivated or volunteer grasses and legumes, from fodder trees or from cropland, is the key to livestock production in Southeast Asia and the South Pacific. Crop residues and by-products alone are inadequate for animal production, and the developing world cannot afford the inefficiency of feeding ruminants with grain and other potential human foods. Improvement of animal production for meat, milk, fibre, draught, and social or religious purposes is thus strongly dependent on improving the quality and quantity of forages of all types.

World meat production from domestic livestock is estimated to be 148 900 thousand tonnes (32% bovine meat, 6% sheep and goat meat, 39% pig meat, 20% poultry meat and 3% other meat). Of this, 62% is produced in developed countries and the remainder in developing countries.

In the developing countries, 37% of all meat is produced by ruminants, 28% comes from bovines and 9% from sheep and goats. On the other hand, 70% of the world cattle and buffalo populations are in the developing countries. In other words, ruminants in the developing countries, which are mainly in the tropics, grow more slowly and produce less meat and milk than those in the developed countries with temperate climates. The main objective for meat and milk production in the developing countries in the tropics should be to increase the productivity of these animals rather than to increase their numbers. The poor performance of these animals is associated with poor nutrition, disease, climatic stress and genotype.

In countries where there is insufficient food for humans, ruminants must rely largely on feeds unsuitable for monogastric animals, namely forages grown on land unsuitable for cropping and the fibrous residues of crops. In Indonesia, the major agricultural lands are used primarily for crop production and the density of livestock populations is generally higher in these areas. Here livestock is kept mainly for draught purposes and for production of manure. It is fed largely on crop residues, grasses and tree leaves. Much work has been carried out on intensive, multiple-crop rice-based systems to increase the crop yield of the land. This will indirectly increase the fibrous residues available for livestock feed; however, work on the possibility of introducing forage plants into the cropping pattern is very limited. Introduction of legumes into the cropping system would help to restore soil fertility and improve the quality of available roughage for livestock. I believe that this area should be studied more extensively.

Another area of forage production is in association with plantation crops such as coconut, oil palm, rubber and coffee. With some plantation crops, such as oil palm and rubber, the potential for combining pasture and crop production exists only in the early years of establishment of the plantation. However, in coconut and coffee plantations it has been shown that forages can be established and maintained. For example, leucaena has been used as a cover tree in coffee plantations of Central Java. Similarly leucaena has been successfully planted between coconut trees, and used as support for vanilla. During the early introduction, people worried that introducing leucaena and vanilla into a coconut plantation would reduce production. However, with good management, a plantation which used to produce only coconuts can now also produce vanilla and good quality forage for livestock. The possibility of developing appropriate combinations of plantation crops and forage production is another area to be studied.

Use of upland areas for cultivation in various parts of the world, including Indonesia, has caused several major problems. Population growth has forced the cultivation of

steeper and steeper slopes without proper conservation measures. Terraces are often poorly constructed and maintained, and this expansion together with unsuitable cropping patterns has aggravated erosion problems. Watershed development is one of the major activities in Indonesia and other Asian countries. Ways of constructing good bench terraces, and the cropping systems needed to reduce erosion yet maintain or improve productivity have been studied and developed in Indonesia. Bench terracing will reduce the usable cropland by 30 to 50%. To compensate for this loss, the terrace riser must be utilised effectively. Grasses and legumes can be planted on both risers and lips of the terraces. This has two functions, namely to reduce erosion and to provide cut feed for ruminants which will increase the farmer's income. The types of grasses and legumes suitable for these purposes need further investigation. For the uplands of West Java these forages have been identified.

In the less populated areas, which are generally also the drier areas, some native pasture resources occur. Much of this native pasture is savanna or savanna woodland that has resulted from the degradation of climax forest. In many areas it is maintained by regular, dry season fires. In Indonesia it has been estimated that 16 million ha of land has *Imperata cylindrica* either as a dominant or minor component of the grassland. This area is increasing annually by 0.15 million ha mostly as a result of shifting cultivation practices. Little research has been carried out in these savanna areas. There has been no extensive systematic study of their botanical composition, ecology and seasonal variations in yield and quality. I hope this meeting can come up with definite recommendations for developing and managing these areas.

Food crops, industrial crops, hillsides and the savanna areas already mentioned are the most likely areas where forages can be planted successfully, although other sites, such as permanent and tidal swamps and agroforestry areas, have potential for forage development.

I would also like to mention here that the quality of tropical forages is generally poorer than that of temperate forages. The fibre content is higher, hence the energy content is lower. It has long been known that voluntary intake of a poor quality, high fibre forage is much less than that for a good quality, low fibre forage. This is one of the main reasons why the productivity of ruminants in the tropics is lower than that in temperate regions; they are getting less energy. I would therefore like to appeal to you, as specialists in forage production and in animal science, to focus on quality as well as quantity of tropical forages. Cooperation between plant scientists and animal scientists is crucial in the development of animal husbandry in general. For example, the cultivars Coastcross 1 and Tifon 44 have been developed from a breeding program with *Cynodon dactylon*. They have higher dry matter digestibilities and hence give better liveweight gain than unselected strains. Differences in digestibility have also been reported between genotypes of *Digitaria*, with *D. setivalva* giving generally better performance.

Another important factor in forage development in the tropics is the length and intensity of the wet and dry seasons, which vary greatly from one location to the other (from less than 100mm to more than 2000mm rainfall).

All these factors and others should be considered in the selection, breeding, introduction and management of the forage and pasture species. Besides the agroclimatic conditions, the socioeconomic impact of such development must also be considered as an important factor. There are certainly many other factors to be considered and other options to be explored in relation to improving forage production (for example, nature of soils, which I have not mentioned here). I leave it entirely up to the competent experts so well represented at this conference to elaborate on this.

In earlier times and in other countries it was sometimes possible for forage scientists,

working alone, to introduce or develop useful new species or cultivars. In Southeast Asia in the 1980s it is essential that the improvement of the forage resource be tackled by team work with full consideration being given to the requirements and interactions of the total agricultural system. We have in Indonesia a strong concept of 'gotong royong' — working together to achieve things we cannot achieve as individuals. I believe this meeting will prove yet another example of the success of this approach.

J.H. Hutasoit
Junior Minister for Development
of Livestock and Fisheries Production
Indonesia

Ruminant Production Trends in Southeast Asia and the South Pacific, and the Need for Forages

J.V. Remenyi and J.R. McWilliam*

THE need for forages is a derived demand that cannot be divorced from factors that determine the demand for ruminant animals in developing countries. These factors fall into eight categories: (i) the total number of ruminants, which establishes the minimum immediate demand for forage supplies for herd maintenance purposes; (ii) the proportion of the ruminant population needed for draught power; (iii) the intensity and vigour with which ruminant meat and milk production is pursued; (iv) changes in the demand for ruminant meats and livestock products in response to economic growth, especially trends in real income; (v) demographic trends, including rural unemployment and the impact of increasing urbanisation; (vi) absolute and relative changes in the real price of meat and livestock products; (vii) changes in individual and community tastes and preferences favouring protein-rich foods; (viii) technical progress in the efficiency of livestock production/management systems.

In absolute terms large ruminants dominate the red-meat livestock sector. In 1983 there were 45 million head of cattle and buffalo in Southeast Asia and the South Pacific compared to only 16 million sheep and goats. This reflects the importance of draught animals throughout countries in the region, but especially in Thailand and the Philippines. Only in Indonesia do we find the total number of small ruminants exceeding the number of cattle and buffaloes. Indicative data are summarised in Table 1.

Table 1. The relative importance of small and large ruminants in selected countries (1984).

Country	No./km^2 Large	No./km^2 Small	Ratio of large:small ruminants/km^2
Indonesia	4.6	6.3	0.7
Malaysia	2.1	1.2	1.8
Philippines	16.0	5.1	3.1
Thailand	22.0	0.2	110.0

Source: Petheram, et al. 1985.

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Draught animals account for around 80% of large ruminants in Thailand and the Philippines, declining to average not more than half that percentage in most other Southeast Asian countries. De Boer (1982, p. 17), quotes Ramaswamy to the effect that the need for draught animals will increase by around 0.8% per annum till the turn of the century. This implies a rate of growth in demand for livestock for draught services below what can be expected from trends in demand for large ruminants for meat and milk. Nonetheless, in the decade and a half to the year 2000, the shift favouring cattle and buffalo production for non-draught purposes will not be so significant as to change the fact that draught animals are, and will continue to be, the most important consumers of forage feed resources amongst the livestock of Southeast Asia and the South Pacific. Moreover, trends in production systems will favour multi-purpose animals, from which farmers will demand more work, more meat and more milk per beast. Therefore, the need for forage inputs into the large ruminant sector will increase more than proportionately with growth in numbers.

Within the large ruminant sector, growth trends are likely to continue to favour cattle over buffaloes in both absolute and relative terms. This is already evident from the historical data for ASEAN and other countries in Southeast Asia. With the exception of Kampuchea and Thailand, the percentage increase in cattle numbers has either equalled or exceeded that for buffaloes in every case. The data are summarised in Table 2.

There are three basic reasons why we should expect future changes in large ruminant numbers also to favour cattle over buffaloes. First, and most important, is the trend away from reliance on draught power in favour of tractors and other automotive transport. The global oil crises in 1973 and 1979 did suppress this trend, and encouraged farmers, transporters and researchers to re-emphasise the importance of draught power. But the long-term historical trend towards increased reliance on petrol and diesel engines has not been reversed. Second, recent research in Africa and elsewhere (e.g. Anderson 1985) indicates that the

Table 2. Indices of ruminant numbers, 1983 (1969–71= 100).

	Cattle	Buffalo	Sheep	Goats
Malaysia	176	99	174	97
PNG	170	na	na	100
Burma	135	135	147	134
Vanuatu	130	na	na	133
Laos	117	98	na	170
Philippines	114	66	107	233
Vietnam	114	102	164	111
Fiji	105	na	na	85
Indonesia	104	79	134	114
Thailand	103	109	54	88
New Caledonia	83	na	50	57
Kampuchea	51	52	50	100
Total SEA and				
S. Pacific	111	92	134	125

na, not applicable.

Source: Calculated from data in FAO Production Yearbooks, reproduced in Table 4.

critical goal of future research in the use of draught animal power will be directed at more efficient use of the existing stock of draught power resources. Success will be measured by the ability of researchers to devise systems that will economise on the need for draught power in crop production, not by growth in numbers of draught animals or the spread of their use in agriculture. Third, consumer preferences are biased towards beef and veal over buffalo meats. To the extent that demand for red meats is sensitive to growth in income and a successful tourist industry, demand will encourage farmers to raise cattle rather than buffalo for meat and livestock products (especially dairy products).

If cattle and buffaloes dominate the ruminant scene in absolute terms, they have not done so in the growth stakes. This is clear from the comparative indices shown in Table 2, but it is strikingly demonstrated in the three parts of Fig. 1. Throughout Southeast Asia it is sheep and goat numbers that have increased the

most. Since small ruminants in Southeast Asia are largely the preserve of smallholders in backyard cut-and-carry-based production systems, it is the needs of this system that will define important parameters for future forage research.

In the Philippines, the growth in goat numbers has been nothing short of spectacular, while in Malaysia cattle and sheep numbers have increased apace as structural changes in the tree crop sector have favoured the incorporation of a livestock component, especially in the rubber-producing areas. In Burma, growth in ruminant numbers has been well above average for Southeast Asia, and consistent across the main classes of large and small animals. However, Indonesia continues to dominate the small ruminant picture, accounting for more than three-quarters of all small ruminants in Southeast Asia and the South Pacific in 1983.

The rapid growth experienced in small ruminant and cattle numbers throughout most of Southeast Asia and the South Pacific is symptomatic of the ubiquitous support and sponsorship of governments for programs that have subsidised or promoted cattle and small ruminant enterprises, especially in the past decade. However, these trends also reflect the impact of rapid workforce growth rates on the availability of 'surplus' labour for herding, tending, and collecting forage on a cut-and-carry basis. Governments in the region have sought to exploit the employment potential of ruminant production systems that are directly dependent on the success of cut-and-carry forage–livestock production. As a result, throughout most of ASEAN and the rest of Southeast Asia, the majority of ruminant producers are dependent on labour-intensive, as opposed to land-intensive, livestock husbandry technologies. It is therefore important to reiterate that the focus in assessing the need for forage improvement will come from the labour-intensive and smallholder-oriented
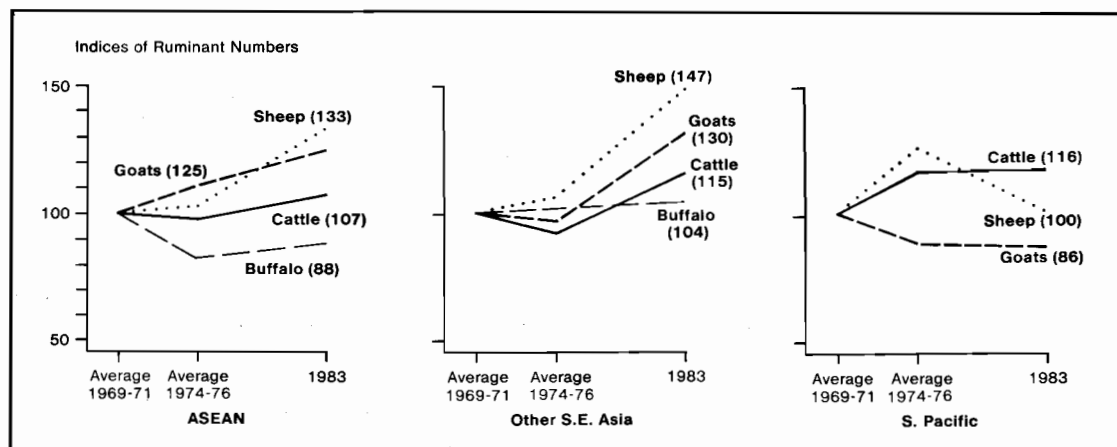
Fig. 1. Indices of trends in ruminant numbers in Southeast Asia and the South Pacific.

livestock sector. Thus, a large part of the research needed will involve cultivars and management techniques suited to cut-and-carry and other smallholder biased systems.

Of the eight factors noted at the outset determining the derived demand for forage production and research, the one that is more central than any other to future shifts in demand for livestock is economic growth. This is especially so because in Southeast Asia and the South Pacific increases in income tend to result in proportionate increases in demand for meat. In a recent report, researchers at the Washington D.C.-based International Food Policy Research Institute (IFPRI) used this datum to calculate the likely increase in demand for meat by 1990 and the year 2000, assuming income trends since the 1960s are sustained. The results are summarised in Table 3.

Table 3. Projected meat consumption and production trends in East and Southeast Asia.*

| | (Million tonnes) | | | |
| | Actual | | Projections | |
	1961–65	1973–77	1990	2000
Meat consumption	2.2	3.4	7.3	12.8
Meat production**	2.1	3.2	5.4	7.9
Balance	–0.1	–0.2	–1.9	–4.9

* Includes ASEAN, Burma, Fiji, Hong Kong, Kampuchea, N. and S. Korea, Laos, Mongolia, PNG and Vietnam.

** Ruminant meats represented 55% in 1961–65 and 51% in 1973–77.

Source: Sarma and Yeung 1975.

If trends in meat consumption and production since 1960 in East and Southeast Asia continue to the year 2000, the region's level of self-sufficiency in meat production is projected to decline from 94% in 1973–77 to 74% in 1990 and only 62% at the turn of the century. These declines in levels of self-sufficiency can be expected despite a projected fourfold increase in the level of meat production in the region, with half of the total accounted for by ruminant meats. In other words, demand for all classes of ruminant meats is expected to substantially outstrip the capacity of the region to supply consumers from local production, even if local livestock enterprises succeed in expanding their output fourfold. Success will require commensurate increases in forage supplies and other harvested feed inputs.

The IFPRI projections of demand and supply are based on a continuance of historical trends. These may be considered conservative, especially on the demand side. Nonetheless, the implications of the projections

do provide us with a baseline against which to judge the future need for forage supplies and forage research. In summary, they indicate that failing any improvement in the quality of forage grown, over the next 15 years there will need to be at least a doubling in forage availability, simply to sustain ruminant meat production trends of recent years. This level of increase raises many questions, not the least of which is the competition for land suitable for forage production from alternative uses in cropping, forestry, aquaculture, conservation, other non-agricultural uses (e.g. quarrying, housing, manufacturing) and the demands of urban expansion.

Projections of demand and supply in response to income trends are only part of the story. We also need to allow for the increase in demand for ruminant meat and livestock products that is likely to be generated by the trend to urban living and any associated change in consumer preferences favouring high levels of meat and livestock products consumption. Intuitively, the shift to urban living throughout most of Asia and the Pacific is less likely to be as significant a factor in the short or medium term as in the long run, but it will help sustain a high income-elasticity of demand for meat and livestock products. This can only add to the certainty with which we can expect forecast increases in demand to be realised. It underlines the importance of acting now to ensure that future increases in demand can be met in a timely and socially optimal way from efficient domestic production.

Trends in Ruminant Populations

We have already observed that there is a marked difference in the population trends between large ruminants and small ruminants in Asia and the Pacific. Fig. 1 contrasts these trends, using index numbers where the average for the years 1969–71 is set equal to 100.

In the ASEAN and other Southeast Asian countries, sheep numbers have shown the most rapid increases, with goats and cattle in Southeast Asia other than ASEAN showing the next highest growth. The increase in cattle and buffalo numbers in ASEAN has been modest at best, and done no more than recover to levels that had been attained less than a half decade earlier. However, in the rest of Southeast Asia, trends in large ruminant numbers between 1974–76 and 1983 showed substantial growth in response to agricultural recovery in Burma, Vietnam and Laos following the decline of military hostilities. In all cases the data show ruminant numbers in the South Pacific to be declining or stagnant. However, there is reason to believe that both cattle and goat numbers have been on the increase in the last few years.

Livestock numbers since 1969–71 for individual

countries in Southeast Asia and the South Pacific are shown in Table 4. The data show that for large ruminants the concentration of numbers is in three countries — Burma, Thailand and Indonesia. Among small ruminants one country, Indonesia, accounts for more than three-quarters of total numbers. On a correspondence basis alone, therefore, one could expect a substantial bias in the allocation of research resources towards Indonesia. Similarly, the major source of any increase in demand for forage in ASEAN is less likely to come from the large ruminant than the small ruminant sector. If trends since 1960 continue to 2000, it is in areas where goat and sheep production are expanding that forage improvement programs will need to be concentrated. Outside ASEAN, Burma has experienced contrary trends, with increases in large ruminant numbers the dominant factor in the need for new forage resources.

The Need for Forage

The greatest demand for forage now and in the future will be in the smallholder cropping sector, because of the higher concentration of animals and the reduced availability of land for forage production.

Provided adequate labour is available to harvest the forage under the cut-and-carry system, and effective use is made of crop residues, this sector will continue to provide the major feed resource for ruminant production in Southeast Asia.

The other underexploited source of forage which can be cut or harvested by grazing animals is that grown in association with plantation crops such as rubber, coconut and oil palm. Although a relatively new system in the Asia–Pacific region, it is particularly suited to sheep and goats and has potential for expansion in the Philippines, Indonesia and Malaysia, and also in some of the larger islands in the South Pacific.

The least exploited feed resources in the region are the extensive native grasslands, usually dominated by *Imperata cylindrica*, which are the result of shifting cultivation and fire. They are widespread in the outer islands of Indonesia and also in the Philippines, northeast Thailand, Burma and Papua New Guinea.

In all these systems, native or naturalised pastures, usually dominated by grasses, make up the bulk of the forage consumed by animals. The low quality and seasonal nature of these native forages, together with

Table 4. Ruminant numbers in Southeast Asia and the Pacific

| | Large ruminants | | | | | | Small ruminants | | | | | |
| | Cattle '000 head | | | Buffalo '000 head | | | Sheep '000 head | | | Goats '000 head | | |
Years	69–71	74–76	1983	69–71	74–76	1983	69–71	74–76	1983	69–71	74–76	1983
ASEAN	12860	12593	13746	13596	11160	11913	3314	3392	4418	8138	8970	10144
Brunei	2	3	4	16	14	15	na	na	na	1	1	2
Indonesia	6338	6239	6600	3180	2424	2500	3207	3267	4300	6941	7252	1900
Malaysia	314	425	600	303	286	300	38	46	66	362	352	350
Philippines	1701	1716	1938	4452	2723	2946	28	30	30	798	1333	1859
Singapore	8	5	4	3	2	2	na	na	na	2	2	3
Thailand	4470	4205	4600	5642	5711	6150	41	49	22	34	30	30
Other SE Asia	11350	10409	13038	5761	5150	5918	190	200	279	790	761	1029
Burma	6949	7410	9400	1593	1710	2150	177	187	260	573	579	770
Kampuchea	2233	1150	1148	903	593	468	2	2	1	1	1	1
Laos	418	326	490	932	621	910	na	na	na	34	31	58
Vietnam	1750	1523	2000	2333	2226	2390	11	11	18	182	190	200
South Pacific	492	571	571	na	na	na	4	5	4	101	89	87
Fiji	149	158	157	na	na	na	na	na	na	65	56	55
N. Caledonia	120	113	100	na	na	na	4	5	2	14	11	8
PNG	79	126	134	na	na	na	na	na	2	16	15	16
Samoa	22	22	26	na	na	na	na	na	na	na	na	na
Solomon Is.	12	23	23	na	na	na	na	na	na	na	na	na
Vanuatu	77	105	100	na	na	na	na	na	na	6	7	8
Other	33	24	31	na	na	na	na	na	na	na	na	na

Source: FAO, Production Year Book, various years.

the low intake by animals and their poor digestibility, are the major factors contributing to the low productivity of the ruminant population in the region.

As yet, improved pastures, and especially the use of tropical forage legumes, have made no significant contribution to the total forage production in the tropics, but this situation may change in the future.

Forage research programs have been undertaken by a number of countries in the region, involving the use of improved perennial grasses and legumes for cut and grazed forage. Shrub and tree legumes are also incorporated as a high quality feed supplement, especially in smallholder systems, along with other concentrates and mineral supplements.

The success of these efforts to develop suitable species to improve the quality and quantity of the forage resources of the region will largely determine the extent to which the rate of growth of the ruminant population. Availability of high quality forage will also determine the extent to which the growing demand for draught animals and other livestock products can be satisfied.

Conclusions

There are six conclusions we would like to highlight:

1. If there is no change in the typical feed regime and projected trends in animal numbers are sustained to the turn of the century, the demand for forage resources in Southeast Asia and the South Pacific will double. This increase is projected despite a decline in meat self-sufficiency from around 95% in 1980 to only 62% in the year 2000. The need for added forage resources will come from a forecast quadrupling in meat production in the regions, plus draught power needs expected to increase by around 0.8% per annum over the same period.

2. Trends in growth rates and increases in livestock numbers will favour the small ruminants over the large, and cattle over buffaloes. The picture in terms of livestock units is similar if less clear. Conversion factors between large and small ruminants are declining as average slaughter weights of large ruminants decline and small ruminants rise. However, there is a limit to the extent to which this gap can be bridged. The significant factor is the increase in feed requirements 'at the margin' as a result of growth.

This is demonstrated in Fig. 2. Current maintenance needs are indicated by A and B, where A substantially exceeds B. In terms of increases in need, however, the totals are given by the distances marked as a and b, where b can be expected to substantially exceed a. It is this divergence that highlights the significance of growth in the small ruminant sector, especially in

smallholder-oriented livestock enterprises, and the importance of improving forage and pasture supplies for the more intensive smallholder sector. In many countries this growth is closely associated with structural change and investment in tree crop production.
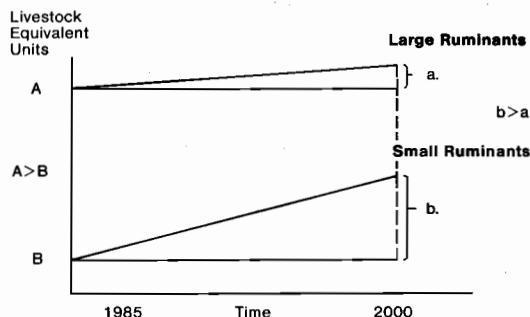
Fig. 2. Predicted increases in large and small ruminant populations between 1985 and 2000.

3. The relative shortage of land in those regions with the highest animal populations will demand that increases in forage needs are in large part met from improvements in the quality of supplies available, not merely from increased quantities.

4. Growing forage crops for livestock production is not a traditional activity for the majority of smallholders and farmers in Southeast Asia or the South Pacific. Consequently, the spread of systems incorporating forage and pasture activities must be seen as constrained by essential and non-negotiable demands of intensive cropping systems. In many countries, especially the densely populated parts of Indonesia, Philippines and Thailand, one of those constraints is the very small proportion of land area available for forage and pasture development. Another is the high opportunity-cost of labour, especially at critical times in the crop cycle.

5. Indonesia dominates the small ruminant sector in Southeast Asia, accounting for more than three-quarters of total sheep and goat numbers. The correspondence principle would indicate, therefore, some bias in research favouring the country where most of the animals are to be found. However, the data also indicate that it is small ruminants in association with smallholder systems and plantation crops that is growing most rapidly. This experience is common to many countries in Southeast Asia.

6. In the final analysis the need is not for forages alone, but forages within the farming systems adapted to the economic realities of farmers. In some instances this may result in abandonment of livestock activities in favour of more profitable horticulture, aquaculture,

or tree crop enterprises adapted to scarce land and labour resources of many small farmers.

References

Anderson, F.M. 1985. Draught animal power systems in Sub-Saharan Africa: their production impact and research needs. Paper presented to ACIAR Draught Animal Power Workshop, James Cook University, Townsville, July.

De Boer, J.A. 1982. Overview: livestock development: the Asian experience. In: Fine, J.C. and Lattimore, R.G., ed., Livestock in Asia: Issues and Policies, IDRC, Ottawa, 13–28.

FAO, various years, Production Yearbooks, Rome.

Petheram, R.J., Thahar, A., and Bernsten, R.H. 1985. Socioeconomic aspects of draught animal power in Southeast Asia, with special reference to Java. In: Copland, J.W., ed., Draught animal power for production: proceedings of an international workshop held at James Cook University, Townsville, Qld., Australia, 10–16 July 1985. ACIAR Proceedings Series No. 10, 13–19.

Sarma, J.S., and Yeung, P. 1975. Livestock products in the Third World: past trends and projections to 1990 and 2000. IFPRI, Washington D.C., Research Report 49, April.

Present and Projected Ruminant Production Systems of Southeast Asia and the South Pacific

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THE extensive literature on the farming systems of the world (Duckham and Masefield 1970; Ruthenberg 1976; Spalding 1979) supports the view that agroecological conditions are a principal determinant of the types of crop and livestock systems which develop at any particular location. Since livestock systems, and especially ruminant systems must invariably depend on vegetation or crops for their feed base, these studies are especially relevant.

FAO (1980) provided a useful illustration of the genesis of livestock systems (Fig. 1). Climate, and to a lesser extent soils, affect the vegetation that develops and determine whether crops can be grown. These in turn determine the feed base, its quantity, quality and dispersion. The feed base, together with the disease challenge, determine the potential animal husbandry systems that may develop. Economic forces, increases in demand for animal products, prices of alternative feeds and relative prices of outputs then influence the choice of animal husbandry systems and their integration into what become traditional socioeconomic and cultural systems. Growth of incomes and population and the opening up of these systems to outside influences could result in changes which lead to more productive systems, or in cases where the system cannot cope, to regression. Side by side with the changes occurring in the traditional system we often see the development of commercial systems which may be imported from overseas or in a few cases may be developed within the country itself. These commercial enterprises tend to be somewhat less dependent on the agroecological environment than do the traditional systems. The stock are more likely to be housed and to be fed at least partly on feed purchased from off the farm or even imported.

In the arid areas of the world, the vegetation that develops as a consequence of the prevailing climate provides a very sparse feed resource base which can only be used by ruminants under a migratory system.

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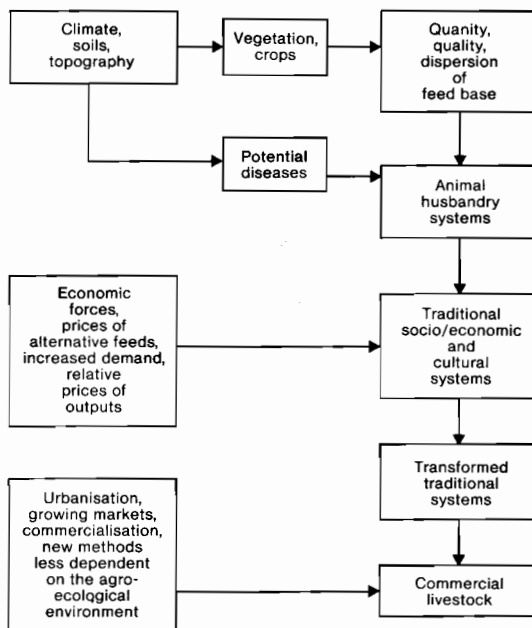
Fig 1. Genesis of livestock systems.

Thus ruminant production systems in the arid tropics are primarily nomadic systems. However, the interplay of the other factors set out in Fig. 1 could result in more productive systems being developed. For instance, if investment funds are available and if appropriate steps are taken to produce feed under irrigation, mitigate the effects of climate on livestock, and maintain a high level of management practices, then high ambient temperatures should not hamper successful dairy development with European breeds in the Near East (Ansell 1976).

In the humid areas of the world, sedentary systems become possible because feed is generally available in greater abundance and livestock keepers are able to stay in one place and graze their stock in the neighbourhood. Crop production also becomes more important and mixed crop and livestock systems can develop. Thus, sedentary systems can be classified into those that are solely or very dominantly livestock systems and those that are mixed systems. The basic

determinants of this classification are also climate, soils and topography. However, within each of the sedentary systems, man can so alter the environment or the feed base as to make the system less dependent on the natural environment.

Present Ruminant Production Systems in the Region

The prevailing ruminant production systems in this region are all sedentary and include some that are solely livestock systems and others that are mixed crop and livestock systems. The mixed systems dominate. This dominance is attributable to a number of factors, of which the most important is the small average size of holdings and the resulting complementarities between crops and livestock. Thus, livestock provide draught power and manure for the crop enterprise, while the latter produces the crop residues and by-products that serve as animal feed.

Present ruminant production systems in Southeast Asia and the South Pacific have evolved in response to the total availability of land, the type of crop production practised, the frequency of cropping, the area of uncultivated waste land and the number of animals. They may be classified into the following categories:

1. extensive systems;
2. systems combining arable cropping;
3. systems integrated with tree cropping.

Extensive Systems

These are usually based on grazing of large areas of unproductive or marginal land which are unable to support crop production. But they also include more productive tracts in locations where land is not limiting and substantial areas are available for ranching under various land development schemes. Thus, several private and quasi-private commercial ranching enterprises were established in northeast Thailand, Mindanao Island in the Philippines and the eastern islands of Indonesia. They cover 1000 or more hectares of land and carry large permanent herds at relatively low stocking rates. The viability of these enterprises has been dependent on a combination of some or all of the following factors:

(a) availability of surplus stock for purchase at low prices from surrounding smallholders;
(b) possibility of improving the genetic base of the stock through crossbreeding;
(c) ability of the ranch to achieve substantially higher levels of productivity than the smallholders;
(d) realisation of a premium price for ranch-produced beef.

In some cases, direct and indirect input subsidies have also contributed to financial viability.

The total number of animals and people that benefit from the kind of extensive system described above is relatively small. Although output per man is high, the capital investment is also high. The latter includes cost of stock, fences, wells, pumps, handling yards and buildings.

Systems Combining Arable Cropping

Where crop production is important, ruminant production systems have evolved so as to ensure that animals contribute to efficient crop production and at the same time do not compete with crops for land or cause damage to crops. Thus, animals play a supplementary role to arable cropping. Three main types of ruminant production systems that combine with arable cropping may be identified. These are: (i) roadside, communal and stubble grazing; (ii) tethering; and (iii) cut-and-carry feeding.

The three are not mutually exclusive. Grazing on roadsides and on communal (waste) land may be practised by landless stock owners as well as others when their privately owned lands are under arable crop cultivation. Grazing in rice fields is restricted to periods immediately after harvest when the feeds available consist of the aftermath of the rice crop (viz. rice stubble and some regrowth from the stubble), any weeds which grow in the paddies, the grasses that are found on paddy bunds, and browse from shrubs and trees that grow on it. Where multiple cropping is practised, the crop aftermath may be burnt after the harvest and stubble grazing may be severely restricted or nonexistent.

Tethering is adopted when there is a need to prevent animals wandering into areas being cropped and also to ensure that they graze down the available feed in a given area before they are moved. This type of confinement feeding is most popular in Southeast Asia because multiple cropping is very widespread in this region. The animals may be tethered on waste grazing areas close to the farm, or on rice fields after harvest to regulate stubble grazing, or close to stacks of rice straw to allow self-feeding.

In the cut-and-carry system a large proportion of the feed is usually brought in from outside the holding because of the small size of holdings in relation to the number of animals kept. The system is subject to the vagaries of seasonal abundance and shortage of forage that characterise it. Since the livestock are housed most of the time, this results in a growing dependence on high priced concentrate feeds during lean periods.

Only limited success has been achieved with ruminant production systems that have evolved in association with arable cropping in Southeast Asia and

the South Pacific. This is not surprising when the primary requirement is that all arable land must be used for food crop production and the availability of cultivated forage for animal feeding is limited. Also, the majority of the ruminants (certainly the large ruminants) in this region are maintained mainly for products or services of a non-food nature.

Systems Integrated With Tree Cropping

Ruminant production under tree crops, notably coconut, oil palm and rubber, is assuming increasing importance in Southeast Asia and the South Pacific. The advantages of integrating ruminant production with tree crop production have usually been looked at from a crop viewpoint. They are: (a) increased fertility of the land via the return of dung and urine; (b) control of waste herbage growth and reduced use of weedicides; (c) easier management of the crop; (d) distinct possibilities of increased crop yields.

It is of course recognised that the sale of animals and their products do add to the returns from the system, but little or no effort has been made to maximise their contribution. In consequence, the stock-carrying capacity of land under tree crops is much more variable than under any other system.

An extension of ruminant production under tree crops is the grazing of cattle in natural forests or reafforested areas. It has been shown in Western Samoa (for instance Pottier 1984) that cattle grazing in such areas provide a secondary financial return which, in the period prior to harvest, may in fact represent the main return, apart from the occasional sale of thinned trees. The use of vegetable or root crops during the first two years after planting the trees, followed by cattle grazing, may represent one of the few combinations likely to attract landowners to the idea of replanting trees, because forests are then seen as long-term investments. Also, in tropical areas the shade offered by the forest creates a better environment for livestock than open spaces, particularly by reducing heat stress — provided that suitable pasture species are found to grow under conditions of reduced light.

Projected Ruminant Production Systems in the Region

The requirements of the market and the feed resources available have been major forces in influencing the ruminant production systems that have developed in the past. These forces are likely to play an even more important role in the future. Barring major catastrophes, the human population in the region will at least double before it ceases to grow, and will do so in the next 30–40 years. This growth is likely to be accompanied by even greater shifts in the feed

resources available. There will be increased dependence on crop residues and agroindustrial by-products for ruminant production and greater efforts to make more effective use of un-utilised, under-utilised and fallow lands. Thus breeders of ruminant livestock would need to recognise that the massive importations of Friesian cattle with voracious appetites and high milk yields that require high levels of concentrate feeding, especially cereal grains, protein meals and high quality roughages, will prove counterproductive in both the short and long term. Feed grains will be diverted almost entirely to monogastrics, protein meals somewhat less so, and high quality forages will only be available as supplementary feeds. It is unlikely then that any new ruminant production systems will develop, but rather there will be refinements and improvements of existing systems, as follows:

Extensive Systems

If extensive systems are to survive against pressure on land for arable cultivation, they would need to become more productive. This could be achieved, inter alia, by enhancing the quality of the forage produced through legume introduction. Thus in the more extensive 'alang alang' slopes in the outer islands of Indonesia (Sumatra, Sulawesi, Borneo and the eastern islands such as Flores, Sumba and Timor), it is possible that legume-based grass pastures may, through the nitrogen fixed by legumes and the return of nutrients from animals, restore some fertility and permit crops to be grown in rotation with the pasture system. The benefits would be a better integrated system and possbily better cash flow from the cropping sector. It is of course recognised that the successful introduction of this type of farming would depend on the availability of seed for the establishment of sown pastures, the farmer's ability to manage legumes in grass pastures, and the adoption of fencing to control stocking rates and exclude animals from the crop areas.

Improvements in the quality of the forage should also be accompanied by enhanced genetic potential of the animals to achieve higher growth rates through selection and crossbreeding, and by market development. The latter may involve seeking more remunerative overseas export markets through integration with specialist fattening (finishing) operations. In the past, feedlots have not been particularly successful for the following reasons:

(a) Large supplies of feeder cattle could only be gathered at great expense.
(b) The premium paid for finished beef was often inadequate.
(c) Fresh green feed was too seasonal.

(d) Low roughage quality was compensated for by using large quantities of expensive concentrate feed of variable nutritive value.

Therefore, for feedlotting to be viable in the future, the following conditions would need to be satisfied:

(a) A good roughage base must exist in close proximity to the feedlot.
(b) Concentrate feeds of reliable quality must be available.
(c) The concentrate–beef price ratio must be favourable.
(d) The price differential between mature and young animals must make feedlotting attractive.

Systems Combining Arable Cropping

The future pattern of development of ruminant production systems in the arable areas of Southeast Asia would be governed largely by the importance of draught animals for crop cultiviation and farm transport in small holdings. FAO, as part of its 'Agriculture : 2000' study (FAO 1981) estimated that at least 20 million more draught animals will be needed by the year 2000, the biggest increase being in the Far East. At the same time there is also need for a 4.5%/annum increase in animal protein production in the developing countries. Clearly then, the greatest opportunities for development lie in a combination of crop–livestock production practices that would help integrate the raising of large ruminants as a source of power for specific operations, with their potential role as an effective source of milk and meat in what may otherwise continue to be a predominantly crop agriculture.

Roadside and communal grazing would prove undependable as a basis for such development. Publicly financed communal pastures are unlikely to be successful, because without regulated use they soon become heavily overgrazed. This does not, however, rule out a village-oriented farming systems approach to the establishment and effective use of communal pastures.

Forage production on a crop rotation basis offers the greatest chance of success. This should be accompanied by careful evaluation of the desirable areas of fodder crop per ruminant animal unit in different cropping situations and on different sizes of farms. Very little information is available to indicate what the optimal stocking density per unit of arable land should be. By and large though, the availabiltiy of land on a rotation basis for forage crop production is likely to be very limited. But every effort needs to be made to maximise the yield and quality of the forage produced. The use of tree legume or pasture strips between cropping areas may be considered as an alternative to crop and pasture rotations.

Thus there is no escaping from the fact that the most widely available and low cost feeds for ruminants in the arable areas will continue to be crop residues and agroindustrial by-products. The challenge then would be to develop feeding systems based on large amounts of lignocellulosic materials that are simple, practical and convincing and within the limits of the farmers' capacity and resource availability. This challenge has not been effectively met so far.

Viewed against this feed resource base, the recent large scale importations into Southeast Asia of *Bos taurus* cattle and the proliferation of crossbreeding programs for milk and meat production give cause for concern, because they are so often accompanied by acceptance of high levels of concentrate feeding. The role of the ruminant animal in the areas of arable cropping is primarily to convert fibrous agricultural wastes into animal products. The concentrates and the cultivated forages that are fed must be restricted to levels that maximise the intake of the basal feed and not to levels that are deemed necessary for high production. Clearly then, large scale importations of purebred *Bos taurus* cattle have no place in such developments. But that does not necessarily imply that there is no role for crossbreeding under these conditions; rather it means that any breeding program should have as its objective the production of animals which utilise available feed resources in the most efficient way and convert them into needed products (Mahadevan 1981). Crossbred *Bos taurus* × *Bos indicus* cattle have demonstrated that this objective is attainable in terms of milk, meat and draught production under good managerial conditions. (Gryseels and Goe 1984). In a setting of pronounced land scarcity and high population pressure, the conclusions concerning breeding objectives for cattle apply also to the raising of other classes of ruminants.

Systems Integrated with Tree Cropping

The potential for integrating ruminant production with tree crops is illustrated by developments in the Solomon Islands and Western Samoa where some 48 % and 60 % respectively of the national beef herds are to be found in the coconut plantations (Quartermain 1981). Recent data from Malaysia (Devendra 1985, and Chee and Wong in these proceedings) also suggest that mixed grazing by large and small ruminants may be beneficial in oil palm estates: the yield of fresh fruit could be substantially increased.

Future developments in integrating ruminant production with tree crops would be dependent on greater emphasis being placed on the animal component. As at

present, very little information is available on dry matter production under various tree crops, optimum stocking densities, feeding behaviour of large and small ruminants under the system and the need for supplementary feeding. These deficiencies in knowledge should be remedied before the full potential of the system could be realised.

Conclusions

It may be concluded from this overview that no drastic changes are foreseen in ruminant production systems in Southeast Asia and the South Pacific in the immediate future or in the longer term. Major shifts in resource use would be difficult to achieve unless returns from the new systems proposed are demonstrably superior. Changes must therefore be introduced gradually and must ensure income stability and low risk. The principal aim should be to make maximum use of the basic feed resource that is available, which in most situations will be crop residues and/or low quality roughages. In addition, improved delivery systems should be developed for the essential suplementary feeds, which would ideally be some combination of high quality forages e.g. leguminous fodders and agroindustrial by-products or other feed concentrates.

A need to develop low cost, simple interventions acceptable to farmers is foreseen. They should include nutrition, breeding, health and management and should be combined into appropriate technology packages whose technical and socioeconomic feasibility should be tested during development.

References

Ansell, R.H. 1976. Maintaining European dairy cattle in the Near East. Wld. Anim. Rev. (FAO), 20, 1–7.

Devendra, C. 1985. Integrated farming systems involving small ruminants. Proceedings of the 3rd Asian–Australian Animal Science Congress. (In press).

Duckham, A.M. and Masefield, O.D. 1970. Farming Systems of the World. Chatto and Windus, London.

FAO 1980. The classification of world livestock systems. Typescript, 37p.

FAO 1981. Agriculture : Toward 2000. Economic and Social Development Series 23. 134p.

Gryseels, G. , and Goe, M.R. 1984. Energy flows on smallholder farms in the Ethiopian highlands. ILCA Bulletin No. 17, 2–9.

Mahadevan, P. 1981. Pastures and animal production. Keynote Address. In: Hacker, J.B., ed., Proceedings of the International Symposium on Nutritional Limits to Animal Production from Pastures. CAB, 1–17.

Pottier, D. 1984. Running cattle under trees: an experiment in agroforestry. Unasylva (FAO), 36, 23–27.

Quartermain, A.R. 1981. Livestock. In: Word, R.G. and Proctor, A., ed., Agriculture, Choices and Constraints. Asian Development Bank. 261–292.

Ruthenberg, H. 1976. Farming systems in the Tropics. Oxford University Press, Oxford.

Spalding, C.R.W. 1979. An Introduction to Agricultural Systems. Applied Science, London.

Interrelationships of Ruminant Production and Socioeconomic Systems in Southeast Asia and the South Pacific

Gunawan Satari*

RUMINANTS appear to have been among the first animals to be domesticated by man. As hunting for wild animals became less and less successful, trapped ruminants were brought home alive and kept in confinement to become a food source in times of emergency. This confinement also gave man an opportunity to learn how to rear them and their offspring on the available forage.

Along with the domestication of seeds and plants, confinement of ruminants marked a new era of cultural development — the beginning of settled agriculture. The existing ruminants developed in various ways as a result of interactions between climatic, edaphic, cultural, sociological, economic and political factors. These were manifested by the prevailing species, breed and types developed in each country to serve man's needs.

As to the extent to which ruminant production would be beneficial to the socioeconomic systems of a country, it stands to reason that there will be no generally applicable answer. The same will also be true of constraints imposed by the socioeconomic systems of ruminant production. Ruminant breeding is influenced by a complex of factors which will understandably differ from country to country. These factors include choice of forage species, breed and type of animal, climatic and edaphic conditions as well as the purposes for which ruminants are bred. The last of these introduces socioeconomic factors to which might be added psychological and political motivation. In short the researcher has to deal with genetic potential, environmental factors, and the social and economic structures of the country in question.

To meet this challenge a comprehensive 'farming systems' approach has been developed which takes account of all the factors already mentioned. In order to improve livestock production as an integral part of agricultural development an effective program of farming systems research should be promoted.

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Benefits of Ruminant Production to the Socioeconomic System

The philosophy or ideology of a country can affect its livestock farming systems. Ruminants may have many or only a few uses, and corresponding benefits to the socioeconomic system. For example, killing animals, including ruminants, and eating meat are expressly prohibited in Buddhism and Hinduism, so in these cultures they are of benefit only in providing milk, draught power, manure and fuel. On the other hand, neither Islam nor Christianity have taboos against killing animals or eating meat. In fact, Moslems have a ritual in which animal sacrifice forms part of their religion.

In a country with freedom of worship, the matter of meat eating offers specialisation in the livestock industry through the diversity of religious practice. Hindus or Buddhists may raise the livestock, but the butchers and meat-sellers may be of other religions. Opportunities also exist to diversify livestock production.

The role and function of ruminants in Asian countries differs from that of the pastoral societies in Africa where cattle herding is often a principal economic activity. Ruminant husbandry in Asia complements cropping and supports crop production by providing animal draught power for land preparation, threshing and haulage, besides providing manure and additional income.

Traditional ruminant husbandry has yet another aspect in the agrarian communities of Asian countries. It is quite common for crop-producing farmers to keep a few cattle or buffalo, but not to depend on them for the major part of their income. The animals are looked after by a herder, who can be called upon by the landowner to perform specific duties. Payment for this is made in kind, as a share of the progeny. This practice is common in Java and also in some other Indonesian islands. Herders may even be obliged by their hereditary duty to look after the land owner's cattle.

The system of cattle tenancy may differ from country to country. In Sri Lanka, although the contract

is more commercial, it is still traditional in nature. The Philippines has an analogous system in which a patron–client relationship is sometimes used by landless farmers or poor persons as a means of obtaining work and income opportunity by rearing their patrons' cattle. In west Java surveys show that more than a quarter of the sheep and goats are owned by landless rural workers in some villages.

Owning animals is also an advantage to tenants if their contract with the landowner is broken. They provide some economic security in that they can be taken away by the dispossessed tenant.

In some communities cattle or buffalo are still a decisive component in the negotiation of bride wealth and bride price. In Burma, it is the cattle that set the value of the bride price. Four cattle there is a bride price for a well-to-do commoner. In Sri Lanka, when a daughter marries she receives cattle as a dowry from her parents and the land is left for the sons to inherit.

Ruminants are also involved in human medicine in some countries. This is particularly true of some parts in India, where the urine and dung of ruminants are ingredients of the indigenous medicines.

Ruminants are ranked by communities first on the basis of their economic value but often by other, less expected criteria. For example, in parts of northern India a Murrah buffalo is valued more than a cow because buffalo milk produces more ghee. Cattle may be a status symbol in that they are kept by higher castes whereas lower castes keep only pigs and poultry. In the Indonesian province of South Sulawesi, spotted buffaloes are valued more than black ones because of the status attached to using them in certain funeral rites. In the parts of Java where ram fighting is popular, owning winners confers prestige out of all relation to their economic value. Total number of cattle or buffalo owned is again a symbol of wealth in many societies.

'Commercial' ruminants are also, of course, significant in socioeconomic systems. The political environment can encourage commercial beef production or dairying since it determines the structure and function of livestock farming systems. This implies a policy on availability of inputs into and fiscal control of the system.

Subsidies, taxes and levies imposed will also have an influence, as will measures that limit or encourage imports and exports.

The policy of a government, consistently supported by effective pressure groups, will determine the success of failure of any agricultural research program. This has been demonstrated by the Dairy Package Program sponsored by the Ministry of Cooperatives in Indonesia. Selected farmers are provided with credit to buy dairy cattle and finance production inputs.

Acquisition and repayment are arranged and administered by the village cooperative. The farmers are required to concentrate on producing milk. Credit is repaid by deducting the equivalent market price from the milk volume delivered to the cooperative. This is usually completed after five lactation periods. There are multiple benefits to the socioeconomic systems from programs like this: for example the opportunity for personal enterprise, increased income, of foreign currency saving through reduction of milk imports, and dietary improvement.

Constraints Imposed by the Socioeconomic Systems

Sociocultural Aspects

THE RELIGIOUS FACTOR

An example of the influence already mentioned is the Buddhist and Hindu prohibition on slaughtering animals and eating meat.

STATUS SYMBOLS

The ranking of certain species of animals according to the caste of their owners does not constrain a development program from a sociological viewpoint. Neither does accumulation of large numbers of animals as an indicator of wealth, although this can decrease the economic efficiency of a program. If animals are sold on reaching marketable age the farmer should be able to acquire more cash and replace his stock more frequently than if the animals are simply accumulated. Where there is an efficient turnover of animals the carrying capacity of a given area of land is increased.

POPULATION PRESSURE

High population pressure can affect animal culture, and land farmed intensively for food crops can leave little room for forage crops. The island of Java is an extreme example, such that the peasant must resort to stall feeding his animals. Part of the feed is derived from foodcrop waste, and for the rest the peasant has to rely on natural grass from bunds, road sides and public lands. This situation is termed 'zero grazing' or 'the flying herd system'.

Nevertheless, traditional livestock can thrive under these conditions. Large and small ruminants alike can provide the peasants with a source of cash when sold in times of emergency. They also function as a means of saving money when young animals are bought and raised (at hidden cost) until marketing age. Manure assists soil fertility and increases crop production. By providing draught power for hire large ruminants can provide their owners with additional income. Accordingly, livestock rearing provides alternative em-

ployment and may help to reduce or curb rural-to-urban migration.

Economic Aspects

The political philosophy adopted, particularly in ASEAN member countries, and the prevailing economic system can give free business opportunities to animal production enterprises. However, most ruminant production is done by peasants who are crop growers, with relatively few specialist stock-rearers. So animal husbandry takes second place to cropping.

Meat in the ordinary market is derived from the traditional sector. Meat for discriminating and well-to-do consumers is often imported, and has little effect on the marketing of local meat.

Large-scale beef production was pioneered in the Philippines. In Indonesia this type of commercial beef production is being encouraged, particularly in the outer islands, where, admittedly marginal, land is abundant. This opportunity is open either to foreign investment or as a joint venture with national counterparts. However, the prospects for large-scale sheep and goat production are not as promising as those for beef.

Constraints in the economic systems of Indonesia can be attributed to the slow responses of the institutional services involved. Up to the present the return to peasants has been relatively low because of the high cost of marketing. Cooperatives, designed to shorten the marketing chain, cannot compete with more experienced middlemen. These have the flexibility to respond quickly whereas cooperatives are often constrained by strict bureaucratic procedures.

In an archipelago country like Indonesia, the irregular operation of inter-island vessels may reduce profits due to shrinkage of liveweight or to losses of animals while in quarantine. The distance over which meat or animals must travel to the national capital of Jakarta may be greater than the distance to an export destination such as Singapore. Thus Indonesian consumers may be disadvantaged.

Constraints of the economic system on an animal enterprise are well illustrated by an examination of policies in the dairy industry. Although cattle production is well established, the dairy industry is a relative newcomer. Formerly, national economic policy took little account of dairying. However, when imports of dairy products began to make a significant impact on the external balance of payments in Indonesia, the Philippines and Malaysia, dairy policy rapidly became a political issue. Each central government formulated a national dairy policy allocating a significant amount of the agricultural budget to support these programs. Camoens et al. (1985) have pinpointed the weaknesses

in these policies. They ascribed the usually uneven results of the programs to the problems of inexperienced dairy producers working under tropical conditions, a lack of local rural demand for milk, product perishability and quality control. Other drawbacks are difficulties in establishing year-round feeding systems in the monsoonal tropics, long calving intervals, uncertain returns of capital invested by producer, and lack of cooperative structures that are often essential for milk collection.

The Government of Indonesia has recently revised its policy. Milk plants are now compelled to absorb local milk of good quality delivered by the cooperatives so that they may import a certain proportionate volume of milk powder for their routine process of recombination.

South Pacific Islands

In contrast to the countries in Southeast Asia, the socioeconomic systems in the South Pacific are seemingly not directly conducive to livestock development. Anthropologists tend to consider their societies as pre-modern, closed and static. Efforts should be made to induce gradual changes in attitude and perception towards livestock production. Fiji, however, is more progressive. Ways of promoting the transfer of livestock production technology from the existing enterprises are being sought.

Conclusions and Recommendations

Choice of ruminant is influenced by the peasants' traditions as well as by the feed resources within their reach, either on or outside the farm. Ruminant production thrives under traditional management and its diverse functions help to support the peasants' subsistence and increase their profits.

Ruminant production provides the farmer with a living 'savings bank', it increases farm income, provides a livelihood for landless people, increases employment opportunities, helps conserve agricultural ecosystems and reduces rural-to-urban migration.

The degree of success of a ruminant development program depends on the effectiveness of the socioeconomic systems, a conducive political environment and an appropriate systems approach.

It is strongly recommended that farming systems research to improve ruminant production be given full financial and technical support.

Reference

Camoens, J.K., McDowell, R.E., De Boer, J., Wimaladharma, K.P., and Moog, F.A. 1985. Proceedings of Regional Workshop of Livestock Production Management. Asian Development Bank. Manila.

Introduction and Management Prospects for Forages in Southeast Asia and the South Pacific

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SOUTHEAST Asia and the South Pacific cover a vast geographic area containing a great diversity of agricultural systems, ranging from slash-and-burn cultivation within original tropical rainforests to intensive livestock feedlots supplying the demands of urban centres. Such diversity can only be discussed in broad terms, which are open to immediate contradiction. The opinions and arguments expressed hereafter should never be considered as final definitions. Heterogeneity, diversity and specificity are emphasised throughout and, indeed, form the major threads of discussion.

The natural corollary must be that blanket recommendations are both unwise and unworkable. A parallel system of research should be encouraged, with on-station evaluation complemented by on-farm trials and demonstrations.

Forage development will be better achieved by farmer–led adaptation of techniques and species demonstrated to work under local conditions.

Southeast Asia and the South Pacific

These two regions are frequently mentioned as separate entities, inplying some natural division. In the present context it will be argued that they can be classed as one with respect to the physical opportunities for forage development. The similarities are many; both regions lie largely within the tropics, and the associated physical environments that exist in one area can almost always be found in the other. Of greater importance are the parallel variations within each region. Such variations create the range of environments that determine the physical limits for different forage species.

These environmental variations are pronounced. Both regions contain areas that experience heavy, prolonged and intense rainfall, while at the other extreme, certain locations have extremely irregular rainfall patterns and long dry periods. Soils differ with location but examples of identical soil types will be repeated in a number of areas, many derived from the volcanic chain running down the eastern seaboard of Asia through the Indonesian archipelago and onward to Papua New Guinea (PNG) and the Solomon Islands. The important local temperature variations associated mainly with altitude differences, as Oldeman and Frere (1982) noted, are replicated in the many mountain and hill ridges. Throughout both regions can be found examples of typical tropical environmental climaxes: rainforests; extensive swamps; grasslands; degraded dryland.

The more obvious differences between the two regions concern people and their farming systems. Southeast Asia has a greater mass of people, measured both relatively and absolutely, and as a consequence, higher pressure on land and other resources available. These differences are well expressed in the main staple food systems, with Southeast Asia dominated by irrigated, rainfed and dryland rice and the South Pacific systems focused more on root, tuber and tree crops such as sweet potatoes, taro and bananas. Exceptions spring to mind, e.g. Fiji is an important rice producer in the South Pacific; many roots and tubers are grown as primary or secondary staples in Southeast Asia. But the great levelled, terraced, contoured and irrigated rice systems so common in Southeast Asia are rarely found in the South Pacific, and so constitute a major difference between the two regions with regard to forage prospects.

The second major source of difference relates to the social organisation and cultural beliefs of the two areas. Again, such differences exist within regions, districts and at the local level. Recognised religious groupings provide the easiest statistical classification but beyond religion is often a stronger history of traditional values, many of which are very localised in character, language, beliefs and adherents. Such differences are extremely important, as a farmer's social and cultural environment exert a great influence on goals, attitudes and expectations. Later in the paper it is argued that such socially influenced goals are a

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major determinant of the farmer's attitudes to livestock; on the types of livestock judged important and the possible adoption of different forages and associated systems.

The differing pressure on resources in the two regions can be expressed in a number of ways, including population and stock densities. Table 1 gives consolidated statistics from six Southeast Asian nations and two from the South Pacific.

Table 1. Human and livestock numbers/km^2.

	Southeast Asia (6 countries)	South Pacific (2 countries)
People	334	4
Cattle	17	*
Buffalo	13	*
Sheep	5	*
Goats	11	*
Pigs	20	2

*<0.5
Source: FAO (1983b).

These are national average figures and hide the many variations both within and between countries. For example, Indonesia's national average human population density of some 85 people to the square kilometre obscures situations such as exist on the island of Java, where the average density is now more than 750 people/km^2. Even on Java itself, local variation can be up to 2000 people/km^2 in very intensive areas, down to less than 100 people/km^2 in other locations.

The South Pacific is largely at the lower end of the density spectrum, but still does contain pockets of relatively high population pressure, such as the highlands of PNG or specific cases of crowded small coral islands in Kiribati or Tuvalu. The figures illustrate the diversity of situations into which forages must fit within both regions. At the low-intensity extreme, ruminants may face few apparent competitors for land and feed but in the high-intensity areas, available ground is worked hard and forage production may constitute a minor land-use type.

Table 2 shows the number of livestock/1000 human population (economic density). For immediate con-

Table 2. Number of stock/1000 human population.

	Southeast Asia (6 countries)	South Pacific (2 countries)
Cattle	49	75
Buffalo	37	*
Sheep	16	*
Goats	13	25
Pigs	59	400

*<0.5
Source: FAO (1983b)

trast, one should look at Australia with 15 million people and an estimated 23 million cattle and 133 million sheep sharing the continent. Associated with the relatively low stock/population balance in Southeast Asia and the South Pacific is a generally small share of resources available to each farm family. Smallholders within the area work small plots of ground and own few ruminants, if any (Tillman 1981). The rearing of 1–3 cattle or buffalo or 3–8 sheep is the norm, and has repercussions for forage usage and management that are discussed later. In terms of regional characteristics, the small scale of operations for individual farmers is another important similarity.

The Physical Location of Forages

The preceding section emphasised the heterogeneity of physical environments within Southeast Asia and the South Pacific. A wide range of farming systems has developed to meet this heterogeneity, with an endless diversity of subclasses within each system that are appropriate for specific local conditions. Forages must occupy particular locations within these systems. In order to discuss the prospects for new forages there is a need to develop a convenient model that will express this diversity, and identify how and where forages currently fit and can be developed.

Many classifications have been developed for the two regions, for example: Oldeman (1975); Malingreau (1981); Woods and Dent (1983); Petheram and Thahar (1985). These provide summaries of climatic and other factors relevant to forage production. Climatic criteria, in particular, are frequently used as a first step in area classification, on the premise that climate provides the main physical limits to the performance of different plant species. However, the forage opportunities in two areas with similar climate may be entirely different. One range of forage species may be appropriate to both but introduction, management and utilisation would need to fit the actual land usage in each site.

For this paper, therefore, the importance of the physical environmental factors are acknowledged but temporarily set aside. Hundreds of forage species are recognised, and known to be suited to certain sets of environmental conditions. It is our contention that these environmental conditions are not the main determinant of forage prospects; it is the current usage of land that provides a more realistic classifier (and is also the best integrator of climatic and other factors).

The format presented in Fig. 1 flows from the simple premise that forages must exist in a given location for a period of time. Time is defined as potential duration of the forage crop, ranging from permanent grasslands in extensive systems to ex-
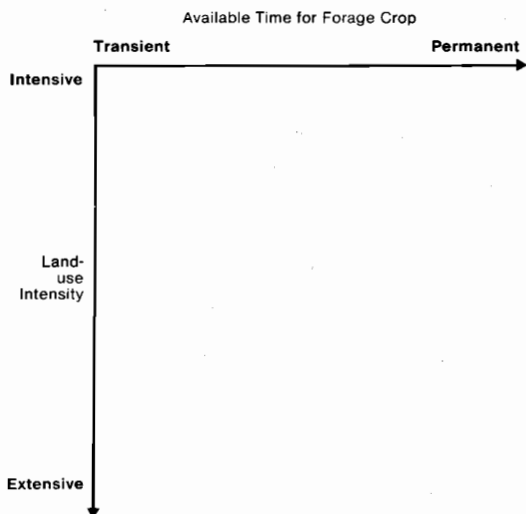
Available Time for Forage Crop

Transient   Permanent

Intensive

Land-
use
Intensity

Extensive

Fig. 1. A two element format for classifying forage opportunities.

tremely short-term between-crop forages in intensive, irrigated, multiple rice-cropping.

The Land-use/Time elements make it possible to locate most commonly occurring farming systems — or parts of such systems — from the two regions, and for agrostologists to suggest potential forages and management that fit the defined slots. Four examples of such 'Forage Opportunities' are given below:

(1) extensive/permanent grasslands;
(2) semi-intensive/permanent forages;
(3) semi-intensive/annual forages;
(4) highly-intensive/short-term forages.

Within any of these broad Land-use/Time slots it may be possible to identify a number of forage opportunities at any particular location. Each opportunity would be more fully described by supplementing the Land-use/Time slot with local climatic and other physical data. Examples of forage opportunities taken from each of the above Land-use/Time categories are given below:

1. Extensive Permanent Forages

a) Privately-owned ranchland, with mixed native grasses and a 6-month wet season. Forage developments would include oversowing with legumes, complete pasture improvement, use of small, high-yielding paddocks, and establishment of 'live fences'.

b) Communally-grazed hillsides, covered with *Imperata cylindrica,* prone to erosion, and subject to a 4-month wet season. Forage development must involve destocking 25% of the area for two years and establishing forage legume tree hedges on contours at 5m intervals. A full area requires eight years for rehabilitation.

c) Communally-grazed and cut roadsides, found in intensive rice-cropping areas with an 8-month wet season. These areas require planting with forage legume tree hedges, which must be protected from grazing for the first year and left two years before cutting.

2. Semi-intensive Permanent Forages

a) Rubber plantations with tree replacement programs. The lateritic soils show erosion under young trees, and there is a 6-month wet season. A broad-leaf cover crop should be sown after land preparation, and forages for dairy cattle should be hand-cut and carried. As the tree canopy develops, forage management should be reassessed.

b) Tea plantations on acid soils with a 4-month wet season. Roadside strips exist between blocks. A creeping grass/legume mixture should be sown after land preparation, and a small stock should be tether-grazed by plantation labourers and families.

3. Semi-intensive Annual Forages

a) Single crop rain-fed rice on deep alluvial soils which retain moisture postharvest. There is a 4-month wet season. Forage improvements recommended are sowing of annual *Stylosanthes* on riceland dykes, to provide seed which can be broadcast into the stubble after harvest, then grazed along with volunteer weeds.

b) Single crop rainfed rice grown during a 6-month wet season. There is some rain after the rice crop, and soya or mung beans should be planted into wet soil after rice harvest. The crop residue should be made available for feeding or conservation.

4. Highly-intensive Short-term Forages

Javier (1978) listed a number of possibilities, including intercrops of fodder legumes such as maize/soybean; rotational cropping with pigeon pea; complete replacement of a continuous rice system with aquatic tropical grasses for beef fattening.

Within any system there will be important pockets of entirely different land-use, many with apparent potential for forage production. The example of grass strips within intensive rice areas has already been given and a contrast would be provided by low-intensity/annual forages. Areas with low population densities may, at first glance, appear suitable for permanent forage development. However, if the cultivators use slash-and-burn techniques in rainforest, the actual cleared areas may provide virtually the only forage source. The sowing of temporary forages would be a useful development, providing small plots of high quality feed within the cleared areas to supplement basal feed grazed from the fringes of the cultivated land.

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Some Major Constraints to Forage Development

The principal considerations of heterogeneity and specificity emphasised thus far must also be applied to constraints affecting the introduction of new forages or amending current systems; the productive factors available to one farmer may be quite different to those of his immediate neighbour and their goals may also be divergent.

The environmental factors affecting the adaptation and production of forages have again been given secondary importance. These have already formed the basis for many years of research work and are frequently reported. Other factors will have as strong or stronger effects on the actual adoption of tested material by the target farming group. Field experience and observation suggest that four such factors frequently provide substantial barriers to forage improvement , either alone or in combination. These are:

(1) access to land and its product;
(2) complexity of forage management;
(3) markets and marketing;
(4) farmer motivation.

1. Access to Land and its Product

A common first social division in the rural sector is between households with land and those without. This heading may obscure appreciation of actual access to land, given the many classes of ownership, renting, sharing and communal usage that are possible, plus the legal and traditional variations in title, inheritance and transfer. Lack of land alone need not inhibit stock-rearing. Southeast Asia abounds with examples of landless households that rear large or small ruminants by utilising material from roadside strips, fallow areas and crop residues either through grazing or cut-and-carry systems. It is more useful to ask who has access to the rural product. The first examples come from contrasting areas of high-intensity land-usage.

In West Java and throughout much of the island, crop residues are essentially available to most of the community; fallow lands, riceland dykes, road and canal verges, recreation areas and forests, etc., can be utilised by any forage gatherer (Thahar et al. 1983). Naturally there will be claims .for preferential access deriving from customary usage, but the user of the feed material is frequently not the owner or renter of the land. This poses obvious problems on who will develop this forage resource and who will use it. The many strips, plots and patches of permanent grasses around villages and croplands are potential candidates for oversowing with legumes or replacement with high-yielding grass/legume mixtures. But, if associated with rights-of-way, houses or recreation, etc.,

these areas are essentially public and the product is available to itinerant stock or gatherers.

A similar situation exists within the cropland areas. As ownership or usage of a particular plot will rest with one household, responsibility for forage development can be more easily assigned, but the developer has no guarantee that he will enjoy all the results from his efforts. Plots are typically small (average farm size is less than 0.5 ha) and the material can be quickly cleared by grazing animals or other people. Fencing and guarding the plot is possible but may constitute an unwelcome social statement and ultimately cannot prevent occasional cutting or outright theft.

Some of these social constraints have been overcome in East Java. West Java is a relatively forage-abundant area with high rainfall, mixed cropping and an overall stocking density lower than average for the island. In Madura, off the northeast coast of Java, the picture changes. Rainfall is lower here than in the west and a long dry period occurs. Soils are generally poor, yet the area currently has the highest cattle stocking rate in Indonesia, frequently exceeding 100 head/km^2. Upland and lowland rice is cropped annually and small patches are also irrigated. Corn is the main staple in very dry, hilly parts.

Farmers have developed a number of forage systems to provide green or conserved feeds and supplements through the long dry period. Corn may be sown before, with or after the main crop, providing tops and then stover for fresh and conserved use; deep-rooted annual legumes are planted into the corn stubble; the grain available for human consumption and leaves fed to stock. As the dry season progresses, a great range of shrub and tree leaves are gathered for supplementary or staple feeds, including *Leucaena, Sesbania,* bamboo and bananas (Petheram et al. 1983). Some green forage is carted in from the mainland for sale, and farmers are adept at combining available material to provide feed for their stock.

The development of such particular feeding systems has been accompanied by more restrictive access to forages. The emphasis is on individual ownership of the resource. Crop residues are usually used by the farmer; in some villages, plastic bags or cloth strips will be hung from the trees or bamboo poles to denote personal access to forage beside roads and paths, on riceland dykes, in fallow areas, on grassed hillsides and beneath tree crops. These 'flags' show that a person claims right to the product of that particular plot and will return at some time to cut it. Many dry upland slopes are left in permanent grass and frequently rented out, with the rearer cutting three or four times during the growing season.

The Madurese are enthusiastic stock rearers who are keenly aware of the feeding needs of their animals and

eager to experiment with new material. The tighter controls on access for forages, however, do not automatically ensure that the developer gets the product. Theft of material is common and a prime cause for bitter disputes in the dry season. The farmers will often indicate that the marginal uplands with dry, stony and poorly-structured soils are the best candidates for forage development; forage improvement in the currently-used areas still has social problems of access.

Smallholder systems in extensive land-use areas would, at first, appear to have fewer land problems. Large reserves of communal land may be available for grazing by some or all of the village livestock. However, development of such areas through oversowing for partial or full improvement requires consensus on the responsibilities of funding, management and offtake. Unless complemented by strict social control, such schemes produce problems of nepotism, with powerful individuals and groups gradually converting land to their own use and excluding less favoured participants. It was, after all, the gradual disappearnance of the common lands into privately-owned strips and blocks that provided a major impetus to the radicalisation of agriculture in Europe and elsewhere.

The systems possbily least encumbered by problems of land and product access are those with established legal title in extensive areas of low population pressure. Their main forage development problems are considered later.

2. Complexity of Forage Management

Changes to an agricultural system invariable require farmers to reallocate some resources, possibly accompanied by absolute increases in one or more inputs. Techniques that increase the value of output, however measured, above the cash and other costs of inputs are more acceptable prima facie candidates for change. It is the belief of the authors that forages rank generally lower than food crops and other enterprises in many farmers' value ratings. Forage techniques that may involve new material, fertilisation, chemical control or increased demand on labour or managerial skills will need to display pronounced absolute benefits before being considered as candidates for adoption.

Among smallholder farmers operating intensive systems, the constraints on management such as lack of capital and limited land resources are fairly obvious and are not discussed in detail. Indeed, in the last section of the paper it is argued that such farmers are among the most eager to experiment with new materials and methods. Complex managerial requirements can be a more important barrier for the extensive, low-intensity rearers contemplating forage development, largely a result of the scale of investment

involved. One example is given here (Perkins 1980), of a proposal to develop a mini-ranch in New Ireland, PNG.

The area was sparsely inhabited and local villagers were willing to allow the development of 1500 ha of native *Themeda* sp. for a ranch. The first proposal called for the purchase of heavy field machinery and total redevelopment of the existing grasslands with high-yielding grass/legume mixtures. The ranch was to be developed from scratch and required substantial capital investment. The forage component, although relatively small in relation to total investment, increased the risk enormously. If the redeveloped pastures proved unstable, the critical assumptions on stocking rate, weight gain, reproduction and turnoff would not be achieved. A budgetary exercise showed the risk posed by pasture redevelopment to be financially unacceptable. A more cautious approach, using the native grasses plus some oversowing trials, was recommended.

3. Markets and Marketing

The first two constraints discussed relate directly to forages and forage systems. The last two are more oblique but possibly more important.

Forages feed ruminants, and ruminants are fed for a purpose. The perceived importance of that purpose will reflect back on the importance of the feeding materials required in the flow of animal production. The conduct of the stock marketing systems is one expression, though indirect, of the value of stock to farmers. Ruminant livestock have a number of uses and, thus, there will exist a multiplicity of formal and informal markets including sales or transfer for draught work, fattening or eventual consumption. This section concentrates on the latter.

A major function of markets and their associated marketing chains is to transfer indications of preference from consumers to suppliers. A well formed market with strong backward and forward information linkages can specify the varying returns for the quantity and quality of the product traded. This allows the supplier, with the resources at his disposal, to make decisions on the management of his enterprise with reduced uncertainty of the likely outcome and reward.

Such signals and responses develop most strongly in frequently used markets. The staple food, vegetable and fruit markets in Southeast Asia and the South Pacific are good examples of developed markets, with both buyers and sellers very keenly aware of the prices relating to different grades and types of produce and the likely seasonal variations in prices. This is a result of their frequent need to enter and act in the market.

Most markets for ruminants in the two regions are less well-defined and the market signals much weaker.

Protein is frequently supplied by vegetables and fish, with chicken the meat of first choice because of small size and convenience for a family meal (Onghokam 1984). Larger ruminants are often reserved for ceremonial or social occasions, to be shared in small individual portions among a large group of people. Village farmers rear small numbers of animals and their entry into the market is very intermittent.

The marketing structures are characterised by long chains of exchange and limited public information, with trading carried on at a very personal level among farmers, traders and buyers. Sabrani et al. (1982) studied sheep and goat markets in West Java, Indonesia; Damanik and Salangka (1983) followed with further work on the role of the village collector. The importance of itinerant farm-gate traders was emphasised and they commented upon the relative lack of knowledge — and even interest — on market prices and conditions expressed by some farmers.

Such systems blur the market signals for the supplier. If higher overall quality is not substantially rewarded by a higher price there is a reduced incentive to reach quality goals. If market sales are intermittent and at the behest of unpredictable circumstances — such as sick animals or a sudden need to raise cash — performance parameters such as weight gain and optimal turn-off point are not important. In the authors' opinion, many markets in the region simply require that animals be maintained for availability and wealth storage, rather than reared to meet specific demand conditions. Feeding systems thus emphasise maintenance rather than performance. The farmer's prime concern is to keep the animal alive with minimal labour. Thus, low quality forages are quite acceptable. A main reason for a lack of interest in upgrading forages may simply be that the market does not reward the extra time, effort and possible expense involved.

4. Farmer Motivation

The ultimate determinant of modifications to agricultural systems lies within the rural household. Farmers will adopt changes and suggestions that: a) meet some perceived need; b) will assist them to achieve some goal; c) are sympathetic to their individual situations; d) are viewed as achievable within their framework of available resources.

The paper has emphasised heterogeneity and diversity throughout, both as providing many physical slots or niches into which forages could be placed and, simultaneously, furnishing the constraints which may prevent such development from taking place. This heterogeneity extends to the many millions of small rural households within Southeast Asia and the South Pacific, each with its particular mix of circumstances, needs, aspirations and goals.

The farmers' attitudes to forage will largely be conditioned by the value placed on ruminant livestock. Many farmers own no herbivorous stock at all. Some feel that the risk is too great; if a smallholder owns two to three cattle, a single death wipes out a major part of his capital. Javier (1978) demonstrated that it was possible for rice farmers in the Philippines to earn a greater income through converting their ricelands to high-yielding forages and fattening beef cattle for the Manila market. Such a change, however, involved substantial capital and a considerable increase in risk. Many farmers could not justify such exposure.

For farmers in some areas, ruminant livestock would be a completely new enterprise. Such was the case in much of the South Pacific, where cattle often provided the first introduction to domestic ruminants, brought in as milk cows on expatriated plantations. Although cattle, sheep and buffalo are now more widespread in the South Pacific, there are still many farmers who are relatively unfamiliar with the management of their animals. The stock is viewed somewhat as a novelty and has not been fully incorporated into the local system.

By contrast, ownership of stock in other cultures may be a highly prized symbol of status, with wealth measured by the number of animals owned and displayed. As with the range possible in physical environments, so there is a long continuum of interest in livestock, ranging from utter indifference up to groups whose main social goals are expressed through their cattle, buffalo, sheep or pigs.

Research into motives for stock-rearing is difficult to undertake. One approach is to examine the more utilitarian aspects of ruminants. These include: draft power for croplands; carting and transport; income from sales; manure; security; family food; consumption and sale of milk, hide, wool and hair; a store of wealth; consumption at conspicuous social and religious events.

Herbivores utilise fibrous materials that the farmer cannot use directly. Products and by-products such as meat, hair, wool, skin, horns, bones and hooves support important processing industries. A farmer's response to questions concerning the importance and use of his livestock will frequently boil these multiple functions down to one or two statements that provide an inadequate framework for developmental action. For example, in a survey of cattle productivity and forage usage in South Sulawesi, Indonesia, respondent farmers were asked to give their reasons for keeping cattle. Draught work and cash were invariably nominated in either order, implying that a reasonable case might be made for developing forage systems that

would increase energy at peak work periods, hasten weight gain and improve reproduction.

Observations over long-term monitoring suggest that such concerns are important but not dominant. Cattle are used at only one short period of the year for land preparation; not all cattle are used at that time; those that work do so fairly lightly. Sales of stock have been both infrequent and irregular, with very few farmers actively participating in trade. Cash and draft provide insufficient explanation of motive: more pervasive appeared a general desire to have cattle there and available when needed for whatever purpose.

Such a motive for stock-rearing appears quite common throughout different societies in Southeast Asia and the South Pacific: a mobile reserve of security, wealth and possible status (Suradisastra 1983). The Madurese farmers of Java hold cattle races throughout the area during the dry season that are an important focus for the local community; sheep farmers in Garut, West Java, rear fighting rams specifically for regular contests. Such commitment to stock will contrast with the many farmers who rear a backyard pen of sheep mainly as an enterprise utilising available material for occasional sale.

Linking these examples is a requirement for maintenance: ensuring that sufficient forage is available to keep the animal alive and acceptance of concomitant slow weight gains and intermittent reproduction. Food crops, industrial crops and, very frequently, alternative labour usage such as labouring, handicrafts and village industries may rank as more rewarding than livestock at present levels of productivity. Montgomery (1981) commented on the low labour absorption and high income elasticity of the livestock sector, thus placing it at a frequent disadvantage to other components of an intensive cropping system. The labour and management skills of the family may flow into a number of channels and be frequently redirected to another more remunerative outlet. Forages will have a rating somewhere within this decision process and, unless such rating is high, interest in forage development will be limited.

Research-based Assistance for Forage Development

There is a tendency for social scientists to place too much emphasis on the constraints facing development rather than the advantages (Chambers 1984). Such a situation may have been exacerbated by misinterpretation of Farming System Research (FSR), in which the portrayal of linkages between the farmer, household, village and culture can give the impression of bonds too strong and inert to accommodate change, or structures too fragile to resist adaptation without bursting apart. Such attitudes are unnecessarily negative. Social and cultural norms are strongly embedded but never immutable; farming systems are site-specific but highly adaptive; motives, attitudes, aspirations and goals will change several times in a farmer's lifetime.

Preceding sections have selected a few major constraints to forage development: these and others will be present in almost infinite variety and highly specific to each location. This does not imply that each suggestion for forage improvement can be contradicted at the outset, but rather that such diversity should be positively acknowledged and research planning and programs designed to accommodate it. The question is how.

The possible mixes of crops, stock and non-farm activities plus cultural and social goals are so numerous that it is patently impossible to devise research programs that fit each niche. Our suggestion is that farmers are the final judges of selecting appropriate forages and management to fit the opportunities available and thus should be included in the research process as quickly as possible. This is not a new suggestion: farmer-oriented research is now widely acknowledged and promoted but there is still a tendency to research materials on-station and develop methods that are offered as a package. In Indonesia, *Leucaena* sp. and 'elephant grass' *(Pennisetum purpureum)* are promoted and introduced in areas where they do not perform well. They are pushed because of proven success, either in other locations or on research stations: extension workers and farmers simply may not be aware that other, more appropriate, alternatives exist.

On-station work should firstly concentrate on researching broad groups of material in respect of climatic and environmental adaptability: soils, moisture, light, temperature, pest and disease tolerance. Simultaneously, descriptive work should be conducted on farms to identify and characterise apparent forage opportunities in relation to the two suggested elements of Land-use and Time (Fig. 1). Such opportunities could then be grouped and listed: riceland dykes; hedgerows; fallow croplands; natural grasslands; extensive pastures, etc. This phase of research is concluded by merging the two evaluations: each potentially adaptive species to be characterised by its physical requirements and potential on-farm physical location and end-use.

To be effective for field use, such a listing should be similar to those a seed company might put on their retail packaging: e.g., 'Performs well on acid soils in lowland areas; drought and shade-tolerant; suitable for use in hedgerows, fencelines or continous plots; establishment period of eighteen months and thereafter

can be trimmed at eight week intervals or greater; a reserve in extended drought periods'. Such basic classifications are handles which the farmers and extension workers can grasp: they suggest physical limits and uses that are appropriate to many farmers' individual situations.

Field research would continue with the establishment of a range of physically adapted forages being established at a number of trial sites, demonstration plots and on farmers' land. This would enable researchers, extension workers and farmers to jointly observe and concur on the suitability of the material and its possible integration into the system. A farmer can see a number of plants performing and indicate those which appear best-fitted to his system. The researcher gets a much better appreciation of which plants appear attractive, where they would fit into the farm system and why they are selected. The technique was accepted in Madura. One farmer selected Hamil grass, *Panicum maximum*, from five species offered for experimentation on shaded field edges. Establishment was a success and, following field visits, 200 kg of seed was imported to meet requests from four thousand farmers.

Such a process relieves much of the burden upon the researcher of making a farmer's choices for him. We should not attempt to do farmers' thinking for them, and there should be a reduction in emphasis on simulation work at research stations; it is almost impossible to simulate the situation, constraints and goals of smallholders or even the physical environment. Research is also often performance-oriented, with potential material being set aside because of poor comparison with high-yielding species. Yield performance may not be a primary target for many producers, and relatively poor performers in research terms may find a place on some farms because they fit a niche that the researcher had no means to predefine.

Lack of knowledge is a frequent barrier to development. Farmers are keen to experiment, test and adapt; avid observers of each other's successes and failures and open to change which they see as providing real benefits to the household. The most obvious examples come from food croppping, where the high-yielding varieties of rice developed at the International Rice Research Institute in the Philippines have — after a sputtering start — become assimilated throughout the Southeast Asian region and extend to some of the most remote areas.

Research goals also require some diversification. Performance indices are only one attribute for farmer consideration, yet they remain a dominant emphasis in research. When researching forages for Southeast Asia and the South Pacific, it is suggested that four more general considerations would also be useful: 1. scale; 2. simplicity; 3. adversity; 4. fitness for purpose.

Scale

For many farmers, forage development is restricted to small plots, strips and patches of land yielding little material individually and with strong competitive 'edge effect'. Yields under competition may mean more than large area yields. Shrub and tree legumes may be planted in clusters of three or four, or even planted as individuals in competition with adjacent fruit and timber trees. Trials need to be designed to observe forage performance under such restricted but realistic conditions.

Simplicity

Complexity as a constraint of a forage development has already been discussed: the natural corollary is that some trials should be established with minimal management, fertiliser and chemical requirements. If farmers do view forage as a low-value crop, then systems requiring high labour and management inputs, or cash resources that must be diverted from important food crops, will have poorer prospects of being received and implemented by the farmer.

Adversity

Farmers will often nominate stony, infertile, eroded or dry lands as being the leading candidates for forage development. Added to these would be the many shaded and semi-shaded areas under tree crops, bamboo, or long-term food crops. Most cropping lands are too valuable to be considered as candidates for permanent forages, so forage species need to be tested in unfavourable conditions of soil nutrition and structure; adverse climates and topography; limited access to light.

Fitness for Purpose

This requires development of the Land-use/Time format proposed, with forages and systems tested in relation to end-use. Many farmers use tree and shrub legumes as a store: their interest is not in maximising continuous yield through height and frequency-of-cutting regimes but rather maximising bulk at times of seasonal deficit. Low-growing legumes in a pasture sward are appropriate for resistance in an open grazing situation; more upright and higher yielding legumes could be tolerated by cut-and-carry farmers with penned animals.

Farmers adapt where change is of value. Even a rearer who views penned sheep as intermittent enterprise has to invest hours each day in selecting, cutting

and carrying forages. For him, the goal may be labour saving rather than animal performance. Farmers are the final integrators of material and ideas into their systems, and consistently show initiative and innovation. Through watching, discussing, visiting other areas and conducting their own trials, farmers determine what works for them in their own locality, given the resources that they manage and the needs that they are trying to satisfy.

References

Chambers, R. 1984 Rural development — putting the last first. Longmans, England, as reviewed by Watson D., Prisma — the Indonesian Indicator (1984), No. 32, Institute for Economic and Social Research, Education and Information, Jakarta, Indonesia.

Damanik, K.I. and Salangka, M.K., 1983. The role of the village collector (Blantik) in the production and marketing systems of small ruminants in Central Java, SR-CRSP Working Paper, No. 28, Balai Penelitian Ternak, Bogor, Indonesia.

FAO, 1983a. Livestock Population in Asia and the Pacific, FAO, Rome, Italy.

FAO 1983b. FAO Production Yearbook. Vol. 37, Rome, Italy.

Javier, E.Q. 1978. Integration of fodder production with intensive cropping systems in Southeast Asia. In: Devendra C., and Hutagalung, R.L., ed., Feedingstuffs for Livestock in South East Asia. Malaysian Society of Animal Production, Serdang, Malaysia, 19–36.

Malingreau, J.P. 1981. A land cover/land use classification for Indonesia. The Indonesian Journal of Geography, II (41), Gadjah Mada University, Indonesia.

Montgomery, R. 1981. Employment generation within the agricultural sector. In: Hansen G.E., ed., Agricultural and Rural Development in Indonesia. Westriew Press, Boulder, USA.

Oldeman, L.R. 1975. An agro-climatic map of Java. Contribution No. 17; Central Research Institute for Agriculture, Bogor, Indonesia.

Oldeman, L.R., and Frere, M. 1982. A study of the agroclimatology of the humid tropics of Southeast Asia, Technical Report, FAO/UNESCO/WMO Intragency Project on Climatology, FAO, Rome, Italy.

Onghokam, 1984. The decline of indigenous commodity trade, Prisma — the Indonesian Indicator, No. 32, Institute for Economic and Soecial Research, Education and Information, Jakarta, Indonesia.

Perkins, J 1980. Huns Project Cattle Unit interim report (mimeo). Department of Primary Industry, Rabaul, Papua New Guinea.

Petheram, R.J. and Thahar, A. 1985. A land classification for livestock research and development. Indonesian Journal of Agricultural Research and Development, Bogor, Indonesia (in press).

Petheram, R.J., Prawirodigdo, S. and Boer, M. 1983. Assessment of hand-fed forage diets in Indonesia, Research Reports, Project for Animal Research and Development (CSIRO), Bogor, Indonesia, 38–39.

Sabrani, M., Mawi, S., Soedjana, T.D., and Knipscheer, H. 1982. A profile of the sheep and goat markets in West Java, Indonesia, SR-CRSP Working Paper, No. 3, Balai Penelitian Ternak, Bogor, Indonesia.

Suradisastra, K. 1983. Social aspects of small ruminant production: a comparative study of West Java, Indonesia, M.Sc. Thesis, Faculty of the Graduate School of University of Missouri, Colombia, USA.

Thahar, A., Petheram, R.J., and Ridwan 1983. Main sources of forages hand-fed to ruminants in West Java. Research Reports, Project for Animal Research and Development (CSIRO), Bogor, Indonesia, 33–35.

Tillman, A.D. 1981. Animal Agriculture in Indonesia. Winrock International Livestock Research and Training Centre, Morrilton, USA.

Woods, S.R. and Dent, F.J. 1983. LECS — A land evaluation computer system methodology. AGOF/INS/78/006. Manual 5 Version 1. Ministry of Agriculture, Indonesia/UNDP/FAO, Bogor, Indonesia.

Sources of Feed for Ruminant Production in Southeast Asia

S.K. Ranjhan*

AGRICULTURE in Southeast Asia is mostly a rice-based farming system where ruminants are primarily kept to provide farm power, and secondarily to provide limited amounts of meat and milk. The majority of the farms are small (between 1–2 ha) where few large ruminants (1–4 head of cattle/buffaloes) along with a few small ruminants (sheep and goats) are raised. About 90% of ruminants in Southeast Asia occur on mixed farms with the smallholder farmers.

The FAO Yearbook, 1983, showed that only 2% of the world's cattle population is found in the region, as against 14% of buffaloes which are mostly used as draught animals. Animal products supply about 30% protein and 10% energy in the diet of the human population which indicates low availability of animal products. Consequently, the region has to import large quantities of animal products (milk and meat). The low productivity is due mainly to poor genetic stock, inadequate health measures and inadequate supply of feed resources throughout the year.

Animal production in the region depends on the farm enterprise to a large extent and, therefore, ruminants are raised on small farms rather than in big commercial herds, except in a few instances of beef production in Indonesia, the Philippines and Malaysia. Ruminants are mostly both housed and grazed where feed is cut and carried, and in both instances are generally supplemented with farm wastes (straws and stovers) and other crop by-products (brans and other milling by-products) during the lean grazing period.

Native grass is the most important feed resource for ruminants which is provided from permanent pasture, unclassified land, and forest areas. Large quantities of fibrous crop residue are provided by land used for food and cash crops (Table 1). The main food crops of the region are rice, sugarcane, cassava, and other plantation crops such as coconut and oil palm. Likewise, other feed grains like corn and sorghum are important, while pulses (mungo, etc.) and beans are the least important.

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A review of the existing literature shows most animal production in Southeast Asia takes place on mixed farms and, therefore, greatly depends on crop production. Ruminant animal production, which greatly influences the smallholder activities, consists of on-farm forage harvesting and utilisation of farm by-products integrated into a feeding system which is determined primarily by the availability of material.

Ration formulations based on the nutritive value and nutrient requirement are never practised by smallholder farmers. Such practices are restricted to commercial feedlots for both ruminants and non-ruminants, and here rations used in the developed countries are used. At present, some countries in the region like Malaysia and the Philippines are working on the nutrient requirement and have feed composition tables (Devendra and Hutagalung 1978; Muller et al. 1974; Nitis et al. 1985; Holm 1971; Castillo and Gerpacio 1976; Zamora and Baguio 1984). These have very limited application in the raising of animals under smallholder conditions.

Sources of Roughage for Ruminants

Grazing

About 20 million ha of permanent pastures provide a major part of roughage intake by the ruminants. Taking a conservative estimate of about 0.8 t dry matter yield/ha/annum (Cruz et at. 1981), these pastures should produce roughly about 16.0 million t of dry matter per year, to supply 50% of the dry matter requirement for 44.6 million large ruminants in the region. Additional potential forage resources are from 240 million ha of forest and 99 million ha of unclassified land, mostly wasteland, which could supply an additional 48.0 and 39.6 million t of dry matter, respectively, totalling about 104 million t (Table 2).

The carrying capacity of the pastures in this region is low (3 ha unimproved pasture, 8 ha forest, and 12 ha wasteland per adult unit) owing to unimproved native grass cover like *Imperata cylindrica,* Themeda *(Themeda triandra),* and other grasses. In time, much of it could be improved by reseeding (Cruz 1982) with

Table 1. Breakup of the land used in different countries of the region, ('ooo ha) 1982.

Countries	Total Area	Land Area	Arable Land	Permanent Crops	Permanent Pastures	Forest	Others
1. Brunei	577	527	4	7	6	415	97
2. Burma	67655	65774	9627	452	361	32163	23171
3. Indonesia	190457	181157	14280	5320	11950	121800	27807
4. Kampuchea	18104	17652	2900	146	580	13372	654
5. Laos	23680	23080	870	20	800	12800	8590
6. Malaysia	32975	32855	1020	3315	27	21910	6583
7. Philippines	30000	29817	7800	4000	1100	12150	4767
8. Singapore	58	57	2	4	—	3	48
9. Thailand	5400	51177	17100	1875	308	15800	16094
10. Vietnam	32956	32536	5660	468	4780	110230	11308

Source: FAO Year Book, 1983.

Table 2. Availability of roughage for ruminants from the grazing area in Southeast Asia.

Classification[1]	Area (million ha)	Yield[2] (t/ha)	Annual dry matter (million t)
Permanent pasture (unimproved)	20.1	0.8	16.8
Forest land	240.0	0.2	48.0
Unclassified land	99.1	0.4	39.6
Total	588.1	—	104.4

[1]Calculated from the data available from the FAO Year Book, 1983

[2]Yield data has been taken on the basis of the work done in the Philippines, PCRDC (Cruz et al. 1981)

leguminous forages like stylo, use of fertiliser, and proper grazing management. This, however, is likely to be a slow and costly long-term development. Unfertilised and unmanaged native grasses have a poor nutritive value ranging between 2.5–7% crude protein and low digestibility. Generally nutritive value is lowest during the dry season and improves at the onset of the wet season (Table 3). During the dry season the nutritive value of the pasture does not sustain liveweight and yearlings (cattle and buffalo) lose between 20–25 kg weight in a six month period. However, during the wet season they gain between 50–100 kg.

Table 3. Chemical composition of unimproved pastures in Central Luzon (Eusebio and Ranjhan 1985).

Season	Crude protein	Ether extract	Crude fibre	Ash	N-free extract	DM diges- tibility
Dry	2.5	2.1	32.5	15.5	47.4	—
Dry	4.3	2.3	33.9	17.1	42.4	60
Dry	4.3	2.5	26.0	13.3	41.5	—
Dry	4.5	2.3	34.0	17.7	41.3	33
Wet	4.8	2.3	33.9	17.2	41.4	—
Wet	4.5	2.3	26.5	16.3	50.4	—
Wet	6.5	2.9	29.4	13.2	48.0	—

Fibrous Crop Residues

Apart from grazing, the bulk of roughage available for ruminants consists of straws and stubbles, special fodder crops, and crop by-products. The potential availability in Southeast Asia of roughages from some food and cash crops is listed in the FAO Yearbook (1983), and potentially available fibrous crop residues are shown in Table 4. It is observed that about 169 million t of crop residues are available from the major crops in the form of straws, stovers, vines, and the like. The yield of 14.2 million t of rice hulls available from the paddy harvest has not been included as a potential source of feed. Rice hulls have poor nutritive value and are not consumed by animals so they are used as fuel or left unused. In some countries, they are used as a source of fibre in beef cattle feedlot rations after being treated with ammonia. The economics of this practice are variable.

From the above calculations it is estimated that the total roughage available from grazing and from crop residues in the region is 273.4 (104.4 + 169.0) million t. Assuming three t of dry matter/animal/year as requirement this could support about 91 million adult animal units. The region has 44.6 million large ruminants (cattle and buffaloes) and 15.8 million small ruminants (sheep and goats). Taking eight small ruminants equivalent to one adult ruminant, small ruminant population can be converted to 1.9 million large units and this would be equivalent to 46.5 million large ruminants.

These calculations assume that feed of suitable quality is available throughout the year and that all forage is accessible and available. Both these assumptions can be seriously questioned. Since the quality of most forage in the region is low, animals are often barely above maintenance. If productivity is to be increased then quality, not quantity of diet is likely to have the greatest impact.

Table 4. Potential availability of crop residues in Southeast Asia from some cereals and food crops (at 90% DM level) ('000 t).

Feed Description	Brunei	Burma	Indonesia	Kampuchea	Laos	Malaysia	Philippines	Thailand	Vietnam	Total
Rice hulls[1]	1	2175	5145	255	150	300	1225	2780	2175	—
Rice straw[2]	10	15103	38306	1760	1040	2009	11535	22841	14926	107107
Wheat straw[3]	—	183	—	—	—	—	—	—	—	183
Maize, stover[3]	—	903	12000	180	117	27	10155	10656	1260	35271
Sorghum, stover[3]	—	357	9	—	—	—	—	981	126	1473
Cassava, leaves[4]	—	3	286	4	4	22	138	1020	162	2179
Sugarcane, bagasse[5]	—	4553	2944	21	4	120	2576	2929	552	13699
Sugarcane, tops[6]	—	3035	1962	15	3	80	1717	1952	368	9132

[1]Extraction rate — rice hulls, 15% regarded as unpalatable and very poor forage, and not included in the roughage availability
[2]Ratio of grain to straw 1:1
[3]Ration of grain to straw 1:3
[4]Leaves, 6% of cassava production
[5]Bagasse, 12% of cane production
[6]Green tops, 20% of sugarcane production or 8% of dry yield

Source of Concentrates for Ruminants

Information on the supply and consumption of the main concentrate feeds is available in the region but the proportion used for ruminants and non-ruminants is not. Corn, sorghum, millet, and other grains are mostly used for the non-ruminants. Limited quantities of corn and coarse grains are, however, used for beef production.

Milling by-products such as brans, oil cakes (peanut, copra, palm, etc.), and nonconventional by-products are available for ruminant feeds. Table 5 shows the potential supply of some concentrate feedstuffs in Southeast Asia.

About 43.2 million t of energy-rich and 2.9 million t of protein-rich concentrate feed ingredients are available. Most of these materials are used by the feed compounding industry to manufacture poultry and pig feeds. The region has insufficient supplies of coarse grains and good protein sources for monogastric animals, which results in substantial importation of corn and soybean meal. Substantial quantities of rice bran, copra meal, and limited quantities of coarse

Table 5. Potential supply of some concentrate feedstuffs in Southeast Asia ('000 t) based on the crop yield (FAO 1983).

SNo.	Feed	Brunei	Burma	Indonesia	Kampuchea	Laos	Malaysia	Philippines	Thailand	Vietnam	Total
1.	Rice bran (10)	1	1450	3430	170	100	200	815	1853	1450	9469
2.	Broken rice (5)	—	725	3715	85	50	100	408	927	725	4735
3.	Corn grain	—	301	3000	60	39	9	3385	3552	420	11757
4.	Millet	—	119	—	—	—	—	—	—	—	119
5.	Sorghum grain	—	—	3	—	—	—	—	327	42	372
6.	Cassava dried chips[1]	—	6	4995	10	6	146	683	5200	1200	12246
7.	Sugarcane, molasses(4%)	—	1517	981	7	1	40	858	976	184	4566
8.	Cotton seed oil residue	—	18	6	3	3	—	1	28	3	62
9.	Palm meats oil residue (35)	—	—	3	—	—	17	—	—	—	20
10.	Coconut meats oil residue (35)	—	—	374	2	—	71	676	14	22	1159
11.	Peanut kernel oil residue (50)	—	346	380	3	5	11	25	78	43	891
12.	Soyabean meal, mechanical (35)	—	15	413	—	4	—	32	247	96	807
	Total energy rich stuff (1–7)	4118	15124	332	196	495	6149	12835	4021	43264	
	Total protein stuff (8–11)	379	1176	8	12	99	734	367	164	2939	

Figures in parenthesis indicate the extraction rate.

grains are diverted for large ruminant feeding, especially for milk production and feedlot fattening. No data are available to indicate the amount of material available as supplements for feeding to smallholder ruminants.

Variation in Quality

There is a great variation in the quality of by-product feed ingredients because of the differences in the processing technique applied. For example, 40–60% of paddy is processed by small dehullers installed in the villages in many developing countries, resulting in only one by-product known as huller rice bran. This is available from processing plants and contains variable amounts of rice hulls (20–50%), which affects its biological value.

Feeding Systems

There are different feeding systems in various countries in the region. In Bali, Indonesia, Nitis (1980) reported that the average diet for cattle during the wet season was comprised of 79% grasses, 14% tree leaves, 2% legumes, 2% straw, 1% banana stem, and 3% other components (Table 6). Buffaloes are given a similar diet, but with markedly less tree leaves. Rice staw is a less preferred feed but it might comprise 30–60% of the diet during the dry season.

In the Philippines, Moog (1980), and Moog et al. (1981) described a seasonal feed profile for backyard cattle raising in a rice/corn system in Batangas. In this system animals depend heavily on volunteer forage species (*Themeda, Imperata,* etc.), and on crop residues and leguminous shrubs at various times of the year. In a rice/coconut feeding system in Quezon, *Imperata cylindrica, Paspalum* and *Cryptococcum* provided the basic feed, supplemented with corn stover during the wet season. Coconut fronds and banana stalks were supplemented with grazing during the dry season.

In Thailand, Sudasna (1983) described the traditional feeding patterns during the wet season. These include waste area, roadsides, canal banks and accessible grazing land, rice stubble, and weeds.

In Burma, rice straw is conserved and fed, together with grasses, to animals in both the dry and wet seasons. Forage legumes/tree leaves, and by-product concentrates are also used.

Specific Interventions

To overcome the seasonal feed deficiencies experienced in most Southeast Asian countries, many developmental efforts have been introduced with varying impact on the smallholder production systems. These include:

- shrub–legume plantings. This has been very successful in the Philippines where ipil-ipil (*Leucaena leucocephala*) has been introduced on a large-scale to supply nutritious feed to ruminants both in wet and dry seasons.
- legume overseeding of native pastures with stylo, Siratro, and grasses increases crop diversification, or where there is dry season pulse production of mungo, cowpea, and other legumes, there are additional sources of residual roughage for ruminant feeding.
- utilisation of crop by-products and concentrates to improve dry season feeding of ruminants.

The conservation of fodder by silage making, hay making, and artificial drying to tide over dry season feeding has not made any impact on the smallholder farmers in Southeast Asia. The bulky character and low sugar content of most tropical grasses, their low initial quality, the inputs required and the losses involved have not encouraged the farmers to use such means to make good the shortfalls of dry season feeding.

References

Castillo, L.S. and Gerpacio, A.L.. 1976. Nutrient composition of some Philippine feedstuffs. Tech. Bul 21, DAS, UP at Los Baños, College, Laguna, Philippines.

Cruz, L. 1982. Semi Annual Technical Report, FAO/UNDP Carabao Research and Development Project, Jan.–June 1982. PCARRD, Philippines.

Cruz, L.C., Mamuad, F.V., Lorenzo, D.L., and Venturina, H.V. 1981. Growth pattern of carabao under range condition. 18th Month Report PHI/78/017.

Devendra, C. and Hutagalung, R.I. 1978. Feedstuffs for livestock in Southeast Asia. Mal. Soc. Anim. Prod., Kuala Lumpur.

Holm, J. 1971. Feed Tables. Livestock Breeding Stations Huey Kale, Chiang Mai, Thailand. (Mimeo). p. 23.

Eusebio, A.N. and Ranjhan, S.K. 1985. Feeding management of grazing carabao in Central Luzon. Doc. 7, PHI/78/017.

FAO 1983. Yearbook, Rome.

Table 6. Supply of feed ingredients for cattle and buffaloes (%).

	Dry Season				Wet Season				
	Grazing	Straw	Tree/ shrubs	Other compo- nents	Grazing	Straw	Tree/ shrubs	Other compo- nents	References
Indonesia	31	50	14	5	79	2	14	5	Nitis 1980
Philippines	35	45	17	3	85	10	4	1	Moog 1980

Moog, F.A. 1980. Backyard cattle raising and its feeding system in Batangas barrio. M.S. Thesis. UP at Los Baños, College, Laguna, Philippines.

Moog, F.A., Nagpala, R.C. and Fulgencio, A.C. 1981. Feeds and feeding practices under different cropping patterns in Batangas and Quezon. (Mimeo.). PCARRD, Los Baños, Laguna, Philippines.

Muller, Z.O., Rollinson, D.H.L. and Neil, N.J. 1974. Suggested feed formulation for poultry and pigs. UNDP/FAO Project INS/72/009 Supporting Livestock Planning Working Paper p. 69.

Nitis, I.M. 1980. Beef cattle and water buffalo production in Southeast Asia. Proc. Int'l. Seminar, APHCA-INFIC. Manila.

Nitis, I.M., Lana, K., Susila, T.G.O., Sukanten, W., and Uchida, S. 1985. Chemical composition of grass shrub and tree leaves in Bali. Udayana University, Denpasar, Bali, Indonesia.

Sudasna, P. 1983. Livestock research for backyard production and/or crop livestock research. Proc. Crop–Livestock Research Workshop. International Rice Research Institute. Los Baños, Laguna, Philippines. 143–168.

Zamora, R.G. and Baguio, S.S. 1984. Feed composition tables for the Philippines. Book Ser. No. 13181., PCARRD, Los Baños, Laguna, Philippines.

Soil and Climatic Constraints to Forage Production

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FORAGE production in Southeast Asia and the South Pacific is generally secondary to food cropping and is therefore relegated to the poorer soils within each soil group. Forages are often produced on areas that have been perturbated by man, to the extent that the topsoil has been removed and placed in food cropping areas. In addition, land has often been reshaped (e.g. bunds around rice paddies) which leads to marked changes in water relations. In the more favourable soils, forages are often grown in association with food and/or tree crops, so that an extra restriction on growth occurs from moisture and light competition.

The grasslands of Southeast Asia and the South Pacific have generally developed from areas that were orginally under forest. With continued slash-and-burn agriculture and increasing population pressure, which leads to shorter and shorter rotations, these forests gradually deteriorate and are replaced by grasslands. It is not possible to estimate the total grassland area in the region but an estimate by Schwaar (1973) for Indonesia puts the total in that country at 21.09 million hectares. Soerjani (1970) estimates that there are 16 million hectares of land in Indonesia which has *Imperata cylindrica* either as a dominant or minor component of the grasslands. He further estimates that this grassland area is increasing at a rate of 0.15 million hectares per annum, mostly as the result of shifting agriculture.

Studies conducted in S. Sulawesi, Indonesia, as part of the Forage Research Project have shown that the productivity of these grasslands is low. In a three year grazing experiment liveweight gain/head was found to be only 90.2 kg/yr when the stocking rate was 0.5 animal/ha and that this declined to 67.0kg/yr when stocking rate was increased to 1/ha.

Whilst the grassland areas of the region may be low in total animal productivity the generally strong grass cover, provided mostly by *Imperata cylindrica,* affords a degree of protection to the soils against erosion.

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Soil Types in the Region

FAO-Unesco (1979) in their soil map of the world, have estimated the areas in the region covered by the various soil types (Table 1). These soil maps use FAO units in classifying the soils and this, together with the nearest equivalent in the USDA Soil Taxonomy System, has been presented in Table 1.

Table 1. Area of major soil types (% of total land area) in Southeast Asia and the South Pacific islands (FAO-Unesco 1979).

Soil Classification		South-	South
	USDA Soil	east	Pacific
FAO	Taxonomy	Asia	Islands*
		% of Area	
Acrisols	Ultisols	51	18.5
Fluvisols	Fluvents	8	15.1
Histosols		6	—
Nilosols	Alfisols/ultisols	5	0.1
Luvisols	Alfisols	5	1.2
Cambisols	Ochrepts/tropepts	5	44.6
Gleysols ·	Aquents	5	0.1
Ferrasols	Oxisols	4	2.9
Lithasols	Inceptisols	3	2.4
Andosols	Andepts	2	3.9
Podzols	Spodosols	2	—
Arenosols	Psamments	2	1.2
Regosols	Orthents/psamments	1	2.0
Vertisols	Vertisols	1	—
Rendzinas	Rendolls	1	7.1
Phaeozems	Ustolls	—	0.8

*Excluding Australia and New Zealand

The ultisol soils are the dominant soils of Thailand, Malaysia and Indonesia where it is estimated that they occupy some 51% of the total area. Within the aquasol/ ultisol group the orthic aquasols (or typical ultisols) occupy about 30% of the total region. These soils are found generally on gently undulating to rolling uplands, mountain slopes, and old alluvial terraces. In their native condition these soils are covered by tropical evergreen rainforest and tropical deciduous and montane-laurel forest. They generally have good physical conditions and are well drained. As these soils are cleared of forest their organic matter content drops rapidly and hence the supply of bases and nutrients declines rapidly. In their cleared state the soils generally have low base saturation and are generally

acid with the acidity increasing with depth. Associated with this increase in acidity with depth is a decline in base saturation and an increase in aluminium. These hostile subsoil conditions lead to a restriction in root growth of forages, and hence they become more susceptible to moisture stress.

The dominant soil in the South Pacific islands is the cambisol (ochrepts/tropepts). These soils occupy some 44.6% of the South Pacific islands (FAO-Unesco 1978), and dominate the landscape of Papua New Guinea, New Caledonia, Vanuatu, Fiji, and Western Samoa. Although the tropepts soils dominate the landscape in Papua New Guinea, they are generally found on steep slopes which limit their agricultural productivity.

With increasing pressures on land to produce food crops for the ever expanding population in both Southeast Asia and the South Pacific it seems evident that forage production will be pushed to less and less favourable soils in the foreseeable future. This poses a challenge for agronomists to devise systems which will provide an adequate supply of quality forage for the increasing animal population associated with the increased human population.

Soil Management

Unlike annual foodcrops, forage crops generally offer the opportunity to maintain a cover on the soil surface throughout the year. In a later section in this paper it will be seen that marked variations in climate bring about marked changes in the productivity of pastures and forages. A cover is generally maintained on the soil surface, however. Since many of the forage-producing soils are located in mountainous, hilly and undulating areas, the retention of surface soils becomes a major problem. Experiments being conducted as part of the Forage Research Project by M.E. Siregar (Siregar et al. 1984) are examining the productivity and soil conservation potential of various grass/legume mixtures when grown on the rises between terraced rice paddies. These experiments are being conducted in the Citanduay Basin in Central Java. In these experiments *Brachiaria brizantha* produced 38.1 tonnes of dry matter/ha over a 48 week period in 1983/84. This was some 24% higher than the yield for *Setaria splendida*. Of major consequence in these studies is the ability of these grasses to control erosion. Measurements of run-off and soil loss made over two 6-week regrowth periods have shown that *Setaria* or *Brachiaria* can reduce the soil loss from 32.5 tonnes per hectare per 12 weeks in the control treatment down to 2 tonnes per hectare per 12 weeks where grasses were planted. These studies show a general relationship between daily soil loss and daily rainfall, with the soil loss decreasing with time after grass cutting as regrowth protects the soil surface. This indicates the need to maintain a good plant cover on the soil surface to minimise erosion risks.

There are numerous options available to introduce forages into tropical production systems. In areas where labour is scarce and land relatively plentiful the opportunity to oversow is an attractive one, as it does not expose the soil surface to erosion. In areas where population pressure is higher and labour more plentiful, the opportunity to cultivate small areas within the existing grass sward or to plant cuttings offers an alternative to clean seedbed preparation.

A major decision regarding forage production in both Southeast Asia and the South Pacific is whether the soil requires some form of amendment to allow satisfactory levels of productivity. As indicated earlier, soils which are left vacant for forage production are generally those of lower general quality than soils used for food cropping. If the agricultural system is sufficiently advanced to allow the use of fertilisers, it is imperative that the correct fertiliser be used to obtain the most efficient productivity. Experiments conducted in Indonesia by Blair et al. (1978) found marked increases to sulfur on a glossudalf (alfisol) soil in S. Sulawesi (Table 2). Fertiliser recommendations for this soil, made on the basis of soil analysis, had previously not included this nutrient.

Table 2. Response of *Centrosema pubescens* to various fertilisers, S. Sulawesi, Indonesia.

Fertiliser	Centro Yield (kg green/ha)
0	4086
100 kg/ha single superphosphate	10491
13 kg/ha elemental S	9993
50 kg/ha triple superphosphate	5054

In many situations fertilisers will not be applied to soils concerned with forage production. Any available fertiliser material will generally be applied to food crops. In these situations it is critical to match the forage species to the prevailing soil conditions. Examples of this process are given in a later paper in these proceedings (Kerridge et al.)

Climatic Constraints to Forage Production

The extent to which the genetic potential of pasture species is realised at any location is essentially determined by soil and climatic factors. With respect to climate there have been numerous attempts to develop agroclimatic relationships and thus infer potential productivity of individual regions or countries. Until recently, the most widely used classification was that produced by Koppen in 1936 or a modification of it (see Lee 1957; Muller 1982; Ayoade 1983). Koppen distinguished five world climate types based largely on thermal regimes which correspond to five principal vegetation groups. Within each group, further subdivisions were made on seasonal incidence and amount of rain to give a total of 24 climate types. Despite the subdivisions, the system was not sufficiently sensitive to predict potential crop or pasture adaptation and failed to adequately describe moisture regimes (Whitmore 1984).

An attempt was made by Mohr (1933) to quantify the effects of precipitation and evaporation in tropical regions by dividing each month of the year into dry, wet or moist categories (wet = ppt. > 100 mm, dry = ppt. < 60 mm, moist = ppt. > 60 < 100 mm). Climatic regions were then distinguished by the number of wet and dry months., Both Mohr's and Koppen's systems have been criticised on the basis that they use monthly means of precipitation which obscure, for example, very dry months (Sukanto 1979) and fail to take account of rainfall reliability. To overcome this suggested weakness Schmidt and Ferguson (1951) computed dry and wet months for individual years using Mohr's criteria and then averaged the resulting figures. Eight zones were characterised using 1.5 dry month increments as divisions, viz. Zone A 0–1.5 dry months, Zone B 1.5–3.0 dry months, etc. Unfortunately, no indication is given as to the length of consecutive wet or dry periods and hence the duration of the growing season.

In temperate regions, two systems which have been widely used in agricultural research are those of Thornthwaite (1954) and Penman (1963). The former uses potential evapotranspiration to compute a Moisture Index, and three sets of subdivisions which describe seasonal variation of effective moisture, temperature and summer concentration of temperature. A total of 120 climatic types are defined, which makes the system difficult to map and unwieldy to use. Penman's formula is much more difficult to apply to climate classification, since it requires a close network of sophisticated meteorological stations to determine estimates of evapotranspiration, and this limits its application in many tropical areas.

More recently Oldeman (1975, 1980) and Las and Oldeman (1980) have developed agroclimatic maps of the major islands of Indonesia, based on the length of the growing season for bunded rice and upland crops. Using evaporation and rainfall data for a number of lowland sites in Southeast Asia, it was estimated that 200 mm of rainfall per month was needed to support the growth of bunded rice and 100 mm per month for upland crops. The length of the wet season, during which bunded rice could be be grown, was defined as the number of consecutive months receiving > 200 mm rainfall. The growing season during which upland crops could be grown was defined as the number of months receiving greater than 100 mm, plus one month at the end of the wet period during which growth would be expected on stored water. This allowed five main climatic categories to be defined, based on the length of the wet season, with further subdivisions based on the length of the dry season, giving a total of 18 agroclimatic zones. The system allows the incorporation of data from a large number of stations, where rainfall was often the only climatic parameter measured. Hence, mapping was accurate and site classification rapid. There are, however, a number of disadvantages to the system, e.g. no account is taken of other limitations to growth such as light and

temperature; rainfall reliability is not considered; the same evaporation rate is assumed for all locations; and it does not consider the effect of soil type and depth on growing season duration.

The increasing availability of computers means that more elaborate techniques can be used to complement the initial classification system of Oldeman. For example, in Australia, Fitzpatrick and Nix (1970) formulated a multifactor growth index which quantified growth of pasture species in relation to light, temperature and moisture regimes. The growth index was a multiplicative function of separate light, temperature and moisture indices. An index value of 1 indicated no restriction to growth, a value of zero indicated no growth, and a value of 0.5 growth at half the maximum rate. The light index was based on a pasture canopy with a leaf area index of 5, and related incoming solar radiation to an index of relative dry matter production. Similarly, the thermal or temperature index related relative dry matter yields to mean daily temperatures, with separate relationships for (a) tropical grasses (b) tropical legumes and (c) temperate grasses and legumes. For the moisture index the ratio of estimated actual to potential evapotranspiration (Ea/Et) was used as a scalar for relative dry matter response. The above approach represents an attempt to characterise pasture growth in relation to plant physiological processes and climatic parameters, and has been successfully adapted, for example, by Williams and Probert (1984). In this paper these methods have been applied to a range of climatic data from various locations in Java, to indicate the utility of simulation techniques.

The Model

A computer program was developed to calculate a daily growth index from rainfall, temperature, evaporation and solar radiation records, using equations similar to those of Fitzpatrick and Nix (1970) and Williams and Probert (1984) (See Appendix 1). Four forms of meteorological data were available:

(a) mean monthly climatic data averaged over a 5–8 year period, compiled by Las and Oldeman (1980); these could be converted to a daily form by linear interpolation.

(b) daily records from meteorological stations operated by the Research Institute for Food Crops — to enter these records into a computer would entail considerable time.

(c) the same records from (b), including averages and totals at approximately 10-day intervals, which could be recalculated into a daily form.

(d) daily rainfall for 13 stations in a computer compatible form from the meteorological office in Jakarta; such records need to be combined with temperature, evapotranspiration and radiation from the nearest station listed by Las and Oldeman in a similar agroclimatic zone.

In order to compare these four forms of data, the

model was run using records from Pusakanegara for the year 1973. Growth indices calculated from full daily data [form (b)] could be regarded as the most accurate of the data forms tested, and showed the greatest day-to-day variation. Other data forms had varying degrees of smoothing relative to full daily data, resulting in the relatively low r^2 values shown in Table 3. The annual mean growth index was, however, similar irrespective of the input data type. Since data type (d) sometimes entailed the use of evaporation, radiation and temperature data from locations a considerable distance from the rainfall recording station, data types (a) and (c) were used for all other simulations reported subsequently in this paper.

Table 3. Comparison of growth index predictions calculated from four forms of climatic data.

Data Form	Annual Mean Growth Index	r^2*	b Co-efficient*
(a) Mean monthly	0.643	0.294	0.576
(b) Daily	0.639	1.000	1.000
(c) 10-day	0.667	0.682	0.678
(d) Daily rainfall and mean monthly temperature, evaporation and radiation	0.641	0.708	0.879

*r^2 and b coefficient for the equation $y = a + bx$, where y is the daily growth index and x the prediction for that day calculated from the data form under test.

Model Development

Mean monthly climatic data were used for seven sites in Java, representing a range of agroclimatic zones, and moisture, temperature, light and growth indices calculated (Fig. 1). These simple simulations indicate that low light intensity during the wet season, and low soil moisture during the dry season are the predominant growth limitations. Temperatures are close to optimum throughout the year at all seven sites. These predictions were compared to Las and Oldeman's 'growing period.' Some differences were noted between the classification given on the agroclimatic map (Oldeman 1975) and that given by Las and Oldeman, viz. Kuningan changes from B_2 (1975) to B_1 (1980); Kendalpayak C_3 to C_2; Genteng D_2 to C_1; Jakenan D_3 to D_2; and Mojosari D_3 to D_2. In general the 1980 classification more closely aligns with the calculated growth indices. Agreement between Oldeman's 1980 classification and growth index predictions is closest for the extremes of wet and dry seasons; the growth index predicts significant forage growth at Genteng, Kuningan and Jakenan during months classified by Oldeman as too dry for crop production. This difference is related to the way months receiving just less than 100 mm are classified: the growth index method includes this as usable moisture for forage
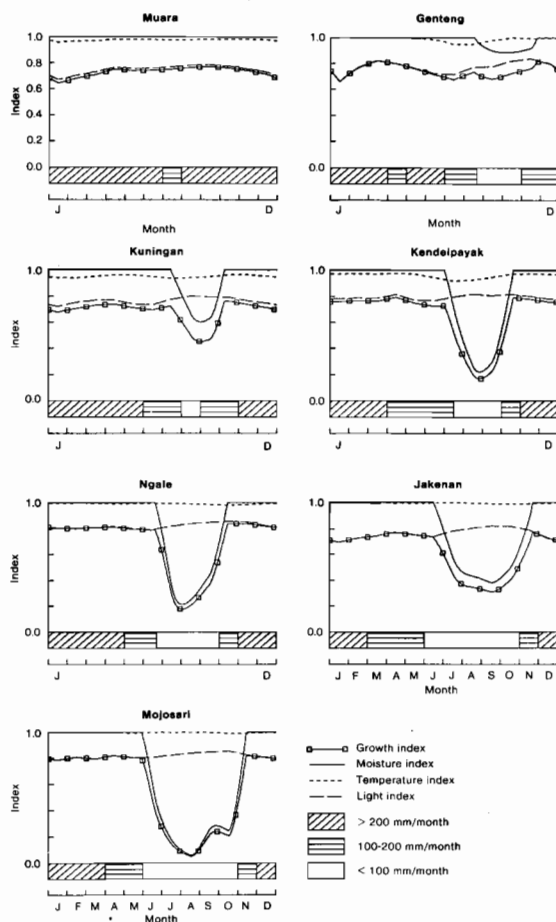
Fig. 1. Growth indices as calculated by the model from mean data for seven locations in Java, and the growing season as classified by Las and Oldeman (1980). The 100–200 mm/month classification includes one month at the end of the wet season when growth can occur on stored water at a rainfall < 100 mm/month.

growth, but Oldeman's classification excludes it on the grounds that it is insufficient for crop production.

Climate Variability

The use of mean rainfall data in calculating growth indices means that dry season forage production estimates are heavily influenced by occasional dry season storms, which contribute to monthly rainfall averages but are not a sufficiently reliable basis for a forage production system. The problems can be overcome by calculating the growth index from actual climatic data for a number of years; daily growth indices for each year are then sorted to enable the median, upper quartile (top 25%) and lower quartile (bottom 25%) to be calculated. Periods of the year with the most reliable forage production are those with the

smallest difference between upper and lower quartile growth indices.

To illustrate the utility of the growth index concept in describing climatic variability, the model was run using 10-day data for Muara (9 years), Genteng (5 years) and Mojosari (9 years) (Fig. 2). Because of the relatively small number of years used in these simulations, the quartile and median curves required smoothing by means of a 50-day weighted moving average to improve the clarity of graphical presentation. At Muara there was little year-to-year or within-year variability in the growth index. In contrast, the growth index for Genteng indicated slower and less reliable growth, particularly in August, September and October. Forages and most upland crops would be expected to continue growth through this 'dry season' period in all but the driest of years. The results from Mojosari illustrate the poor and unreliable growth likely from pastures at this location during the dry season. Annual forage species would be suited to similar locations, where there is a pronounced dry season.

Dry Matter Production

Assuming absolute genetic potential for growth can be estimated, the growth index can be used to estimate dry matter production throughout the year. Cooper (1970) lists annual production from heavily fertilised experimental grass swards between 30 t/ha/yr for *Panicum maximum* in El Salvador to 85 t/ha/yr for *Pennisetum purpureum* at the same location, although over short periods much higher growth rates can be achieved ($\equiv 182$ t/ha/yr). In the study conducted here, a benchmark yield of 45 t/ha/yr was chosen. This was achieved with an absolute genetic potential of 17 g/m^2/day. For tropical legumes, a value of 9.2 g/m^2/day was used, which gives a production of 24 t/ha/yr, equivalent to the leucaena yields recently reported by Mendoza (1983). The median growth index for tropical grasses and legumes was multiplied by these maximum daily growth rates to estimate seasonal forage production at Muara, Genteng and Mojosari (Table 4).

Dry matter production at Muara was similar throughout the year, reflecting the relatively uniform temperature, moisture and light conditions. In comparison, yields at Genteng were higher than at Muara during the wet season (November–May) as a result of more favourable light regime but lower during the dry season (June–October) as moisture becomes limiting. Total annual production was similar at both sites, although much higher than that at Mojosari where dry season yields were extremely low.

These forage production estimates can be used to calculate the area that would need to be harvested to support a 300 kg cow on a diet composed of 50% grass and 50% legume, assuming no use of stubbles or stored feed, and a forage regrowth time of one week. Based on a feed intake of 2% of body weight, an area of between 90 and 180 m^2 would need to be cut each

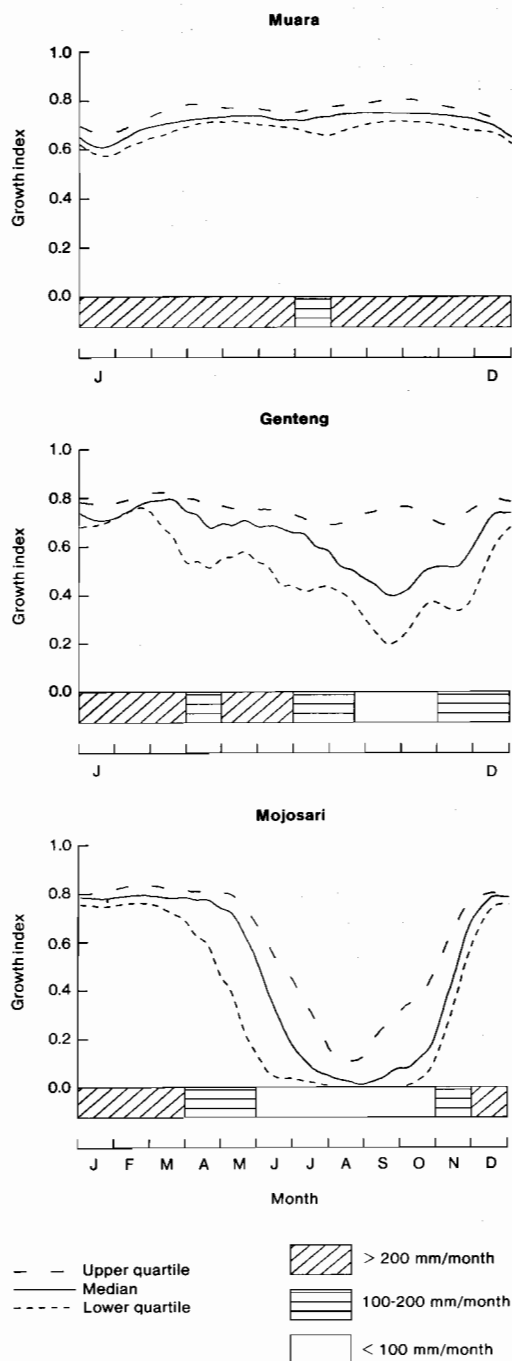**Fig. 2.** Variability in growth indices as calculated by the model from 10-day data, and the growing season as classified by Las and Oldeman (1980).

day at the two wetter locations (Table 4). At Mojosari, dry season productivity is so low that an area of 3600 m^2 would need to be harvested unless stubbles or previously grown forage were included in the diet.

Table 4. Calculated median growth rates for grasses and legumes and the area that would need to be harvested to support a 300 kg cow*.

	Growth rate g/m^2/month		Area harvested m^2/day
	Grass	Legume	
Muara			
January	311	162	125
February	323	170	108
March	373	195	104
April	372	197	100
May	391	208	98
June	367	194	101
July	382	202	101
August	396	210	97
September	382	202	97
October	393	207	98
November	376	199	99
December	370	195	104
Annual (kg/ha/yr)	44374	23410	
Genteng			
January	364	197	104
February	364	195	94
March	417	223	92
April	345	186	106
May	380	204	100
June	347	184	107
July	330	164	121
August	260	133	151
September	211	111	176
October	277	149	137
November	239	127	154
December	398	214	95
Annual (kg/ha/yr)	39338	20883	
Mojosari			
January	410	220	93
February	381	204	90
March	409	219	93
April	394	211	94
May	373	201	102
June	151	81	243
July	37	20	1032
August	11	6	3593
September	21	11	1761
October	42	22	902
November	269	144	137
December	414	221	92
Annual (kg/ha/yr)	29137	15609	

*Data assume diet of 50% grass/legume mixture and a one week regrowth time.

This paper has attempted to characterise the climatic constraints to pasture production in Java, and to illustrate the utility of a modelling approach in plant-climate studies. Previously the relationship between agricultural potential and climate has been addressed from a 'classification' viewpoint, which frequently resulted in complex and unwieldy systems. Conversely, attempts to map climatic areas often lead to over-simplification, with diverse areas being pooled into similar categories. Further, such systems only allow potential productivity to be inferred and may give little indication as to the reliability of forage growth in various seasons.

The simulation approach, in contrast, allows yield predictions to be made and hence quantifies plant production and likely year-to-year variation. In addition, the factors most limiting yield may be identified, and suitably adapted species or management strategies selected for specific locations. The potential of such models is illustrated by the work of Williams and Probert (1984) who, in addition to climatic factors, have incorporated certain soil constraints to characterise pasture production in the semi-arid tropics.

The present model, designed mainly to illustrate the usefulness of a modelling approach, may be criticised on the grounds of excessive simplicity, and the poor quality of data used for forage production estimates. Slightly more complex models can include (a) the use of a soil fertility index (as used by Blair et al. 1976) to allow for growth restriction due to nutrient limitations, and (b) a growth rate potential, which varies with the season, to estimate production from annual species (e.g. White et al. 1983) or species showing a degree of seasonal dormancy. As more forage growth data become available, the modelling approach could be a useful adjunct to Oldeman's classification system more closely matching appropriate forage species to a climatic zone. Models are particularly useful at extending the results of one or two years of field data to a wider range of years, to which a full-scale long term experiment would be prohibitively expensive. Deficiencies in model predictions do not necessarily undermine the modelling approach but instead tend to highlight gaps in present knowledge and emphasise the need and direction of further studies.

Acknowledgment

References

Ayoade, J.O. 1983. Introduction to Climatology for the Tropics. Chichester, USA, John Wiley and Sons.

Blair, G.J., Pualillin, P., and Samosir, S. 1978. Effect of fertilizers on the yield and botanical composition of pastures in South Sulawesi, Indonesia. Agronomy Journal, 70, 559–62.

Blair, G.J. Till, A.R., and Smith, R.C.G. 1976. The phosphorus cycle — what are the sensitive areas? In:

Blair, G.J. ed., Reviews in Rural Science. 3. The efficiency of phosphorus utilization. Armidale, N.S.W. University of New England, 9–20.

Cooper, J.P. 1970. Potential production and energy conversion in temperate and tropical grasses. Herbage Abstracts, 40, 1–15

FAO-Unesco. 1979. Soil Map of the World. Volume IX Southeast Asia. Unesco, Paris.

Fitzpatrick, E.A., and Nix, H.A. 1970. The climatic factor in Australian grassland ecology. In: Moore, R.M., ed., Australian Grasslands. Australian National University Press.

Las, I., and Oldeman, L.R. 1980. Agroclimatic research on rice and secondary crops. Special Series, Physiology Department, Volume A. Central Research Institute for Agriculture, Bogor, Indonesia.

Lee, D.H.K. 1957. Climate and Economic Development in the Tropics. New York. Harper and Brothers.

Mendoza, R.C. 1983. Highlights of research into the use of leucaena for forage in the Philippines. In: The use of leucaena for livestock feed in Asia. Taipei City, Taiwan. ASPAC Food and Fertilizer Technology Center, Extension Bulletin No. 198.

Mohr, E.C. 1933. De bodem der tropen in het algemeen en die van Ned. Indie in het bijzonder. Meded. Kon Ver. Kol. Inst. Amsterdam, D11 No. 31.

Muller, M.J. 1982. Selected climatic data for a global set of standard stations for vegetation science. The Hague. Dr. W. Junk, Publisher.

Oldeman, L.R. 1975. An agroclimatic map of Java. Contributions from the Central Research Institute for Agriculture, Bogor, Indonesia. No. 17. 1–22.

  1980. The agroclimatic classification of rice growing environments in Indonesia. In: Agrometeorology of the Rice Crop. Manila, Philippines. The International Rice Research Institute.

Penman, H.L. 1963. Vegetation and Hydrology. Commonwealth Agricultural Bureaux, England.

Schmidt, F.H., and Ferguson, J.H.A. 1951. Rainfall types based on wet and dry period ratios for Indonesia with Western New Guinea. Verhandelingen, Kementerian Perhubungan, Djawatan Meteorologi dan Geofisik, Djakarta, No. 42, p. 77.

Schwaar, D.C. 1973. Land capability appraisal Indonesia — land use appraisal. FAO, Bogor, Indonesia.

Siregar, M.E., Ivory, D.A., and Blair G.J. 1984. Productivity and erosion control capability of selected grasses and legumes in upland cropping systems of Java. In: Forage Research Project Annual Report 1984, Indonesia, p. 14.

Soerjani, M. 1970. Alang-alang (Imperata cylindrica (L) Beauv.): Pattern of growth as related to its problem of control. BIOTROP Bulletin 1, 80.

Sukanto, M. 1969. Climate of Indonesia. In: Arakawa, H., ed., World Survey of Climatology, Vol. 8. Climates of Northern and Eastern Asia. Amsterdam–London. Elsevier. 215–229.

Sweeney, F.C., and Hopkinson, J.M. 1975. Vegetative growth of nineteen tropical and sub-tropical pasture grasses and legumes in relation to temperature. Tropical Grasslands, 9, 209–217.

Thornthwaite, C.W. 1954. A re-examination of the concept and measurement of potential transpiration. In: Mather, J.R. ed., The measurement of potential evapotranspiration. C.W. Thornthwaite Associates. Laboratory of Climatology Publications.

Williams, J., and Probert, M.E. 1984. Characterisation of the soil-climate constraints for predicting pasture production in the semi-arid tropics. Proceedings of the International Workshop on Soils, ACIAR-IBSRAM, September 1983, Townsville, Australia.

White, D.H., Bowman, P.J., Morley, F.H.W., McManus, W.R., and Filan, S.J. 1983. A simulation model of a breeding ewe flock. Agricultural Systems, 9, 149–189.

Whitmore, T.C. 1984. Tropical Rainforests of the Far East. Oxford. Clarendon Press.

Appendix 1

1. LI $= 1 - \exp(-0.0047\ \text{RADI})$
2. RADI $= \text{SOLRAD}\ (1 - \exp(-0.5\ \text{GAI}))$
3. TI $=$ Function of temperature from Sweeney and Hopkinson (1975). This generalised tropical grass temperature response was used to simulate grass growth, and the Siratro curve for legume growth.
4. GI $= \text{TI.SI.LI}$
5. DG $= \text{GI.GRP}$
6. RASM $= \text{ASM/ASMAX}$
7. ETEP $= 0.87\ (1 - \exp(-1.09\ \text{GAI}))$
8. EAET $= 1$ for RASM > 0.8
   RASM/0.8 for RASM < 0.8
9. EA $=$ EPT.EAET.ETEP if EA $<$ ASM; otherwise EA $=$ ASM
10. ASM $= \text{ASM} + \text{PRECIP} - \text{EA}$
11. SI $= \text{RASM}/0.8$ for RASM < 0.8
    SI $= 1$ for RASM > 0.8

Symbols

ASM	available soil moisture in root zone (mm)
ASMAX	maximum soil water store in root zone (mm) [50]*
DG	Daily herbage growth (g/m^2/day)
EA	Actual soil and plant evaporation (mm/day)
EAET	Ratio of actual to potential evapotranspiration
EPT	Class A pan evaporation (mm/day)
ETEP	Ratio of potential to pan evaporation
exp	Exponential function; $\exp(x) = e^x$
GAI	Green leaf area index (m^2 leaf area/m^2 horizontal ground surface) [4]*
GI	Growth index indicating the relative reduction in growth rate from a combination of temperature, soil moisture, and light limitations (as a decimal)
GRP	Growth rate potential (g/m^2/day) [17 for grasses, 9.2 for legumes]*
LI	Light index indicating the relative reductions in growth rate of herbage due to suboptimal quantities of light being intercepted (as a decimal)
RADI	Radiation intercepted (cal/cm^2/day)
SI	Soil index indicating the relative reduction in growth due to soil moisture restriction (as a decimal)
SOLRAD	Solar radiation (cal/cm^2/day)
TI	Temperature index indicating the relative reduction in growth of herbage due to suboptimal temperature (as a decimal)

* These are the values used for simulations reported in this paper.

Exotic and Native Legumes for Forage Production in Southeast Asia

R. Schultze-Kraft*

A REVIEW of tropical forage research and production in Southeast Asia and the South Pacific region shows that relatively few legume species have been identified as successful commercially or are considered as highly promising for potential commercial use. The few identified include: *Centrosema pubescens, Desmodium ovalifolium, Macroptilium atropurpureum, Pueraria phaseoloides, Stylosanthes guianensis, S. hamata, S. humilis,* and *S. scabra* (e.g., Hassan and Izham, 1984; Topark-Ngarm, 1984).

These legumes are essentially Australian cultivars, introduced as such, and for well documented descriptions and details on their forage attributes, see Bogdan (1977), Skerman (1977), and Burt et al. (1983). In view of apparent adoption problems in the region, it seems justified to question the extent to which additional promising germplasm options are available. This paper attempts to answer this question by presenting a brief analysis of the potential of legumes native to Southeast Asia, as well as a summary of experiences with a series of new, promising species in tropical America.

The Environmental Framework

An analysis of the environments available for forage production in Southeast Asia and South Pacific shows a broad range of situations, each of which implies different selection criteria to be used during the germplasm evaluation processes. The climatic conditions seem to be rather favourable with respect to total annual rainfall, which characterises the region as predominantly humid with some areas classified as subhumid. However, the distribution of rainfall is variable, and the length of the dry season ranges generally from < two consecutive months receiving less than 100 mm in the humid areas, to > six months as in subhumid Nusa Tenggara in Indonesia (Ivory and Siregar 1984). Soils in the region vary from fertile alluvial to acid, phosphorus and cation-deficient oxisols and ultisols characteristic of extensive areas of the humid tropics.

While the region seems similar to other tropical areas, in terms of climatic and edaphic constraints to forage production, the diversity of production systems in Southeast Asia represents a particular challenge in the process of species evaluation. Legumes are needed for:

(a) intensively used communal grazing lands and roadsides, and thus should be able to withstand overgrazing and to persist through adequate regeneration mechanisms;

(b) cut-and-carry systems, often in the form of back yard farming, including protein banks for supplementation of rice straw feeding; particular requirements are high productivity and nutritive value;

(c) rotation, or other types of combinations with paddy rice for dry season supplementation of rice straw and stubble; plants should be fast growing and have a low weed potential;

(d) pastures in tree plantations; plants must be shade-tolerant and tree-compatible;

(e) improving naturalised grasslands such as *Imperata* pastures in minimum-input systems; ease of establishment, low nutrient requirements and fire tolerance seem to be particularly important evaluation criteria;

(f) establishment of traditional grass/legume pastures; a vital requirement is high compatibility with companion grasses and legume tolerance to mismanagement.

In view of the diversity of production systems options, the identification of promising legume germplasm represents a rather complex task for the forage agronomist. The climatic conditions constitute an additional complication. Legumes for drier environments should be moderately palatable and drought-tolerant, while those for more humid environments should be of high palatability and tolerant to close defoliation and/or trampling. On the other hand, the diverse production systems represent an advantageous set of various options for germplasm utilisation, once material adapted to the respective climatic, edaphic, and biotic stresses has been identified.

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Each of the before-mentioned major production systems would justify a separate in-depth review of forage legume options. However, in the framework of this presentation only a summary of the potential of species will be offered. This concentrates on perennial legumes, seemingly favoured by the climatic conditions in the region. Thus the interesting topic of short-lived, fast-growing annuals for rotation with paddy rice (Shelton 1980) is excluded. Furthermore, this presentation concentrates on herbaceous legume species, within the Leguminosae systematics of Polhill and Raven (1981) representatives of the Papilionoideae subfamily. The leguminous trees and shrubs, which predominate in the two remaining subfamilies, namely Caesalpinioideae and Mimosoideae, are dealt with in the following presentation (Brewbaker, these proceedings).

Native Species

Germplasm Collection

Southeast Asia is generally considered only a minor centre of origin of forage plants; sometimes (e.g. Harlan 1981) it is even overlooked. However, Williams (1983) in a comprehensive overview of tropical legumes with forage potential, listed 68 genera in the Papilionoideae whose natural distribution extends to tropical Asia. The best known native species are *Pueraria phaseoloides, Desmodium heterocarpon, D. heterophyllum*, and *D. ovalifolium*.

Systematic plant exploration efforts, however, have only very recently started; collection expeditions carried out since 1979 and their results are summarised in Table 1. Altogether, almost 1500 samples have been collected, and due to the continuing engagement in the region of the International Board for Plant Genetic Resources (IBPGR), this figure is increasing steadily.

Whereas the primary objective of IBPGR's involvement is genetic resource conservation, the principal interest of the forage research institutions consists in broadening the germplasm base for eventual cultivar development or breeding. There are basically two aims:

(1) to increase the variability in the well known 'traditional' species, such as *Pueraria phaseoloides*, whose genetic bases have been extremely narrow, the expectation being to find genotypes with which any major constraints in the species could be overcome;

(2) to make available for evaluation purposes a broad range of new species, which may be agronomically as yet unknown or only little known, the expectation being to identify new species with a forage potential.

Table 2 lists firstly those Southeast Asian species which can be considered as traditional forage legumes

Table 1. Collection of native forage legume germplasm in Southeast Asia.

Year	Country	Institutions	Principal genera collected	No. of samples
1979	Thailand	CIAT, TISTR, Livestock Dept.	*Desmodium*	77[1]
1982	Thailand, Malaysia	CIAT, TISTR, MARDI, IBPGR	*Desmodium, Dendrolobium, Phyllodium, Pueraria, Tadehagi*	362[1]
1983	Indonesia	CSIRO, FRP	*Desmodium, Uraria, Alysicarpus*	56[2]
	Papua New Guinea	CSIRO, CIAT	*Desmodium, Codariocalyx, Flemingia, Pueraria, Pycnospora, Uraria*	138[3]
1984	China: Hainan Island	CIAT, SCATC	*Desmodium, Phyllodium, Tadehagi, Pueraria, Alysicarpus*	92[4]
	Thailand	CIAT, TISTR, IBPGR	*Desmodium, Dendrolobium, Phyllodium, Tadehagi, Pueraria*	154[1]
	Indonesia	FRP	*Desmodium, Aeschynome, Alysicarpus*	28[5]
	Indonesia	IBPGR	*Desmodium, Calopogonium, Centrosema, Pseudarthria, Pueraria, Uraria*	494[6]

Sources:
1. Pattanavibul and Schultze-Kraft 1985; 2. Reid and Ivory 1983; 3. B. Pengelly, pers. comm. 4. Schultze-Kraft et al. 1984;
5. Ivory and Yuhaeni 1984; 6. Mehra 1984a and 1984b (unpublished).

Acronyms:
CIAT = Centro Interacional de Agricultura Tropical, Cali, Colombia.
TISTR = Thailand Institute of Scientific and Technological Research, Bangkok, Thailand.
MARDI = Malaysian Agricultural Research and Development Institute, Serdang, Malaysia.
IBPGR = International Board for Plant Genetic Resources, Rome, Italy — Bogor, Indonesia.
CSIRO = Commonwealth Scientific and Industrial Research Organization, Brisbane, Australia.
FRP = Forage Research Project, Armidale, Australia — Bogor, Indonesia.
SCATC = South China Academy of Tropical Crops, Hainan, China.

of known value in the region and/or in other parts of the world. Secondly, additional species and genera are presented, which are only little known, if at all, but which, on the basis of information gathered during collection expeditions and also subsequent preliminary observations in nursery fields, seem to deserve particular attention by research agronomists.

Table 2. Southeast Asian legume species with potential as forage plants.

Traditional species of known potential

Pueraria phaseoloides
Desmodium ovalifolium
Desmodium heterophyllum
Desmodium heterocarpon

Unknown or little-known species of suggested potential

a) *Desmodium strigillosum*   b) *Codariocalyx gyroides*
   Desmodium styracifolium   *Dendrolobium* spp.
   Desmodium gangeticum   *Dicerma biarticulatum*
   Desmodium sequax   *Hegnera obcordata*
   Desmodium velutinum   *Phyllodium* spp.
                                     Tadehagi spp.

c) *Uraria* spp., *Dunbaria* spp., *Flemingia* spp.

The Traditional Species

Pueraria phaseoloides (tropical kudzu) This vigorous species is particularly well known throughout the tropics, but its principle use in Southeast Asia is still as a cover crop in tree plantations. The widespread commercial cultivar (to which probably most pre-1982 accessions could be allocated) is particularly well adapted to the humid tropics. There, however, its economic importance as a pasture plant seems to be limited by low cattle acceptance. In less humid environments, a major constraint of commercial *P. phaseoloides* is lack of drought tolerance. For example, in the Llanos Orientales of Colombia with 2000 mm annual rainfall, tropical kudzu is a successful legume, but defoliates completely when the dry season extends beyond 2.5 months without any rainfall. Also, the somewhat higher K and Mg requirements of the common tropical kudzu represent a constraint to its use in poorer oxisols and ultisols. No diseases or insect pests have been reported that could be considered as major limitations to the productivity of the species. Recent collecting activities have yielded approximately 120 accessions, and preliminary observations in introduction nurseries in Colombia indicate that there is considerable variation in this new germplasm, seemingly also with respect to drought tolerance. Ongoing in-depth evaluation will show whether the present variability is sufficient to overcome the constraints to a broader use of *P. phaseoloides* as forage plant.

Desmodium ovalifolium   Although Ohashi (1973) considers this species to be part of *D. heterocarpon* ssp. *heterocarpon* var. *heterocarpon*, the old species name is used here in order to differentiate this prostrate, strongly stoloniferous form from the common *D. heterocarpon* types as represented by cv. Florida. *Desmodium ovalifolium*, probably due to its low establishment vigor, seems not to be widely used either in Southeast Asia or elsewhere, although commercial seed is available. The advantages of this species include shade tolerance (which, together with its non-climbing habit, makes it particularly valuable as a cover crop in tree plantations), its vigorous stoloniferous growth habit (which makes it an ideal companion legume for aggressive, stoloniferous grasses such as *Brachiaria* spp.), and its low nutrient requirements. The feeding value of *D. ovalifolium* is moderate, due to its rather low palatability, high tannin content and low apparent digestibility. Similar to tropical kudzu, it is particularly well adapted to the humid tropics and is not very drought-tolerant. Recently, the commercial cultivar has proved to be susceptible to a devastating stem gall nematode in the Colombian Llanos Orientales, as well as to *Synchytrium* false-rust (Lenné et al. 1985). Screening of the recently assembled new collection of approximately 80 ecotypes is revealing considerable variation regarding drought tolerance and disease resistance. Current in-depth evaluation is expected to show whether the new collection contains ecotypes with the desired plant characters. The convenience of further increasing the natural variability or of initiating a breeding project can then be considered.

Desmodium heterophyllum Of this species, an Australian commercial variety is available (cv. Johnstone), which is similar to *D. ovalifolium* in its excellent adaptation to the humid tropics, stoloniferous growth habit and shade tolerance. It is, however, considerably less productive and less drought-tolerant than *D. ovalifolium*. It has a higher nutritive value, but also requires higher soil fertility. Preliminary observations in the recent collections do not indicate any major dry matter production superiority of new ecotypes over the commercial variety.

D. heterocarpon   This subshrub has gained some importance in the southern part of the state of Florida, USA (cv. Florida). However, this variety as well as other *D. heterocarpon* germplasm seems to be highly susceptible to *Meloidogyne* root-knot nematodes, not only in Florida (Kretschmer et al. 1980), but also in Colombia (Lenné 1981). Here, screening of a collection comprising approximately 80 new, morphologically variable ecotypes from a wide range of Southeast Asian origins, has shown remarkably high

general susceptibility to little-leaf mycoplasma (CIAT 1984).

New Germplasm

In Table 2, the unknown or little known native species are separated into three groups: (1) species within the genus *Desmodium;* (2) species of allied genera according to Ohashi's *Desmodium* treatise (Ohashi 1973); (3) a selection of other interesting genera.

(1) Among *Desmodium* spp., *D. strigillosum* and *D. styracifolium* are emerging in CIAT plant nurseries in Colombia as particularly interesting. Due to initial misidentification, germplasm of both species had been included in *D. heterocarpon* observation trials, and eventually stood out because of resistance to little-leaf mycoplasma and root-knot nematode (CIAT 1984). *Desmodium strigillosum* is a leafy, semi-erect subshrub which seems to be well adapted to low soil fertility and drought stress. Within the polymorphic species *D. styracifolium,* the prostrate forms which have *D. heterocarpon*-type leaflet markings appear to be particularly productive.

No evaluations have been done yet with *D. gangeticum.* This very widespread and consequently adaptable species, however, seems to deserve some attention for environments in which a persistent but low-productivity legume (that in many respects is quite similar to the South American *D. incanum*) might have a role.

Desmodium sequax is another species which has not been looked at by agronomists. It is a stemmy shrub and was included in Table 2 on the basis of its remarkable vigour and lack of disease problems. The situation with *D. velutinum* is similar; this species, however, also contains some fairly decumbent, leafy forms. Some accessions are showing very good growth on acid, infertile soils.

(2) *Codariocalyx gyroides* is the agronomically best known species (Lazier 1981) within the group of genera that is very closely related to *Desmodium.* The major constraints of this vigorous, leafy forage bush are susceptibility to root-knot nematode (Lenné 1981) and little-leaf mycoplasma as well as low palatability.

The remaining species within the allied genera group have been included in the list of legumes with forage potential because of their close relationship with *Desmodium,* and also their usually remarkable productivity. As yet none of them has undergone any systematic agronomic evaluation. According to observations during respective collecting missions and in plant introduction nurseries, *Hegnera obcordata* and some *Tadehagi triquetrum* types are herbaceous with prostrate to semi-erect growth habits. The other

species comprise erect shrubs and some trees.

(3) The third group of three genera which deserve attention by germplasm evaluation agronomists, includes *Uraria, Dunbaria,* and *Flemingia. Uraria* has been observed to contain a series of forms which, though not very productive, are readily eaten by cattle and withstand heavy grazing. Collected *Dunbaria* germplasm (yet unidentified at species level) represents vigorous, leafy climbers with good drought resistance. Within the genus *Flemingia* most germplasm of the leafy, erect shrub *F. macrophylla* (syn. *F. congesta*) is impressive for its drought resistance and extraordinary dry matter production and regrowth potential on very acid, low fertility soils.

Conclusions

1. As a result of recent collecting missions, a considerable amount of germplasm of traditional legumes as well as new, as yet little known species is now available to tropical forage researchers. Although the figures given in Table 1 appear to be satisfactory, herbarium studies and comparisons between botanical literature and reports of recent collecting missions indicate that (a) only a small fraction of the natural variability has as yet been collected in the form of germplasm, and (b) that a considerable amount of genetic erosion has already taken place due to rapid extension of land under cropping. Thus, the continuation of collecting activities should be encouraged and systematic sampling of native legumes extended to areas which as yet have not been covered.

2. The genetic bases of the traditional species *Pueraria phaseoloides, Desmodium ovalifolium, D. heterophyllum* and *D. heterocarpon* have been considerably broadened. Now the expectation of identifying superior genotypes which might overcome specific constraints within this increased variability seems to be justified, and systematic evaluation of the new collections under a range of environmental conditions is fundamental.

3. The new species should be considered a genetic resource of considerable eventual value for the region as well as the rest of the world. Most of them, however, await assessment of their forage potential. Determination of palatability seems to be one of the major research priorities.

Exotic Species

Tropical America is generally regarded as the major centre of diversity of tropical legumes and most of the cultivated species are of tropical American origin (Williams 1983). Although Africa has provided three commercial forage legumes, namely *Lablab purpureus, Lotononis bainesii,* and *Neonotonia wightii,*

the New World tropics continue to be considered a particularly promising source of legume germplasm. Much of the recent plant exploration activities have concentrated on tropical America.

Traditional Species

As the presentations on regional experiences with forage evaluation in Southeast Asia and South Pacific have shown (see section 'The Evaluation of Forages', these proceedings), exotic legume species regarded as successful or highly promising are exclusively from tropical America (Table 3).

Table 3. Herbaceous forage legumes from tropical America with potential for Southeast Asia and the South Pacific region.

Traditional species of known potential	
Calopogonium mucunoides	Stylosanthes guianensis
Centrosema pubescens	Stylosanthes hamata
Macroptilium atro-	Stylosanthes humilis
purpureum	Stylosanthes scabra

Promising non-traditional species	
Arachis pintoi	Zornia glabra
Centrosema brasilianum	Zornia latifolia
Centrosema macrocarpum	Stylosanthes capitata
Centrosema sp. n.	S. guianensis var. pauciflora
	Stylosanthes macrocephala

Of these traditional species, *Calopogonium mucunoides* is still much more successful as a prolifically seeding cover crop for tree plantations rather than as a forage legume, at least with respect to the commercial variety. Its major limitations are low drought tolerance and palatability.

Similarly, *Centrosema pubescens* is still primarily used as a cover crop in plantations, but has high forage potential throughout the region due to its perenniality, broad climatic adaptation including drought tolerance, and high nutritive value. While no major biotic constraints limiting the productivity of commercial *C. pubescens* in Southeast Asia are known, poor adaptation to acid soils of low fertility seems to be a limitation in the ultisol areas of the region.

Similar to *C. pubescens*, commercial *Stylosanthes guianensis* is well adapted to humid as well as drier environments. Its soil fertility requirements, however, are considerably lower. *Stylosanthes guianensis* is one of the best researched tropical forage species (Stace and Edye 1984); its use is primarily for grazed pastures. Its principal problem is susceptibility to anthracnose, a fungal disease which limits the production potential of *S. guianensis* throughout the tropics. In humid tropical areas of South America close to the equator, the performance of *S. guianensis* is much

better due to higher anthracnose resistance, than in savanna climates (Lenné 1985).

Anthracnose can also affect the productivity of the other three traditional *Stylosanthes* species mentioned in Table 3, namely *S. hamata, S. humilis,* and *S. scabra*. The potential of these legumes, however, is restricted to subhumid and drier environments. Whereas *S. humilis,* an annual species, and *S. hamata,* a weak perennial, are herbaceous with prostrate to semi-erect growth habits, *S. scabra* is a stemmy, semi-erect to erect, perenniating shrub.

The potential of *Macroptilium atropurpureum* (Siratro) seems to be restricted to grazing situations in subhumid and drier environments where drought tolerance is its principal advantage. Low dry matter production appears to be its main disadvantage with respect to other traditional exotic species.

Promising Non-traditional Species

Legume evaluation work, conducted in a series of environments in Colombia and other countries of tropical America by CIAT and, within the International Tropical Pasture Evaluation Network (RIEPT), by participating national institutions, is revealing several new legume species as particularly promising (CIAT 1980–1984):

Arachis pintoi A perennial groundnut species which due to its stoloniferous growth habit is an interesting option as a companion legume for prostrate, aggressive grasses such as *Brachiaria humidicola* and *B. dictyonèura* (Grof 1985). Tolerance of heavy grazing is a particularly positive attribute. Low dry season productivity seems to be its major limitation; plants, however, survive more than three months of drought.

Centrosema brasilianum This medium-productive, trailing–climbing species is well adapted to acid, infertile soils and shows excellent drought tolerance. Susceptibility to *Rhizoctonia* foliar blight is its principal limitation in humid environments (Lenné et al. 1985).

Centrosema macrocarpum A vigorous, very productive, drought and disease tolerant climber, which grows well on acid, low fertility soils. Intolerance of heavy grazing and seasonal confinement of seed production seem to be the principal negative features of many accessions.

Centrosema sp.n. This new, yet undescribed species is closely related to *C. pubescens*. Its distinguishing attributes are medium to high productivity, tolerance of acid, low fertility soils, disease resistance, good dry season performance and tolerance of heavy grazing.

Zornia glabra and *Z. latifolia* Both species are of medium productivity, have good drought tolerance and high nutritive value; their palatability, however, seems to be moderate to low, especially in *Z. glabra*. Diseases, mainly *Sphaceloma* scab and *Drechslera* leaf spot, can be serious limitations, particularly to *Z. latifolia* (Lenné et al. 1985).

Stylosanthes capitata and *S. macrocephala* These are two typical savanna species of rather low to medium dry matter productivity, but higher seed production and anthracnose resistance than *S. guianensis*. In Southeast Asia, however, they would most likely only have a limited potential since their relative advantage is in areas with prolonged dry seasons and acid, low fertility soils. *S. capitata* and *S. macrocephala* have a high nutritive value and are readily consumed by cattle.

In contrast, *S. guianensis* var. *pauciflora*, the recently established taxon for the 'tardio' forms of *S. guianensis* (Brandao et al. 1985), representing also typical savanna plants, is of medium nutritive value and low palatability. Similar to the common *S. guianensis* forms, this variety is productive in humid areas as well as in regions with prolonged dry seasons. Anthracnose resistance and drought tolerance are higher than in common *S. guianensis*, but the seed production potential is lower.

In addition to the legumes mentioned in Table 3, the following genera, which as yet are agronomically new or only little known, but which on the basis of observations during collection trips seem to be have a good potential, particularly deserve systematic screening: *Aeschynomene, Dioclea, Galactia*, and *Vigna*, as well as other species of *Centrosema, Desmodium*, and *Macroptilium*.

Conclusions

Considerable knowledge has been accumulated about the forage potential of traditional exotic species and the variability within respective collections. Furthermore, very comprehensive collections of individual species have been assembled and are available. For example, about 25% of the total CIAT forage legume collection of more than 12 000 accessions account for the above mentioned traditional species. To screen a broader range of germplasm and, possibly, subsequent breeding seems to be the most effective approach to overcome any major adoption limiting constraint that might have been identified for a particular species in a given environment in Southeast Asia and South Pacific. In addition, new legume options emerging as promising from work in tropical America warrant evaluation in the region.

Native vs. Exotic Legumes — Research Priorities

The performance of plants is often superior outside the centre of origin of the respective species than within the centre (Jennings and Cock 1977). One of the reasons is that the plant's centre of diversification is also the centre of diversification of the plant's natural enemies in the form of diseases and insect pests. Therefore, introduced species may have a fundamental advantage over native species. The successful performance of the commercial cultivars of *Desmodium ovalifolium* and *Pueraria phaseoloides* outside their centre of origin in tropical America can be regarded as an example for the applicability of this concept to wild, unimproved species. It seems to be for this reason also that forage researchers outside tropical Asia have developed a special interest in germplasm from this region. Southeast Asia and the South Pacific therefore have a genetic resource of particular importance to offer to the rest of the world.

Since this possible advantage of exotic over native species only holds as long as the natural enemies of the plants are not exported together with the germplasm, attention is called to the need for increased efforts by the forage agronomists to avoid the transfer of pests and diseases, in addition to prevailing phytosanitary regulations.

On the other hand, the primary gene centres of a species are at the same time believed to be sources for resistance to local pathogens and pests (Leppik 1970). For this reason, continuation of germplasm collection in the Southeast Asian region deserves and justifies continuing support from international organisations and national institutes.

A research strategy for forage legume evaluation in the Southeast Asian and South Pacific regions could be developed upon the following bases:

1. initial concentration on exotic species, taking advantage of the considerable amount of collection and evaluation work carried out by institutions outside the region;

2. concentration on selecting among the natural variability within existing collections; breeding projects should be discouraged initially but should be considered if natural variability fails to provide the needed combination of characters;

3. evaluation and screening of a broader germplasm base, not only using selections made in other regions that may have reached cultivar status; the success of 'Khon Kaen stylo', which was developed from a CSIRO accession (Khon Kaen University 1984), is a good example;

4. creation of mechanisms to co-ordinate regional plant evaluation efforts. A network system should be

considered, which could include: (a) two principal screening sites, reflecting the two major climatic zones of the region, for selection of a broader range of germplasm and for eventual seed multiplication, and (b) a series of other sites for regional testing within each climatic zone.

It should be borne in mind, however, that selection of species alone will not solve the plant limitations to forage production. Appropriate management is of utmost importance and through complementary and back-up research we need to know our legumes better and to understand 'how the plant processes, which control the plant responses of growth and nitrogen fixation, may be manipulated by grazing and cutting management' (Humphreys 1984).

References

Bogdan, A.V. 1977. Tropical Pasture and Fodder Plants (Grasses and Legumes). Longman, London and New York. 475 p.

Brandao, M.F., Costa, N.M.S., and Schultze-Kraft, R. 1985. *Pauciflora*, uma nova variedade de *Stylosanthes guianensis* (Aubl.) Sw.. XXXVI National Botanical Congress, 20–26 January 1985, Curitiba, Paraná, Brazil.

Burt, R.L., Rotar, P.P., Walker, J.L., and Silvey, M.W. ed. 1983. The role of *Centrosema*, *Desmodium*, and *Stylosanthes* in improving tropical pastures. Westview Tropical Agriculture Series, No. 6, Boulder, 292 p.

CIAT. 1980–1984. Annual Reports, Tropical Pastures Program; 1980, 1981, 1982, 1983, 1984. CIAT, Cali, Colombia.

Grof, B. 1985. Forage attributes of the perennial groundnut *Arachis pintoi* in a tropical savanna environment in Colombia. XV International Grassland Congress, Kyoto, Japan.

Harlan, J.R. 1981. Use of genetic resources for improvement of forage species. In: Smith, J.A., and Hays, V.W., ed., Proceedings, 14th International Grassland Congress, Lexington, Kentucky, 29–34.

Hassan Wahab and Izham Ahmad 1984. Status of pasture research and development in Peninsular Malaysia. In: Asian Pastures, Recent Advances in Pasture Research and Development in S.E. Asia. FFTC Book Series No. 25, Food and Fertilizer Technology Center for the Asian and Pacific Region, Taipei, Taiwan, 30–43.

Humphreys, L.R. 1984. Grazing management and the persistence of yield in tropical pasture legumes. In: Asian Pastures, Recent Advances in Pasture Research and Development in S.E. Asia. FFTC Book Series No. 25, Food and Fertilizer Technology Center for the Asian and Pacific Region, Taipei, Taiwan, 1–11.

Ivory, D.A., and Siregar, M.E. 1984. Forage research in Indonesia: past and present. In: Asian Pastures, Recent Advances in Pasture Research and Development in S.E. Asia. FFTC Book Series No. 25, Food and Fertilizer Technology Center for the Asian and Pacific Region, Taipei, 12–29.

Ivory, D.A. and Yuhaeni, S. 1984. Collection of native herbaceous and shrub legumes in Java and Sumatra. Forage Research Project, Annual Report 1984, Ciawi and Ujung Pandeng, Indonesia, 5–6.

Jennings, P.R., and Cock, J.H. 1977. Centers of origin of crops and their productivity. Economic Botany 31(1), 51–54.

Khon Kaen University 1984. Pasture Improvement Project. Final Report. Faculty of Agriculture, Khon Kaen, Thailand.

Kretschmer, A.E. Jr., Sonoda, R.M., and Snyder, G.H. 1980. Resistance of *Desmodium heterocarpon* and other tropical legumes to root-knot nematodes. Tropical Grasslands 14(2), 115–120.

Lazier, J. 1981. Effect of cutting height and frequency on dry matter production of *Codariocalyx gyroides* (Syn. *Desmodium gyroides*) in Belize, Central America. Tropical Grasslands 15(1), 10–16.

Lenné, J.M. 1981. Reactions of *Desmodium* species and other tropical pasture legumes to the root-knot nematode *Meloidogyne javanica*. Tropical Grasslands 15(1), 17–20.

1985. Recent advances in the understanding of anthracnose of *Stylosanthes* in tropical America. XV International Grassland Congress, Kyoto, Japan.

Lenné, J.M., Pizarro, E.A., and Toledo, J.M. 1985. Importance of diseases as constraints to pasture legume adaptation in the tropical American lowlands. XV International Grassland Congress, Kyoto, Japan.

Leppik, E.E. 1970. Gene centres of plants as sources of disease resistance. Annual Review of Phytopathology, 8, 323–344.

Ohashi, H. 1973. The Asiatic species of *Desmodium* and its allied genera (Leguminosae). Gingkoana — Contributions to the flora of Asia and the Pacific region, No. 1. Tokyo, Japan. 328 p.

Pattanavibul, S., and Schultze-Kraft, R. 1985. Collecting germplasm of *Desmodium* and *Pueraria phaseoloides* in Thailand and Peninsular Malaysia. XV International Grassland Congress, Kyoto, Japan.

Polhill, P.M., and Raven, P.H. ed. 1981. Advances in Legume Systematics. Part 1 and Part 2. Royal Botanic Gardens, Kew, England. 1049 p.

Reid, R., and Ivory, D.A. 1983. Forage introduction for the northern tropics. CSIRO Division of Tropical Crops and Pastures, Annual Report 1982–83, 19.

Schultze-Kraft, R., Jiang, H., and Huang, X. 1984. Tropical forage legumes on Hainan Island, China. Plant Genetic Resources Newsletter 59, IBPGR-FAO, Rome, Italy, 1–3.

Shelton, H.M. 1980. Dry-season legume forages to follow paddy rice in N.E. Thailand. 1. Species evaluation and effectiveness of native rhizobium for nitrogen fixation. Experimental Agriculture, 16, 57–66.

Skerman, P.J. 1977. Tropical Forage Legumes. FAO, Rome, Italy.

Stace, H.M., and Edye, L.A., ed. 1984. The Biology and Agronomy of *Stylosanthes*. Academic Press, Australia, 636 p.

Topark-Ngarm, A. 1984. Pasture research and development in Thailand. In: Asian Pastures, Recent Advances in Pasture Research and Development in S.E. Asia. FFTC Book Series No. 25, Food and Fertiliser Technology Center for the Asian and Pacific Region, Taipei, Taiwan, 58–64.

Williams, R.J. 1983. Tropical Legumes. In: McIvor, J.G. and Bray, R.A., ed., Genetic Resources of Forage Plants. CSIRO, Melbourne, Australia, 17–37.

Leguminous Trees and Shrubs for Southeast Asia and the South Pacific

J.L. Brewbaker*

TREES and shrubs have provided valuable fodder to man's domesticated animals probably since the time of their domestication. Carob beans (*Ceratonia siliqua* — not N-fixing), cytisus shrub (*Medicago arborea*) and Khejri *(Prosopis cineraria)* are legumes represented in writings over 2000 years ago as fodder trees (Robinson 1985). At least 75% of the shrubs and trees of Africa, for example, serve as browse plants to some extent, and many of these are N-fixing (Skerman 1977). N-fixing species normally have high-protein foliage, and the pods of many species are excellent sources of energy as well as protein. Legumes complement grasses as the premier feedstuffs for all herbivores, notably by increasing animal intake levels and protein in the feed (Le Houerou 1978; Minson 1980).

Legume trees and shrubs have co-evolved with herbivorous animals, however, and have achieved means of protecting themselves from such browsing (Gray 1969; Rosenthal and Janzen 1979). Among these protective devices are thorns, toxins, fibrous foliage, and simply the height of tree crowns. This protection is most notable in the arid and semi-arid shrubs that often grow in open grasslands with low density foliage that is retained into long dry seasons. Thorns charactise many woody legumes, notably their juvenile growth e.g., *Acacia, Mimosa, Prosopis* spp.

Thornless species are described aptly as 'unarmed' by the taxonomist. Other woody legumes rapidly outgrow most predatory animals, but fall prey to the larger ones, e.g. elephants, giraffes, and (in the past) to huge prehistoric beasts and birds.

Toxic substances are of two general classes, those that deter feeding and those that poison the animal. High levels of feeding-deterrent tannins occur in many tropical legumes, at highest concentrations in juvenile foliage (Mahyuddin 1983; Tangendjaja and Lowry 1984). This is often evident in the brownish coloration of young foliage. Common toxins of legumes are the cyanogenic compounds. Excessively fibrous foliage is not common in legumes that have finely-divided pinnate and bipinnate leaves. However, the phyllodes (expanded leaf petioles) that characterise most Australian acacias are fibrous or coriaceous and often of low digestibility.

Premier reviews of fodder shrubs and trees include those on legumes by Skerman (1977) and NAS (1979), and on Africa by Le Houerou (as cited in Le Houerou 1980a). Regional reviews include those on fodder species in Africa (Dougall and Bogdan 1958; Lamprey et al. 1980; Jurriaanse 1950; Le Houerou 1980a, 1980b); Australia (Chippendale and Jephcott 1963; Everist 1969), Nepal (Panday 1982), and India (Sharma 1977; Singh 1982). It is clear that the loss of forests in the tropics, occurring at a rate of 10-20 million hectares per year, will make the wild fodder tree a thing of the past for many countries (Brewbaker et al. 1982). Tropical forests are expected to cover only 750 million ha by 2000 AD, a loss of 75% in this century alone. Most of this remnant will be in the Americas and Indonesia. Natural grazing lands comprise over 3 billion hectares, however, to which the addition of legume shrubs and trees could have major impact in fodder intake and nutritional value. Multi-purpose trees that can serve both for fodder and fuelwood are increasingly valued in the tropics, and fodder should be an economically important co-product in fuelwood and timber harvest of legumes (Brewbaker et al. 1984; Burley and Von Carlowitz 1984).

N-Fixing Trees and Shrubs as Fodder Plants

A vast array of trees and shrubs serve as animal fodder in the tropics and subtropics, often browsed or casually lopped and fed (Le Houerou 1980b; Skerman 1977). More than 200 species of trees that are known or believed to fix nitrogen are reportedly useful as fodder species, nearly all of which are tropical or subtropical. A detailed report concerning about half these species (Brewbaker, in press) and a related database formed the source from which Table 1 was prepared. The 25 selected species are known to serve widely as fodder and known to fix nitrogen (Allen and Allen 1981; Halliday 1984).

N-fixation characterises most legumes (over 92% of mimosoids and papilionoids, but 34% caesalpinioids), but also selected genera in eight other flowering plant families — Betulaceae, Casuarinaceae, Coriariaceae, Elaeagnaceae, Myricaceae, Rhamnaceae, Rosaceae, and Ulmaceae. A list is appended to Table 1 of

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Table 1. Tropical N-fixing fodder trees and shrubs

	Common names	Origin	Distribution	Uses	Description	Forage Value	Comments
Acacia (Mimosoideae; Leguminosae)							
A. albida Del.	Winterthorn, Kad	Africa	Widespread, now to India, Israel	Fodder, ornamental shade, green manure	Tree to 20m; = *A. leucophloea:* leafless in rainy season; bipinnate; thorny; drought tolerant to 300mm; frost sensitive	*	Pods eaten, also foliage (dry season); fast growth if watered (10m in 7 yr)
A. aneura F. Muell. ex Benth.	Mulga	Australia	Widespread (150m ha)	Hard wood; fuelwood, ornamental, variably browsed by stock	Shrub or tree to 12m; slow growth; phyllodes; high drought tolerance (to 200mm); frost tolerant; frost sensitive	**	Some varieties good stock fodder; 'the most important fodder tree in Australia' (Everist 1969); widely browsed; low foliage DMD (39%); little success in Africa
A. estrophiolata F. Muell.	Ironwood	Australia	not outside Australia	—	Tree to 15m; phyllodes; slow growing, long-lived; drought tolerant	*	Foliage eaten avidly, but grows too tall
A. farnesiana (L.) Willd.	Cassie, Huisache (Mex.) Sweet Acacia, Mimosa Bush, Klu (Hawaii)	Americas	Worldwide	Ornamental, cultivated for perfume, tannin, dyes, gums	Shrub 2–7m; bipinnate; forms thickets; stipular spines (<1cm); frost tolerant; rapid growth; weeds; tolerant of heavy clay	*	Pods browsed when young; foliage DMD 54%, contains cyanogenic glycosides
A. nilotica (L.) Del	Babul (India) Munga (Africa) Prickly acacia (Australia)	India; Africa	Widespread	Firewood, charcoal, tannin and gum source, fodder	Tree 6–12m; very thorny; bipinnate; tropics, midlands; frost susceptible, drought tolerant, deciduous	**	Good leaf and pod fodder yields and quality; pods sweet, readily eaten, but can cause bloat, often yields well; many insect pests
A. nubica Benth.	Last (Sudan)	NE Africa	—	Browse shrub	Shrub to 5m; thorny; bipinnate	*	Important browse shrub to Africa
A. pendula A. Cunn. Myall ex G. Don.	Myall	Australia	Introduced in Israel	Fodder, shade tree, timber, fuelwood	Tree to 8m; stately; phyllodes; subtropical, drought tolerant	*	Drought-stock fodder; foliage DMD 47%
A. polyacantha Willd.	Khair, Catechu Tree	Africa, India	—	Fodder, charcoal, black gum, dye	Tree to 25m; coppices well, long-lived; bipinnate; = *A. catechu;* recurved spines; weedy; midlands to 1000m; takes mild frost, low drought tolerance	*	Good fodder DMD (61%); fair growth rate; many insect and disease pests; low tannin (1.5%)
A. seyal Del.	Thirsty Thorn, Dushe (Nigeria)	N. Africa	—	Wood, gums and tannins; important feed (pods, leaves, bark)	Slender tree to 12m; bipinnate; long thorns; semi-arid tropics	*	Bark is a valued feed, up to 10% protein; leaves and pods also fed in Africa
A. victoriae Benth.	Gundabluey, Acacia Bush, Elegant Wattle	Australia	Widespread in Australia	Fodder, ornamental windbreak	Shrub to 5m; straggly, often thorny; short-lived, often in thickets; sandy soils; saline and drought tolerant to (to 350mm)	*	Pods browsed, of moderate palatability; leaves retained year-round but low in yield

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Albizia (Mimosoideae; Leguminosae)

A. lebbek (L.) Benth.	Siris Woman's Tongue	Asia Africa	Worldwide	Ornamental, fuelwood, fodder, furniture	Tree to 25m; wide **adaptability**, dry-humid tropics, to 1500m elevation, to 600mm rainfall; growth to 8m in 8 yr	*	Supplementary fodder; new growth toxic; DMD 45–55% (to 73%, Singh 1982)

Cajanus (Papilionoideae; Leguminosae)

C. Cajan (L.) Millsp.	Pigeon pea, Dhal, Catjang (Asia)	Africa (cultivated <2000 BC)	India, worldwide	Food, medicinal, green manure, fodder, windbreak, honey	Variable perennial shrub to 4m; annual types for food; dry tropics, low to midland; not frost or fire tolerant	*	Rare use as fodder, browse or hay (including pods); leaf DMD 53%, small stem DMD 42%; not persistent under grazing

Chamaecytisus (Papilionoideae; Leguminosae)

C. palmensis (Christ) Bisby et Nicholls	Tagasaste	Canary Islands	Long in New Zealand	Browse	Shrub to 6m; subtropical, frost tolerant, drought tolerant	*	High leaf DMD (75%) and browse DMD (53%)

Desmanthus (Mimosoideae; Leguminosae)

D. virgatus (L.) Willd.	Donkey Bean	South and Central America	Widespread worldwide	Browse, fodder	Subshrub to 3m; aggressive, coppices and reseeds well; unarmed; mesic tropics but drought tolerant; not acid tolerant	**	Leaf DMD good (53%); short-lived, needs frequent cutting

Desmodium (Papilionoideae; Leguminosae)

D. discolor Vog.	Horse Marmalade (S. Africa)	S. America	Widely distributed	Fodder	Subshrub to 3m; woody when mature; subtropical, frost hardy	*	Highly palatable

Gliricidia (Papilionoideae; Leguminosae)

G. sepium (Jacq.) Walp.	Madre de Cacao, Quickstick	Central America/ Mexico	Worldwide	Firewood, timber, shade, ornamental, fodder	Tree to 15m; easily propogated by cuttings; rapid growth; dry to mesic tropics to 1000m	**	Foliage variously appraised around the world, often unused, occasionally valued highly; DMD high (55% browse samples, 68% leaves); low tannins (<1%), high leaf lignin (5.5%); reportedly toxic to horses; carries toxins in bark, seeds, roots ('rat poison', basis of species epithet)

Leucaena (Mimosoideae; Leguminosae)

L. leucocephala (Lam.) de Wit	Leucaena, Ipil-ipil Lamtoro	Central America, Mexico	Worldwide	Fodder, fuelwood, shade, pulpwood, lumber, food	Tree to 20m; dry to mesic tropics; not acid tolerant; growth slow in highlands; widely studied and planted; fast growth	***	High DMD (55–72%), good protein; restricted feed use to non-ruminants due to mimosine and DHP
Leucaena spp.	—	N. America	Uncommon yet internationally	Food, fodder, fuelwood	Shrubs, and trees to 20m; dry to mesic, lowland to highland	*	Browse fodder common on *L. lanceolata;* breeders using *L. pulverulenta* (high tannins), *L. collinsii, L. diversifolia* and others to improve cold tolerance, acid tolerance and yield of *L. leucocephela*

Medicago (Papilionoideae; Leguminosae)

M. arborea	Tree Medic Cytisus Shrub	Greece	Throughout Mediterranean	Described <100 AD as valuable goat fodder	Small shrub to 4m; greyish silky hairs; sub-temperate, not hardy against severe frost; drought tolerant	*	Goat browse, not widely used

Table 1 cont.

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	Common names	Origin	Distribution	Uses	Description	Forage Value	Comments
Prosopis (Mimosoideae; Leguminosae)							
P. alba/ chilensis (P. alba Griseb., *P. chilensis* (Mol.) Stuntz)	—	S. America	—	Firewood, timber, fodder (pods), shade	Trees to 15m; thorny; hot dry tropics, to 100mm, also to highlands (3000m in Argentina)	*	Pods are staple cattle food; little use of foliage
P. cineraria (L.) Druce	Khejri	India	—	Used before 1000 BC, firewood, charcoal, fodder, green manure, postwood	Tree to 9m; thorny, hot dry tropics to 100mm, normally 500–800mm; light demanding	*	Highly valued in desert areas; DMD low (40%); seedlings heavily browsed
P. pallida/ juliflora 'complex' *(P. pallida* Humb. and Bon. ex Willd. and *P. juliflora* (Swartz) DC)	Algaroba, Ironwood, Keawe (Hawaii)	Central and South America	Widespread	Fuelwood, charcoal, fodder (pods), honey, wood	Trees to 15m; thorny (segreg.); hot dry tropics (to 200mm); saline tolerant	*	Pods important fodder source; 25% sugar, 17% protein; foliage little used
Pterocarpus (Mimosoideae; Leguminosae)							
P. erinaceus Poir.	African rosewood, Apepe	W. Africa	—	Wood for tools and posts, fodder, dyes and tannin, afforestation	Tree to 15m(?); mesic tropics; good on shallow soils	*	Foliage considered good fodder; planted as stock feed
P. marsupium Roxb.	—	India	—	Fodder, fuelwood, timber	Tree to 30m; coppices and pollards well; mesic tropics, some frost tolerance	*	Widely lopped for fodder in India, quality fair
Robinia (Papilionoideae; Leguminosae)							
R. pseudoacacia L.	Black locust	N. America	Widespread in highland tropics	Fuelwood, ornamental, honey, reforestation, land stabilisation	Tree to 20m; fast growth; highland tropics (to 3000m); one of the few temperate N-fixing legume trees; forms thickets	*	Fodder variously appraised, possibly genetically variable; toxicity of young shoots, bark, leaves, and seed reported (cattle, horses, man); alkaloids robitin and robin, also tannins (to 3%); low DMD reported (27%)
Sesbania (Papilionoideae; Leguminosae)							
S. grandiflora (L.) Poir	W. Indian Pea Tree, Katurai (Philippines) Agati (Indonesia) Gallito (Caribbean)	Indonesia(?)	Worldwide	Food (flowers, pods, leaves); fodder; pulpwood, ornamental	Tree to 10m; = *S. formosa* F. Muell; short-lived; fast growth; mesic tropics (>1000mm); tolerant of waterlogging	*	Fodder of good quality, but slow foliage regeneration

Note: Some outstanding fodder legume shrubs or trees that do not nodulate include: *Bauhinia purpurea, B. racemosa, B. variegata, Butea frondosa, B. monosperma, Ceratonia siliqua* and *Gleditsia triacanthos.*

outstanding fodder legume trees that are not known to nodulate. Few of these trees have been the subject of extensive research. If it is argued that grass species will continue to provide the primary energy source in tropical fodder, the shrub and tree species must be viewed primarily as a protein source. Many non-nodulated trees of natural forests can serve as excellent browse, e.g., *Artocarpus, Azidarachta, Brosimum, Ficus,* and others. However, it is doubtful that these species can be used economically as high-protein fodder without N fertilisation, which is better allocated directly to the grasses themselves.

Restrictions applied in the development of Table 1 were that (1) any kind of fodder — foliage, pods, seeds — would be considered; (2) species for Southeast Asia and the South Pacific were defined to include those present or of suspected potential anywhere in the region; (3) all woody perennials that grow as shrubs (to 3 m) or as trees (above 3 m) were considered, excluding only prostrate sub-shrubs and woody vines; (4) all species were known or presumed to regrow readily when browsed or pollarded as hedge. All species could be grown from seed, but very few are known to propagate vegetatively with ease, e.g., *Gliricidia sepium.*

Oustanding N-Fixing Fodder Trees and Shrubs

Fodder value of the 25 outstanding species in Table 1 was denoted by an empirical scale:
*** Excellent; fodder species of wide use and high value
** Good; species that are used and deserve research, but with limitations such as slow growth or low DMD (dry matter digestibility)
* Fair; species that are used despite difficulties of use, quality, management

Species designated by one or more asterisks in Table 1 are considered 'outstanding' for the following discussion. Among the acacias, only *Acacia aneura* and *A. nilotica* were rated **. The former has been little tested outside Australia or planted there, and the latter is thorny; both are highly drought tolerant but slow in growth. The following species were given one asterisk: *A. albida, A. estrophiolata;l A. farnesiana; A. nubica; A. pendula, A. polyacantha, A. seyal* and *A. victoriae. Acacia* is the largest and most ecologically diverse of N-fixing genera (est. 1200 species, about 800 in the Australasian assemblage), and fodder use in this genus has been widely documented (Bamualin et al. 1980; Chippendale and Jephcott 1963; Cossalter 1985; Everist 1969; Jurriaanse 1950; Pellew 1980; Skerman 1977). Many species have outstanding drought tolerance, and probably deserve more serious evaluation as fodder species, not least among these *A. aneura* and *A. nilotica.* However, most of the listed species have low digestibility, thorniness, slow growth, or other undesirable traits.

Species of the genus *Albizia* are often toxic and high in tannins, although fodder growth can be rapid; only *A. lebbeck*(*) is rated here. *Cajanus cajan* (*) is not an important fodder species, but has fair DMD and is the subject of intensive international research as a food crop. *Chamaecytisus palmensis* (*) is a sub-temperate shrub of considerable promise. *Desmanthus virgatus* is rated ** here for its aggressive growth and good DMD, especially under intensive harvesting. It generally occupies the same ecological niche as leucaena, which outyields it. More should be known of the other species in this genus. The shrubby *Desmodium discolor* (*) is fairly palatable and vigorous, but little used as fodder. *Gliricidia sepium* is rated ** for its wide dispersal and acceptibility, but reports on its forage are notably variable and it is sometimes unused as fodder or believed toxic. Different ruminant bacteria or varietal differences might be surmised in this case.

Leucaena leucocephala (***) is highly rated internationally, and the subject of extensive research and of our annual publication, 'Leucaena Research Reports' (NFTA, Waimanalo, Hawaii). It is notably limited to non-acid soils and warm tropics. Several other species among the 12 or more in this genus are of interest in breeding to improve these traits, including *L. collinsii, L. diversifolia, L. lanceolata,* and *L. pulverulenta. Medicago arborea* (*) has historic use as goat fodder but few modern disciples. Several *Prosopis* spp. are noted as useful dryland fodders (largely pods), but are thorny and slow in growth. *Pterocarpus erinaceus* (*) is an African tree reportedly planted as stock feed, and *P. marsupium* (*)is lopped commonly in India. *Robinia pseudoacacia* (*) is listed here primarily as it is one of few 'cold-tolerant N-fixing trees, but it has poor digestibility. *Sesbania grandiflora* (*) is a widely grown food and ornamental tree that has excellent fodder but is short-lived and restricted in habitat.

Forage Quality and Chemical Composition Data

The species given 'fair' to 'excellent' ratings in Table 1 represent about 25% of those listed by Brewbaker (in press) and less than 10% of those indicated as fodder trees in the literature reviewed. It is clear that forage quality (Table 2) has much to do with this attrition. Many legume shrubs and trees are simply unpalatable to animals, and usable only if mixed judiciously in feeds.

DMD data are regarded as the most important values in Table 2. They are as yet available for only a few species, and are clearly to be desired for all. DMD values are now obtained most readily using in vitro enzymatic digestion by bacterial 'cellulases' (McLeod and Minson 1978). They are also derived from fistulated animals with the nylon bag technique. DMD values averaged 60% for leaves of 17 fodder legume species (Minson and Wilson 1980), and such values correlated well with fibre and lignin values (Bamualin et al. 1980). Tropical grasses are notably lower in DMD than temperate grasses, again directly related to fibre contents (Minson 1980). Values cited are presumed to represent 'bite sample' unless otherwise

Table 2. Forage quality of species in Table 1 (see text for notations)

Species		CP	Fat	CF	NFE	Ash	P	Ca	Mg	K	Si	DMD
Acacia albida		14.7	1.7	18.5	58.9	5.7	.18	.90	.19	1.25	.5	
A. aneura		6.9	4.1	26.2	52.9	9.9	.04	2.6		0.80		
		12.0				4.9	.11					39.2
		11.7	2.7	29.0	49.6	6.7	.07	1.29				
A. farnesiana		22.8				6.5	.21					54.0
		18.4	2.0	18.5	56.5	4.4	.24	0.47				
A. nilotica		13.6	8.1	10.7	59.8	7.1	.14	1.80	.19	0.80	.8	
		12.9	2.6	11.3	56.7	5.5						
		11.9	2.2	21.9	59.1	5.5	.13	.87				
		15.0	5.1	20.1	51.6	8.2	.19	1.5				
		19.2	3.2	8.1	61.5	8.0	.38	1.9				
	(fruits)	10.4	1.6	17.0	66.7	4.2	.14	.66	.14	1.1	.1	
A. nubica		32.5	1.7	15.8	41.2	8.9	.44	1.71				
A. pendula		16.9	3.4	30.2	37.9	9.3	.11			1.1		
		15.8				6.6	.12					47.2
A. polyacantha		15.5	3.8	22.1	48.7	9.7	.15	2.60				
A. senegal		22.4	3.8	20.2	44.7	8.7	.20	1.22	.30	1.0	.78	
		20.4	2.4	27.7	41.9	7.7	.20	1.38		1.16		
	(mature)	14.1	3.4	43.1	33.7	5.7						
	(immature)	33.6	3.0	29.0	28.1	5.6						
A. seyal		18.5	2.5	18.3	54.1	6.1	.27	1.1	.34	1.14	.57	
		15.2	2.7	19.2	55.9	7.0	.17	1.39		.72	.37	
A. lebbek		22.2	1.8	36.6	34.8	4.6						50
		21.6	3.7	31.8	33.6	9.3	.20	1.9				73
		29.2	3.5	25.3	34.5	7.5	.20	1.8	.50			
Cajanus cajan		17.3	6.0	28.1	39.7	6.7						
	(leaf)	15.8		29.2		5.5	.22					53
	(small stem)	10.5		48.7		4.4	.25					42
	(whole plant meal)	14.8	1.7	28.9	39.9							
Desmanthus virgatus (lf)		14.6		19.5		8.5	.19					53.3
	(stem)	7.0		50.5		4.2	.17					32.4
		11.5	2.1	43.9	37.2	5.8						
Gliricidia sepium (leaf)		15.6		21.2		5.5	.13					68.2
		28.1										54.8
		25.0		35.0		3.8						
Leucaena leucocephala		20.3	5.5	18.3	47.5	9.3	.16	2.3	.6	1.3		
		22.7	2.7	13.6	60.1	7.6						
		21.5	6.5	14.3	49.5	4.3	.17	2.7				71.4
		23.2	4.2	13.1	50.3	9.2						51.1
		15.2	3.0	15.0	55.7	11.1	.19	2.99				
		23		34		4.6						
		20.0	6.5	14.1	48.3	11.2						
	(leaf tips)	18.8	2.3	37.7	34.5	6.6						
	(leaf)	15.9		18.3		9.3	.17					68.8
	(stem)	4.4		57.7		3.4	.22					26.2
L. retusa		17.7	3.9	24.3	47.7	6.4	.13	2.82	.22	1.3		
Medicago arborea		14.0	2.9	23.0	52.5	7.7	.19	1.5		1.86		
Prosopis chilensis		21.2	3.6	31.0	42.9	6.5	.22	1.95				
(=*P. alba*)		21.2	3.2	28.5	41.8	5.4	.16	1.91	.21	1.48		
	(fruits)	12.6	2.0	25.1	53.3	4.6	.20	.65				
	(fruits)	13.7	1.9	27.9	52.6	3.9	.20	.65	.11	1.42		
P. cineraria		14	3	19	57	7	.3	2.5				41
	(fruits)	14.6	3.5	19.5	55.8	6.6	.32	2.72				
P. juliflora (=*pallida*)		17.2	3.2	21.8	46.2	10.8						
		19.0	2.9	21.6	47.9	8.5	.22	2.08				
		18.2	3.3	29.7	41.9	6.8	.16	.67		1.5		
	(fruits)	13.2	2.8	23.1	54.4	4.5	.15	.27	.10	1.4	.10	
	(fruits)	11.8	3.0	26.0	55.0	4.1	.25	.35		1.73		
	(fruits)	13.0	2.5	27.4	52.5	4.6						
	(fruits)	10.2	0.6	25.4	60.0	3.8						
Pterocarpus erinaceus		15.0	2.4	27.3	47.3	7.8	.16	.96	.43	2.8	.7	
		19.0	2.7	35.5	35.6	7.2	.24	.56		2.44		

Table 2 cont.

Species	CP	Fat	CF	NFE	Ash	P	Ca	Mg	K	Si	DMD
Robinia pseudoacacia	14.8	5.3	16.9	52.9	10.1	.10			.9		27
	25.2	3.3	17.2	46.5	7.5	.32	1.5				
	20.5	1.4	17.5	54.6	6.1	.15	1.1				
	21.4	3.5	21.3	45.0	8.8	.18	2.50				
Samanea saman	24.0		48		4.6						
Sesbania grandiflora	34.8	4.2	7.5	48.7	12.5	.33	2.33				
	30.1	2.0	5.1	42.3	10.5						

noted, and are drawn largely from studies of Bamualin et al. (1980), McLeod (1973), Mahyuddin (1983), Russell (1947) and Singh (1982). The values range very widely from high 60s for species like *Gliricidia* and *Leucaena* down to the 30s for fibrous, often phyllodinous species. Animal intake of these species is expected to be related directly to DMD, and within a species to DMD of the tissues browsed (Minson 1983).

The few tannin values available are also included in Table 1. High tannins clearly act as feeding deterrents, e.g. in calliandra, and possibly also complex proteins as well. Several toxic substances have been identified in the species reviewed, e.g. robitin in *Robinia*, cyanogenic glycosides and fluoroacetic acid in some acacias. Strong odors of crushed leaves often are associated with low animal intake, as can occur in *Gliricidia* and *Pongamia*. Other toxins are known for *Cytisus, Erythrina,* and *Sophora* spp. (Table 1).

Proximate analytic data are summarised as percentage dry matter in Table 2. The abbreviations used are as follows:

CP   Crude protein (N × 6.25%)
Fat   Ether extractable fraction
CF   Crude fibre (acid detergent)
NFE   Nitrogen-free extract, (primarily carbohydrates)
Ash   Total minerals after calcination
P, Ca, Mg, K, and Si are percentages of dry matter.

Protein (CP) data for N-fixing trees are high with rare exceptions, even in the fruits (pods). Some comparative values are 16% for all tested tropical and temperate legumes, and 9% for all grasses (Minson 1980). All African browse plants average around 12% (Le Houerou 1980a). Protein values diminish in older leaves and are notably lower in petiolar and stem tissues of woody plants.

Fibre (CF) contents of leaves are highly variable in Table 2, with bipinnate leaves notably lower in content than are phyllodes. Comparative values would include averages of about 25% and 35% for temperate and tropical forage grasses, respectively (Minson 1980). The data for phosphorus (P) and calcium (Ca) vary considerably among species and samples, but generally indicate adequacy for animal needs. Few data are available on sodium, not included in the table, but they are often very low. No data were obtained on sulfur contents, also expected to be low in some locations. Browse foliage of these woody species is generally of high nutritional status, if the animal finds it palatable enough to eat.

Species Mixtures and Mixed Feeds

Pasture managers of temperate herbaceous leys think automatically of mixed stands, normally grass plus legume. Why not similar mixtures for the tropics, using woody species? Some examples of successful tropical agroforestry systems include leucaena hedgerows in grass pastures, scattered timber or fuelwood trees in grass pastures, and border or fencerows of legumes like *Gliricidia* around animal grazing areas.

A remarkable number of highly palatable fodder trees do not fix nitrogen, and it would be myopic to conclude this paper with no consideration of them. Most trees lopped for fodder are not N-fixing (Singh 1982, Le Houerou 1980a, 1980b), notably in tropical highlands. N-fixing woody species become progressively more rare as one goes away from the equator, and actinorhizal plants more common (e.g., *Alnus, Ceanothus, Elaeagnus, Parasponia*). The highly productive fodder trees and shrubs that do not fix nitrogen include *Artemisia, Artocarpus, Atriplex, Azidirachta, Bauhinia*, Cassia*, Ceratonia*, Cercidium*, Ficus, Gleditschia*, Haloxylon, Morus, Quercus* and *Parkinsonia** (Le Houerou 1978). Some of these (asterisked) are legumes that do not nodulate (Halliday 1984). Forage management specialists should encourage use of all these species where adapted, with a major option being that of mixing fodder in cut-and-carry systems (Tangendjaja and Lowry 1984).

Species mixtures become economically viable for temperate pastures only with the 'fine-tuning' of species, variety, fertility and animal management patterns. The mixtures of woody species and grasses, notably in hedge and fence rows, will deserve similar long-range consideration for browse or cut-and-carry systems in the tropics.

References

Allen, O.N., and Allen, E.K. 1981. The Leguminosae: a source book of characteristics, uses, and nodulation. University of Wisconsin Press, Madison, Wisconsin, 812 p.

Bamualin, A., Jones, R.J., and Murray, R.M. 1980. Nutritive value of tropical browse legumes in the dry season. Proceedings, Australian Society of Animal Production, 13, 229–232.

Brewbaker, J.L., ed., in press. Use of nitrogen-fixing trees as forage. Nitrogen Fixing Tree Association, Waimanalo, Hawaii, USA.

Brewbaker, J.L., van den Beldt, R., and MacDicken, K.

1982. Nitrogen-fixing tree resources: potentials and limitations. In: Graham, P.H., and Harris, S.C., ed., BNF Technology for Tropical Agriculture. CIAT, Cali, Colombia, 413–425.

1984. Fuelwood uses and properties of nitrogen-fixing trees. Pesquisa Agropecuaria Brasileira, 19, 193–204.

Burley, J., and von Carlowitz, P., ed. 1984. Multipurpose tree germplasm. Mimeo, ICRAF, Nairobi, Kenya.

Chippendale, G.M., and Jephcott, B.R. 1963. Topfeed: the fodder trees and shrubs of Central Australia. Animal Industry Branch, Department of Primary Industry, N.T., Australia.

Cossalter, C. 1985. Introduction of Australian acacias in dry tropical Africa. In: Felker, P., ed., Symposium on establishment and production of tree plantings in semi-arid regions. Texas A. and I. University, Kingsville, Texas, USA.

Dougall, H.W., and Bogdan, A.V. 1958. Browse plants in Kenya. East African Agricultural Journal, April 1958, 236–246.

Everist, S.L. 1969. Use of fodder trees and shrubs. Queensland Department of Primary Industries, Division of Plant Industry Leaflet No. 1024. Queensland, Australia, 44p.

Gray, S.G. 1969. The place of trees and shrubs as sources of forage in tropical and subtropical pastures. Tropical Grasslands, 3, 57–62.

Halliday, J. 1984. Register of nodulation reports for leguminous trees and other arboreal genera with nitrogen fixing members. Nitrogen Fixing Tree Association Research Reports 2, 38–45.

Jurriaanse, A. 1950. Fodder trees. In: Farming in South Africa, 181–188.

Lamprey, H.F. Herlocker, D.J., and Field, C.R. 1980. Report on the state of knowledge on browse in East Africa in 1980. In: Le Houerou, H.N., ed., Browse in Africa. ILCA, Addis Ababa, Ethiopia, 33–54.

Le Houerou, H.N. 1978. The role of shrubs and trees in the management of natural grazing lands (with particular reference to protein production). In: Proceedings, Eighth World Forestry Congress, Jakarta, Indonesia.

1980a. Chemical composition and nutritive value of browse in tropical West Africa. In: Le Houerou, H.N., ed., Browse in Africa. ILCA, Addis Ababa, Ethiopia, 261–297.

1980b. Browse in Northern Africa. In: Le Houerou, H.N., ed., Browse in Africa. ILCA, Addis Ababa, Ethiopia, 55–82.

Mahyuddin, P. 1983. Nutritive value of tree legume leaves. In: 1983 Research Report, BPT, Ciawi, Indonesia.

McLeod, M.N. 1973. The digestibility and the N, P and ash contents of the leaves of some Australian trees and shrubs. Australian Journal of Experimental Agriculture and Animal Husbandry, 13, 245–250.

McLeod, M.N. and Minson, D.J. 1978. The accuracy of the pepsin-cellulase technique for estimating the dry matter digestibility in vivo of grasses and legumes. Animal Feed Science and Technology, 3, 277–287.

Minson, D.J. 1980. Nutritional differences between tropical and temperate pastures. In: Morley, F.H.W., ed., Grazing Animals, Elsevier Publishing Co., Amsterdam.

1983. Forage quality: assessing the plant–animal complex. Proceedings, 14th International Grassland Congress, Lexington, Kentucky, USA, 23–29.

Minson, D.J., and Wilson, J.R. 1980. Comparative digestibility of tropical and temperate forage — a contrast between grasses and legumes. Journal, Australian Institute of Agricultural Science, 247–249.

NAS (National Academy of Science, USA) 1979. Tropical legumes: resources for the future. U.S. National Academy of Science, Washington, D.C., 331 p.

Panday, K. 1982. Fodder trees and tree fodder in Nepal. Swiss Federal Institute of Forestry Research, Birmensdorf, Switzerland, 107 p.

Pellew, R.A. 1980. The production and consumption of acacia browse and its potential for animal protein production. In: Le Houerou, L.N., ed., Browse in Africa, ILCA, Addis Ababa, 223–231.

Robinson, P.J. 1985. Trees as fodder crops. In: Cannell, M.G.R., and Jackson, J.E., ed., Attributes of Trees as Crop Plants. Institute of Terrestrial Ecology, Huntingdon, U.K., 281–300.

Rosenthal, G.A., and Janzen, D.H. 1979. Herbivores; their interaction with secondary plant metabolites. Academic Press, New York.

Russell, F.C. 1947. The chemical composition and digestibility of fodder shrubs and trees. In: The use and misuse of shrubs and trees as fodder, Imperial Agricultural Bureau, London.

Sharma, O.P. 1977. Fodder trees of Himachal Pradesh. Indian Farming, 88–92.

Singh, R.V. 1982. Fodder trees of India. Oxford and IBH Publishing Co., New Delhi, India. 663p.

Skerman, P.J. 1977. Tropical forage legumes. FAO Plant Production and Protection Series, No. 2, FAO, Rome.

Tangendjaja, B., and Lowry, J.B. 1984. Leucaena in animal and human nutrition in Indonesia. In: Craswell, E.T., and Tangendjaja, B., ed., Shrub Legume Research in Indonesia and Australia, ACIAR Proceedings Series No. 3, 28–32.

Non-leguminous Trees and Shrubs as Forage for Ruminants

R. Soedomo*, P.M. Ginting* and G.J. Blair**

IN comparison with non-legume trees and shrubs, a great deal of research emphasis has been placed on various aspects of the forage value of leguminous tree and shrub legume species throughout the world. In contrast, forestry research for fuel and wood production has focused on non-leguminous species.

Animal raisers in tropical countries generally have fewer forage resources than their counterparts in the temperate regions and, particularly in many areas of Southeast Asia, land is also a scarce resource. For these reasons farmers in Southeast Asia have utilised forage resources from a very wide range of plant species including non-leguminous trees and shrubs. In many areas the most important species are those which supply both animal feed and fuelwood. In regions where fuelwood is of prime concern six non-leguminous genera are identified (National Academy of Science 1980) as having a duel fuel/forage role (Table 1). Little is known of the specific contribution that these forages make to animal productivity in the region.

Fodder trees (both leguminous and non-leguminous) play an important role in production in arid and semi-arid areas of the world. In India and Pakistan fodder trees of the genera *Grewia*, *Celtis* and *Ficus* have been used to replace concentrates for cattle and sheep in hill pastures (Byington and Child 1981).

Non-leguminous fodder trees play an important role in feeding systems in Bali, Indonesia. Nitis et al. (1985) list some 43 species that have been recorded as being used in Bali.

In the Northern Territory of Australia a wide range of non-leguminous trees and shrubs are used as animal fodder. In areas where rainfall is in the range of 150–300 mm/year native fodder trees and shrubs become an important feed resource. Askew and Mitchell (1978) list the main value of these species as:

a. a food reserve in times of drought;
b. a nutrient supplement when grasses have dried off and are of low food value;
c. shade and landscape stabilisers.

These authors indicate that forage from trees and shrubs can contribute up to 10% of the total diet in cattle in times of drought. This proportion increases in the diet of sheep and goats. The authors classify the 19 main non-leguminous species that are used as fodder in the Northern Territory on a scale ranging from excellent to poor in relation to protein, phosphorus, calcium, magnesium and digestibility.

In the very dry areas of Australia, genera within the family Chenopodiaceae, such as *Atriplex* and *Kochia*, play an important role in animal production. Leigh (1972) indicates that these shrubs are high in nitrogen, sodium, potassium and chloride salts. A range of analytical data from two genera is presented in Table 2.

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Table 1. Genera of tree and shrub species identified as having a prime role in fuel production and a secondary forage role (National Academy of Science 1980).

Region	Family	Genus	Plant parts eaten by livestock
Humid Tropics	Sterculiaceae	*Gauzuma*	Young foliage, fruits
	Ulmaceae	*Trema*	Leaves and branches
Tropical highlands	Ulmaceae	*Trema*	Leaves and branches
Arid/semi arid tropics	Combretaceae	*Anogeissus*	Foliage
	Euphorbiaceae	*Emblica*	Foliage, fruits
	Chenopodiaceae	*Haloxylon*	Foliage
	Rhamnaceae	*Zizyphus*	Foliage, fruit

Table 2. Published values for sodium, potassium, chloride, crude protein and digestibility in the genera *Atriplex* and *Kochia* (Leigh 1972).

Genus	Sodium	Potassium	Chloride	Crude Protein	Digestibility
			(% of total diet)		
Atriplex	3.2–8.2	1.1–7.2	3.9–14.3	10.0–21.9	52–74
Kochia	6.6	1.5	3.4	15.1–22.0	58

Table 3. Amount of tree leaf fed (% of total leaf) to goats during the dry season in various climatic zones in Bali (Nitis pers. comm.).

Climatic zone (Schmidt and Ferguson 1951)	No. dry months	Legume (% of total leaf fed)	Non-legume
B	1.5–3	14.5	23.5
C	3–4.5	18.7	33.8
D	4.5–6	19.6	42.5
E	6–7.5	28.0	5.9
F	7.5–9	37.8	26.9

Table 4. Percentage of farmers feeding various forages to small ruminants in W. Java (Djajanegara et al. 1982).

Forage	Lowland	Upland
	(% of farmers)	
Native grass	86	100
Corn tops	2	70
Legume straw	1	32
Rice straw	0	13
Sesbania sp.	20	0
Artocarpus sp.	0	10
Banana leaves	0	72
Cassava leaves	3	22

The high sodium levels found in these plants may be of value in areas where sodium is low in other species, but in the areas of Australia where these plants grow the high sodium content can be deleterious to livestock because it creates an excessive need for water.

Non-leguminous Trees in Feeding Systems

There are few reported studies of the role that non-leguminous trees and shrubs play in production systems in Southeast Asia and the South Pacific. Two groups in Indonesia, (Udayana University, Bali, and the Balai Penelitian Ternak – N. Carolina CRSP project at Bogor), have been active in this field of research. Both of these groups have measured the contribution of various feed sources to ruminants in different climatic zones, farming systems and seasons in both Java and Bali.

Nitis (pers. comm.) found that during the dry season more non-leguminous tree leaf was fed to goats than leguminous tree leaf in climatic zones where the dry season extended to six months (Table 3).

In the very dry areas, tree leaf (both legume and non-legume) made up approximately 65% of the total leaf fed during the dry season. The importance of tree leaf as a feed source is too often overlooked.

A survey conducted by Djajanegara et al. (1982) in upland and lowland (rice producing) areas of West Java indicated that livestock feeding practices varied markedly between the two areas. In the lowland group 20% of farmers fed the tree legume *Sesbania*, whereas none followed this practice in the upland area (Table 4).

On the other hand only 3% of lowland farmers used cassava leaves whereas 10, 72 and 22% of upland farmers fed *Artocarpus* (Jackfruit), *Musa* (Banana) and *Manihot* (Cassava) leaves respectively. This reflects not only differences in the availability of feed resources in the two areas but also that non-leguminous feed can be a vital source of feed in certain areas.

Seasonal (wet and dry) and regional differences in the role of tree leaves in sheep and goat production has been investigated by van Eys et al. (1983). The percentages of tree and shrub leaves in the diet of small ruminants were 9.8, 0.6, 12.2 in the wet season for Garut, Ciburuy and Cirebon, and for the same locations during the dry season the percentages were 11.5, 1.8 and 15.0. At all locations the proportion of shrub and tree leaves in the diet increased in the dry season, which is a reflection of the lower availability of other feedstuff.

At all these locations the proportion of non-leguminous species fed exceeded that from tree legumes. A high proportion of the leaf fed consisted of banana leaves at Garut, in both the wet and dry season, and of hibiscus leaves at Cirebon, during the dry season. The feeding of hibiscus leaf has long been practiced by farmers in Indonesia (Heyne 1950).

Although Devendra (1981) suggests that the contribution of non-leguminous tree leaves to small ruminant diets is in providing variety and helping to extend diet preference, van Eys et al. (1983) suggest that because such material is often the sole diet for small ruminants, it may play an important nutritional role in village production systems.

Table 5. Proximate analysis and energy content of tree leaves sampled from an area of Bali with a dry season of 1.5–3 months (Nitis et al. 1985).

| Species: | *Sesbania grandiflora* | | *Musa paradisiaca* | |
Season:	Wet	Dry	Wet	Dry
Crude protein	28	25	17	17
Crude fibre	14	19	24	24
Ether extract	4	3	3	3
N-free extract	45	44	44	43
Ash	10	9	11	12
TDN	42	42	38	32
Gross Energy (Mcal/kg)	4.7	4.6	4.3	4.3

Nutritive Value of Non-leguminous, Tree and Shrub Leaves

Several investigators have reported results from proximate and mineral analysis of non-leguminous tree and shrub leaves (Lowry et al. 1983; Nitis et al. 1985) but all these studies suffer from the deficiency that the physiological age, sampling time etc, has not been specified. This problem is highlighted in the data of Prabowo et al. (1984) for *Artocarpus integra* (Jackfruit, Nangka) sampled at Garut, W. Java, who found a fourfold change in magnesium levels in samples taken between June and October.

Given these deficiencies in all the available data on proximate and mineral analysis, non-leguminous tree leaf material compares favourably in some respects with legume tree leaf. Holm (1973) found that although the digestible protein content of *Manihot esculenta* (cassava) (13.9 g/100g) was lower than that in *Sesbania grandiflora* (18.0 g/100g) the starch equivalent of both species was almost equal.

Similar results have been reported from Bali by Nitis et al. (1985) where they reported that banana leaves had lower crude protein and total digestive nutrients (TDN) and higher crude fibre than sesbania leaves (Table 5).

Although there are relatively small differences between leaves from leguminous and non-leguminous trees in their proximate analysis and mineral content, a major difference in their 'quality' may be due to their rate of degradation in the rumen. Minor and Hovell (1978) studied the degradation rate of leaves from several species *in sacco* and found that the rate of dry matter loss from the cassava (34%) and banana leaf (15%) was considerably lower than from leucaena leaf (75%).

A second factor that may discount the feeding value of non-leguminous tree and shrub legumes may be the site of digestion of the feed in the animal. Leigh (1972) reports that the biological value of protein in *Atriplex* sp. is reduced because the stomach plays a less important role in the digestion of organic matter and fibre from this species. He also states that on diets rich in *Atriplex* ruminal absorption of fatty acids is impaired, and protein is extensively degraded to ammonia in the rumen. Such data do not appear to exist for other non-leguminous tree species.

Feeding Trials with Non-leguminous Tree Leaves

Although non-leguminous tree leaves form an important component of the diet at some times in some locations, little data exist on their contribution to maintenance or production of livestock.

Nitis and Lana (1984) found that supplementation of native grass with tree leaves resulted in increased animal growth rates in Bali. They suggested that this was most likely the result of the higher protein content of the tree leaf. Nitis and Lana (1984) also report a response to feeding banana pseudostem to pigs fed on a diet high in rice bran. Pigs on the unsupplemented diet showed signs of parakeratosis (copper deficiency) whereas those supplemented grew normally. A similar increase in growth rate due to supplementation with banana pseudostem has been reported with Bali cattle on a native grass diet.

Soedomo and Ginting (unpubl.) have conducted an experiment in Timor, Indonesia to study the effect of supplementing native grass with rice bran, also tree legume leaves of *Acacia leucophloea* or *Tamarindus indicus* or the leaves of the non-leguminous tree *Melochia umbellata*. This non-leguminous tree grows extensively in Java and the eastern islands of Indonesia. The chemical composition of the feedstuffs used in the study are reported in Table 6.

Although the *Melochia* leaves contained similar gross energy and crude protein to the tree legume leaves, animal productivity was much lower on this feed supplement (Table 7). This was the result of a low intake of dry matter of this species (Table 7).

These data suggest that although the chemical analysis of *Melochia* appears favourable, the intake of this species was low. This emphasises the need to train

animals to accept new feedstuffs prior to such studies and/or investigate anti-nutritive factors such as tannin, phenols or leaf characteristics that may render a forage unacceptable to livestock.

Table 6. Proximate analyses and energy data of feed ingredients (dry matter basis).

Feed ingredients	GE (Mcal/kg)	CP (%)	CF (%)	EE (%)	Ash (%)	NFE (%)
Acacia leucophloea leaves	4.40	12.96	26.02	3.46	9.62	47.94
Tamarindus indicus leaves	4.47	14.08	30.86	2.14	5.75	47.17
Melochia umbellata leaves	4.53	16.16	15.17	2.73	7.79	58.15
Native grass	4.31	7.23	32.04	2.62	7.81	50.30
Rice bran	3.99	10.49	20.41	7.36	15.99	45.75

GE = Gross Energy
CP = Crude Protein
CF = Crude Fibre
EE = Ether Extract
NFE = Nitrogen Free Extract

Table 7. Average daily feed intake (kg/head) and average daily liveweight gain (kg/head) of Bali cattle fed native grass supplemented with different locally available materials.

Supplement	Daily intake (kg/head) Native grass	Supplement	Daily liveweight gain (kg/head)
Rice bran	4.86	2.18	0.44
Acacia	2.02	4.48	0.52
Tamarindus	3.29	2.62	0.34
Melochia	4.13	1.37	0.32

Conclusion

The leaves of non-leguminous tree and shrub species form an important part of animal production systems in some parts of the Southeast Asia. There is little reliable data on the impact that this forage source has on animal productivity and there is an urgent need to obtain such information.

References

Askew, K., and Mitchell, A.S. 1978. The fodder trees and shrubs of the Northern Territory. N.T. Division, Department of Primary Industry, Extension Bulletin No. 16.

Byington, E.K., and Child, R.D. 1981. Forages from the world's forested land for ruminant animal production. In: Child and Byington ed., Potential of the world's forages for ruminant animal production. 2nd ed. Winrock International, Arkansas, USA.

Devendra, C. 1981. Non-conventional feed resources in the S.E. Asian region. World Review of Animal Production, 15, 65.

Djajanegara, A., Thomas, N.T. and Johnson, W.L., 1982. Patterns of goat and sheep production in West Java. Proceedings 3rd International Conference on Goat Production and Disease, Arizona, USA.

Heyne, K., 1950. De nuttige planten van Indonesia. W. van Hoeve's, Gravenhoge.

Holm, J., 1973. The nutritive value of 12 tropical forage plants from Chiang Mai, Thailand, Landw. Forschung 26: 313.

Leigh, J.H., 1972. Saltbush and other chenopod browse shrubs. In: The use of trees and shrubs in the dry country of Australia. Australian Government Publishing Service, Canberra.

Lowry, J.B., Ashari Thahar, Tiolina Sitompul and Petheram, R.J., 1983. Composition of some village ruminant feedstuffs in Indonesia. Proceedings, 5th World Conference on Animal Production.

Minor, S. and Hovell, F.D.De.B., 1978. The evaluation of tropical forages by measures of the rumen bag technique. Tropical Animal Production, 3, 169.

National Academy of Science 1980. Firewood crops: shrubs and tree species for energy production. Washington D.C.

Nitis, I.M. and Lana, K., 1984. Effects of replacing 30% of green roughage with concentrate on the performance of Bali steer. Udayana University, Bali, Indonesia. Final Report to IDRC, Canada. 156p.

Nitis, I.M., Lana, K., Susila, T.G.O., Sukanten, W. and Uchida, S. 1985. Chemical composition of the grass, shrub and tree leaves in Bali. Udayana University, Bali, Indonesia, Supplementary Report No. 1 to IDRC, Canada, 96 p.

Prabowo, A., van Eys, J.E., Mathius, I.W., Rangkuti, M. and Johnson, W.L. 1984. Studies on the mineral nutrition of sheep in W. Java, Indonesia. Small Ruminant–CRSP Working Paper No. 40. Balai Penelitian Ternak, Bogor, Indonesia.

Van Eys, J.E., Mathius, I.W., Thomas, N., Rangkuti, M., and Johnson, W.L. 1983. Forage composition of sheep and goat diets in West Java. Small ruminant–CRSP Working Paper No. 24. Balai Penelitian Ternak, Bogor, Indonesia.

Tropical Grasses: Their Domestication and Role in Animal Feeding Systems

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Of all the plant families, the grasses (Gramineae) are the most important as a feed source for domestic herbivores. Grasses occur in almost all environments and are particularly prominent in the semi-arid tropical areas where they may be the dominant component of the natural vegetation. Man has further encouraged their growth by management (e.g., fire) and deliberate introduction of grasses into areas where previously they were absent or only of minor importance. In this paper we examine the role of grasses (both native and introduced) in animal feeding systems in Southeast Asia and the southern Pacific, and how the effectiveness of grasses in this role can be increased. Although grass seeds (grain) may be important in some animal diets, we concentrate on grasses as herbage plants either grazed in situ, or harvested by a cut-and-carry system. Emphasis is placed on experience in Australia but relevant studies elsewhere in the region are included.

Domestication of Tropical Grasses

Grasses are sown when pastures are being developed in areas lacking a grass flora (e.g. forests) and also as replacements or additional species where grasses are already present (e.g. savannas). Although the need for sown species is obvious when previously forested areas are being developed for grazing, the need is not so apparent when the native vegetation contains a grass component. Sown grasses are used in these situations for three major reasons:

(a) the native species are of inferior quality e.g., *Imperata cylindrica* grasslands;

(b) the productivity of the native species is low e.g. native grasses in brigalow (*Acacia harpophylla*) areas in Australia;

(c) the native species fail to persist under increased grazing pressure e.g., *Themeda australis*.

Compared with temperate regions, the domestication of tropical species is a comparatively recent endeavour. Nevertheless there have been a number of

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attempts in many places throughout the world to develop sown tropical species, and commercial seed (or vegetative material) is available for many varieties. Nearly all the sown tropical forage grasses come from the savanna areas, where the climate is too dry to support a continuous tree cover but is wetter than desert areas (Clayton 1983). Africa, with its large tropical savannas supporting many grazing animals, has a great diversity of grasses and it is the principal source of sown tropical species (Clayton 1983). However, both America and Asia have also contributed species. Although the sown grasses are from savanna areas, most are not the dominant or climax species but belong to the pioneer or early seral stages of succession (Tothill 1978).

Most of the commercially available grasses have been developed by collection of wild strains followed by direct use, or by limited selection within this material. However, plant breeding has been used (Boonman 1978; Hacker 1985) and is likely to be used to a greater extent in the future as the deficiencies and limitations of existing cultivars become apparent.

Role of Tropical Grasses in Animal Feeding Systems

While grasses are important as soil binding agents to protect the soil, ensure landscape stability, and to control weeds in plantations, their major role is as a source of nutrients for herbivores. Since much of the land in Asia and the Pacific is used for food production for humans or for high value crops, pastures are frequently associated with marginal lands which often have problem soils. The plantation crop areas can be important for feeding animals, both for forage production and as a source of by-products to supplement grazing animals (Abdullah Sani and Basery 1982; Wan Mansoor and Tan 1982; Chen and Othman 1983). A number of native grasses (e.g., *Axonopus compressus, Paspalum conjugatum, Ottochloa nodosa*) grow under tree (oil palm, rubber, coconut) canopies and of the sown grasses, *Brachiaria* species are among the most shade tolerant.

The native grasses provide a low-cost feed resource

and are widely used throughout the tropics. They form the basis of the beef cattle industry in northern Australia and are important in other areas in Asia and the Pacific, particularly in drier regions. Although there are many important native grass species (Table 1) their limitations for animal production are similar. Failure to persist under heavy grazing pressure is sometimes a problem but their major limitation is low nutritive value. This is illustrated in Fig. 1 for *Heteropogon contortus* growing at Landsdown near Townsville. Green leaves have a higher nutritive value than other plant parts, but even in green leaves the nitrogen concentration declines rapidly during the growing season (despite adequate water supply) and soon falls below the level necessary for animal growth (about 1%: Hunter et al. 1976; Falvey 1979). As water becomes limiting the herbage senesces and nutrient concentrations fall to very low levels e.g., 0.25% nitrogen and 0.02% phosphorus in dry *H. contortus* leaves at Lansdown (McIvor 1981). Since this low quality herbage must support the animals for much of the year, animal liveweights are characterised by reasonable growth during the growing season, followed by a period of little change and then loss during the late dry season (e.g., Norman 1965). Other nutrients may also be deficient, e.g., survey in Peninsular Malaysia showed widespread deficiencies of phosphorus, potassium, calcium, magnesium, copper, zinc and sodium (Wan Zahari and Devendra 1985).

Table 1. Important grass species occurring naturally in Southeast Asia and the southern Pacific (derived from Partridge 1979; Chen and Othman 1983; Ivory and Siregar 1984; Gutteridge 1985).

Thailand	Malaysia
Arundinaria spp.	*Axonopus compressus*
Dactyloctenium aegypticum	*Ischaemum muticum*
Digitaria adscendens	*I. timorense*
Eragrostis viscosa	*Ottochloa nodosa*
Imperata cylindrica	*Paspalum conjugatum*
Philippines	Papua New Guinea
Callipedium parviflorum	*Arundinella setosa*
Chrysopogon aciculatus	*Imperata cylindrica*
Imperata cylindrica	*Themeda australis*
Themeda triandra	
Indonesia	Fiji
Imperata cylindrica	*Dichanthium caricosum*
	Pennisetum polystachyon

In contrast, many sown grasses are much more productive than the native species (e.g. Table 2) but they require higher soil fertility or fertiliser application to enable them to persist and express their production potential. At the same fertility level, there may be little difference in herbage quality between native and sown
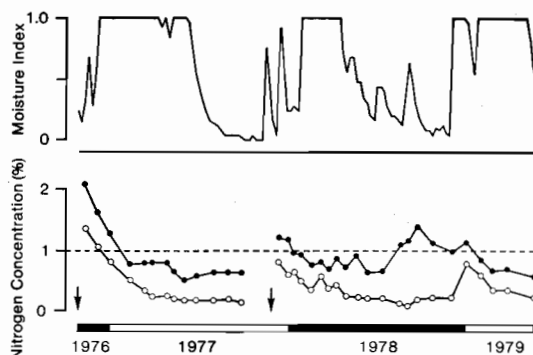

Fig. 1. Growing conditions and herbage quality at Lansdown, near Townsville. (a) Weekly value of the moisture index (Fitzpatrick and Nix 1970).
(b) Nitrogen concentration in green leaf and green stem of *Heteropogon contortus* growing in an ungrazed sward. The arrows indicate date of burning.

grasses (Table 2) and in a three-year grazing experiment in Malaysia, animal production did not decline when a sown grass *(Panicum maximum)* was replaced by the native grasses *(Paspalum conjugatum* and *Axonopus compressus)* under high grazing pressure (Chen et al. 1981). The available improved or higher yielding species cover a wide range of growth habits from tall, erect, tufted species to low growing stoloniferous or rhizomatous species; the latter group are generally more resistant to heavy grazing than the former group. Although sown grasses have many advantages over the native grasses they may be expensive to use due to high seed costs or the need for vegetative propagation, high superphosphate requirements, the need for cultivation at establishment etc. Some approaches to overcoming these limitations are discussed in the next section.

More Effective Grasses for Animal Production

There have been many studies aimed at increasing the effectiveness of tropical grasses for animal production. Two approaches have been adopted; selection of improved genotypes and management of existing material to overcome inherent weaknesses or deficiencies. There are five basic requirements in a pasture species: high dry matter yield, persistence, adequate herbage quality, capacity to associate with other desirable species, and ease of propagation and establishment (Williams et al. 1976). Attempts have been made to improve all of these.

Herbage Yield

High herbage yield is one of the major selection

Table 2. The effect of nitrogen fertiliser application on the herbage yield and nitrogen concentration of native (*Paspalum conjugatum* and *Ischaemum aristatum*) and sown grasses (*Brachiaria decumbens* and *Digitaria decumbens*) in Malaysia (from Ng 1972).

Fertiliser rate (kg N/ha)	Native grasses				Sown grasses			
	P. conjugatum		I. aristatum		B. decumbens		D. decumbens	
	Yield (kg DM/ha)	N. conc. (%)	Yield (kg DM/ha)	N. conc. (%)	Yield (kg DM/ha)	N. conc. (%)	Yield (kg DM/ha)	N. conc. (%)
0	2930	0.95	3140	0.98	9880	0.74	5970	0.80
112	5730	0.95	5000	1.15	14020	0.84	12660	0.88
224	6810	1.12	4780	1.23	19740	0.94	11640	0.92
448	12150	1.25	9300	1.43	19630	0.92	14270	1.15
896	14010	1.76	8450	1.78	14750	1.32	16990	1.63

criteria in most evaluation programs. In intensive systems with high levels of utilisation, animal production may be directly related to increases in yield. In extensive systems yield is less important per se since much of the herbage is not consumed by animals but is burnt or decomposes in situ.

Increasing herbage yield has been a major objective of many agronomic studies. A great number of experiments have been conducted to find ways of overcoming environmental constraints (moisture excess or deficiency, nutrients deficiencies and toxicities), to control weeds, pests and diseases, and to determine suitable cutting and/or grazing management regimes. Tropical grasses give large responses to fertilisers but in recent years the increasing costs of fertilisers have focused attention on grasses with lower fertiliser requirements, particularly in drier areas where overall productivity is lower. In a study of a range of grasses, McIvor (1984a) found the grasses most tolerant of low phosphorus soils were grasses with the smallest response to applied phosphorus.

Since high grass yields may be associated with lower nutritive value and lower proportions of companion legumes in pastures (McIvor 1985), they are also desirable if they do not result in detrimental effects to these attributes.

Persistence

Persistence can be considered as the long term maintenance of herbage yield and involves the perennation of original plants and/or regeneration from seed.

Persistence is particularly important in extensive systems. For pasture development to be economically viable in extensive systems, the pastures must persist for many years so that the establishment costs (which may be the major production cost) can be spread over a long period. This contrasts with ley pastures which are alternated with crops and intensive systems where pastures can be resown if persistence is unsatisfactory. Persistence can involve resistance or tolerance to grazing and cutting, competition from other plants,

drought, waterlogging, shade, low temperatures, high temperatures, diseases, insects, nutrient deficiencies.

Most evaluation and agronomic studies continue for a number of years and by measuring herbage yields over the period they indirectly measure persistence, although there may be no attempt to identify the mechanisms involved.

Herbage Quality

Attempts to improve herbage quality have taken three approaches — high nutritive value of plant parts, an increased ratio of leaf to stem, and a higher proportion of green rather than dead material.

Tropical grasses generally have lower herbage quality than temperate grasses (Norton 1982) and there have been a number of attempts to produce higher quality grasses. Hacker (1982) reviewed the selection and breeding of better quality grasses and concluded that considerable variation exists within species for characteristics associated with quality (digestibility, mineral concentration, carbohydrates, fibre and intake). This variation can be exploited by the plant breeder and has been used to produce experimental lines, e.g., Hacker (in press), and commercial varieties (Burton 1972; Burton and Monson 1978).

Since for any one species leaves are of higher quality than stems (Raymond 1969), an increased proportion of leaves will improve pasture quality. Burton et al. (1969) produced a dwarf strain of *Pennisetum americanum* with a higher proportion of leaf than the normal tall strain; the dwarf strain had higher digestibility and protein content but animal production from the two strains was similar due to the lower yield of the dwarf strain. Using a different approach, Ludlow et al. (1982) used growth regulators to manipulate canopy height to increase leaf density. When CCC was used, this was achieved without a significant effect on canopy photosynthesis, and grazing animals selected a diet of similar chemical composition and digestibility but with a larger bite size.

Another approach to reducing the stem content of a pasture is to use a later flowering variety, or one which only flowers for a restricted period, e.g., *Chloris gayana* cv. Pioneer flowers early in the growing season and continues flowering over an extended period. However, cv. Callide does not flower until later, so it has a much longer period when only vegetative material is present.

Green material has a higher nutritive value than dead material, and the proportion of green may be more important in determining the overall quality of a pasture than the species present. In seasonally dry areas, the rate of decline in green material at the end of the growing season varies between species. For example, in a study in northeast Queensland, sown grasses remained green longer than native grasses (McIvor 1982), while Wilson and 't Mannetje (1978) and McIvor (1984b) have shown that the rate of senescence of individual leaves varies between species. Similarly, species vary in their response to storm rains (McIvor 1982) and this influences the amount of green herbage available at the start of the growing season.

Legume–Grass Associations

Most tropical soils are deficient in nitrogen, and this has led to a search for suitable legumes to grow with grasses, particularly in Australia. The legume not only acts as a source of nitrogen for companion grasses but as a higher quality feed than grass. This is particularly so for mature herbage. Although the nutritive value of legumes also declines with maturity, the rate and extent of the decline is less than that of grasses (Norman and Stewart 1967; Playne 1972).

The tropical grasses have inherently higher growth rates under optimal conditions than legumes (Ludlow and Wilson 1972), and this has sometimes resulted in poor legume persistence, especially if the grasses are taller than the associated legumes. The stoloniferous and rhizomatous grasses form dense swards and this may make it difficult for legumes to re-establish; under the same management the legume content of a sward can often be maintained at a higher level with tussock rather than stoloniferous grasses, e.g., *Panicum maximum* and *Brachiaria decumbens* (McIvor 1978).

Legume-based pastures may be less productive than nitrogen fertilised grass pastures, but they are generally more productive than unfertilised grass and the overall herbage quality is higher.

Propagation and Establishment

Seed production Establishment from seed is the only feasible method for large scale development. However, there are often problems with seed produc-

tion in many tropical grasses, particularly in humid equatorial regions, and this can result in high seed prices. Low levels of seed production may result from many causes: low inflorescence density; poor synchronisation of flowering; infertile florets; high levels of shattering; poor recovery by harvesting machinery and low germination. Breeding for improved seed production has resulted in the release of *Setaria sphacelata* cv. Solander which has double the seed production of the existing cultivar, Narok (Hacker 1985).

Ease of establishment Although establishment from seed is the most common method, vegetative material is also used to establish some species (e.g., *Digitaria decumbens*). In unploughable hill country and in areas with a plentiful supply of labour, vegetative material may be used for other species also. Hacker (1985) outlined a program to cross *Digitaria smutsii* with *D. milanjiana* to incorporate the stoloniferous habit of the latter species into a virtually sterile but otherwise promising accession so it could be vegetatively propagated.

Ability to spread Since a species may not be sown over the whole area where it could be used, ability to colonise new areas is desirable in a pasture plant (the same characteristic in a grass used in cropping areas is undesirable since it may become a weed). The stoloniferous grasses have an obvious advantage in local areas but there is wide variation in the ability of species to spread by seed to new areas e.g., *Urochloa mosambicensis* spreads much more readily than *Cenchrus ciliaris* (Gardener and McIvor 1984).

Conclusions

The tropics cover a wide range of environments and the relative importance of these basic requirements changes from one environment to another. In the high rainfall, long growing season areas which were previously forested, there are many species which will persist. Among these species there is a wide range in herbage yield, and under the relatively intensive management (cultivated seedbeds, fertiliser application, grazing control) herbage yield (and its distribution throughout the year) is an important criterion. In lower rainfall areas with short, unreliable growing seasons, larger areas are available frequently with native grasses as a major component of the vegetation. There are far fewer species adapted to these areas, and the range in herbage yield between species is much less. Level of management is lower and herbage yield is a less important selection criterion. Under these circumstances, factors such as ease of establishment, ability to spread, persistence and legume compatibility become the important criteria.

Grass monocultures are simpler to manage than

mixed grass-legume pastures, and the most widespread use of sown grasses is in intensive systems, with fertiliser application in wet areas and on naturally fertile soils in drier areas. On less fertile soils in semi-arid areas, sown grasses are generally not superior to native grasses. Under these conditions legumes are used to improve the pasture quality, and management aims to maintain a balance between the legume and the native grasses in the pasture.

Grasses already provide the major part of the diet of grazing animals, and this is likely to continue. Tropical forage grasses have only been studied for a few decades, but there are many species and varieties available for commercial use. Much more remains to be done in the collection and study of these grasses, and no doubt more varieties will be selected and released in the future. As more becomes known about the species and their deficiencies are recognised, there should be a role for increased plant breeding to combine desirable characteristics from different strains into one variety.

References

Abdullah Sani, R., and Basery, M. 1982. The integration of cattle with coconut cultivation. 1. Growth performance and production systems. MARDI Research Bulletin, 10, 384–392.

Boonman, J.G. 1978. Rhodes grass breeding in Kenya III. Seed and herbage yield in selections of four maturity classes based upon intra variety variation. Euphytica, 27, 649–656.

Burton, G.W. 1972. Registration of Coastcross 1 Bermuda grass. Crop Science, 1, 125.

Burton, G.W., and Monson, W.G. 1978. Registration of Tifton 44 Bermuda grass. Crop Science, 18, 911.

Burton, G.W., Monson, W.G., Johnson, J.C., Lowrey, R.S., Chapman, H.D., and Marchant, W.H. 1969. Effect of the d_2 dwarf gene on the forage yield and quality of pearl millet. Agronomy Journal, 61, 607–612.

Chen, C.P., Ajit, S.S., and Evans, T.R. 1981. Beef production from three nitrogen fertilised grasses in Malaysia. MARDI Research Bulletin 9, 207–224.

Chen, C.P., and Othman, A. 1983. Effect of cattle production on forage under oil palm — a preliminary report. Proceedings of the Seventh Annual Conference of the Malaysia Society of Animal Production, 214–227.

Clayton, W.D. 1983. Tropical grasses. In: McIvor J.G. and Bray R.A., ed., Genetic Resources of Forage Plants. CSIRO, Melbourne, 39–46.

Falvey, L. 1979. Crude protein percentage of the diet and liveweight change of steers on improved pastures. The Journal of the Australian Institute of Agricultural Science, 45, 267–268.

Fitzpatrick, E.A., and Nix, H.A. 1970. The climatic factor in Australian grassland ecology. In: Moore, R.M., ed., Australian Grasslands. Canberra, Australian National University Press, 3–26.

Gardener, C.J., and McIvor, J.G. 1984. Characteristics associated with the colonising ability of introduced pasture species in the semi-arid tropics. Proceedings of the 2nd International Rangeland Congress.

Gutteridge, R.C. 1985. The productivity of native grasslands oversown with legumes and grazed at five stocking rates in Northeast Thailand. Journal of Agricultural Science, 104, 191–198.

Hacker, J.B. 1982. Selecting and breeding better quality grasses. In: Hacker, J.B. ed., Nutritional Limits to Animal Production from Pastures. Commonwealth Agricultural Bureaux, Farnham Royal, U.K., 305–326.

1985. Breeding tropical grasses for ease of vegetative propagation and for improved seed production. XVth International Grassland Congress, 1985, Kyoto, Japan. (in press).

In press. Selection for nutritive value in *Digitaria milanjiana* 1. Breeding of contrasting full-sib clones differing in leaf digestibility. Australian Journal of Experimental Agriculture.

Hunter, R.A., Siebert, B.D., and Breen, M.J. 1976. The botanical and chemical composition of the diet selected by steers grazing Townsville stylo-grass pastures during a period of liveweight gain. Proceedings of the Australian Society of Animal Production, 11, 457–60.

Ivory, D.A., and Siregar, M.E. 1984. Forage research in Indonesia: past and present. In: Asian Pastures. FFTC Book Series, 25, 12–27.

Ludlow, M.M., and Wilson, G.L. 1972. Photosynthesis of tropical pasture plants. 4. Basis and consequences of differences between grasses and legumes. Australian Journal of Biological Sciences, 25, 1133–1145.

Ludlow, M.M., Stobbs, T.H., Davis, R., and Charles-Edwards, D.A. 1982. Effect of sward structure of two tropical grasses with contrasting canopies on light distribution, net photosynthesis and size of bite harvested by grazing cattle. Australian Journal of Agricultural Research, 33, 187–201.

McIvor, J.G. 1978. The effect of cutting interval and associate grass species on the growth of *Stylosanthes* species near Ingham, north Queensland. Australian Journal of Experimental Agriculture and Animal Husbandry, 18, 546–53.

1981. Seasonal changes in the growth, dry matter distribution and herbage quality of three native grasses in northern Queensland. Australian Journal of Experimental Agriculture and Animal Husbandry, 21, 600–609.

1982. Agronomic potential of introduced grasses grown in north-east Queensland. CSIRO Division of Tropical Crops and Pastures Technical Memorandum No. 29.

1984a. Phosphorus requirements and responses of tropical pasture species: native and introduced grasses, and introduced legumes. Australian Journal of Experimental Agriculture and Animal Husbandry, 24, 370–78.

1984b. Leaf growth and senescence in *Urochloa mosambicensis* and *U. oligotricha* in a seasonally dry tropical environment. Australian Journal of Agricultural Research, 35, 177–87.

1985. The growth of *Urochloa* accessions in grazed swards with *Stylosanthes* near Townsville, north Queensland. Australian Journal of Experimental Agriculture, 25, 61–69.

Ng, T.T. 1972. Comparative responses of some tropical grasses to fertiliser nitrogen in Sarawak, E. Malaysia. Tropical Grasslands, 6, 229–236.

Norman, M.J.T. 1965. Seasonal performance of beef cattle on native pasture at Katherine, N.T. Australian Journal of Experimental Agriculture and Animal Husbandry, 5, 227–231.

Norman, M.J.T., and Stewart, G.A. 1967. Complementary

grazing of native pasture and standing Townsville lucerne in the dry season at Katherine, N.T. Australian Journal of Experimental Agriculture and Animal Husbandry, 7, 225–231.

Norton, B.W. 1982. Differences between species in forage quality. In: Hacker, J.B., ed., Nutritional Limits to Animal Production from Pastures. Commonwealth Agricultural Bureaux, Farnham Royal, U.K., 89–110.

Partridge, I.J. 1979. Improvement of Nadi Blue Grass (*Dichanthium caricosum*) pastures on hill land in Fiji with superphosphate and Siratro: effects of stocking rate on beef production and botanical composition. Tropical Grasslands, 13, 157–164.

Playne, M.J. 1972. Nutritional value of Townsville stylo (*Stylosanthes humilis*) and of speargrass (*Heteropogon contortus*) — dominant pastures fed to sheep. 1. The effect of plant maturity. Australian Journal of Experimental Agriculture and Animal Husbandry, 12, 365–372.

Raymond, W.F. 1969. The nutritive value of forage crops. Advances in Agronomy, 21, 1–108.

Tothill, J.C. 1978. Comparative aspects of the ecology of pastures. In: Wilson, John R., ed., Plant Relations in Pastures. CSIRO: Melbourne, 385–402.

Wan Mansoor, W.S. and Tan, K.H. 1982. Viability of sheep rearing under rubber. In: Jainudeen, M.R., and Omar, A.R., ed., Animal Production and Health in Tropics. Universiti Pertanian Malaysia, Serdang, Malaysia, 333–335.

Wan Zahari, M., and Devendra, C. 1985. The mineral status of indigenous swamp buffaloes, and Kedah-Kelantan cattle in Malaysia — A Survey Report. Mardi Report No. 101, (in press). MARDI, Serdang, Malaysia.

Williams, R.J., Burt, R.L., and Strickland, R.W. 1976. Plant Introduction. In: Tropical Pasture Research — Principles and Methods. Bull. Commonw. Bur. Past. Fld Crops No. 51, 77–100.

Wilson, J.R., and 't Mannetje, L. 1978. Senescence, digestibility and carbohydrate content of buffel grass and green panic leaves in swards. Australian Journal of Agricultural Research, 29, 503–516.

Performance of Germplasm in New Environments

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ONE of the major limitations to increased livestock production in the Southeast Asian and South Pacific region is the inadequate levels of high quality forage for feeding to ruminant animals. Many countries have therefore embarked on regional or national programs to identify superior forages for animal feeding, and to encourage their adoption and use by farmers.

In initiating a program to identify and introduce improved forages into new environments, an overall strategy has to be adopted at the outset. The strategy and methods used will depend on a number of factors, such as the availability of germplasm, the manpower, land, and financial resources and the overall objectives of the program.

The primary objective of forage plant evaluation is to identify forages, which under defined management can increase animal productivity when introduced into an existing farming system. In some instances the improvement of soil fertility and erosion control may be additional major objectives. There are, however, a large number of farming or grazing situations for which the superior forage may be required. Forage plants, when cut or grazed, may be used in the following ways: in intensive or extensive situations; cultivated or oversown situations; for integration with food or plantation crops; for variable levels of grazing management including overgrazed communal lands; for multipurpose use, such as tree legumes which can be used for forage, fuel wood, shade and shelter, and other innumerable situations. Thus, the purpose and situation for which the forage is to be used must be clearly defined when deciding on the strategy to be used in the evaluation program.

In this paper it is intended to consider all aspects of the evaluation process, from assembling the germplasm collection through evaluation procedures, data collection and performance evaluation, to the development of data bases for information exchange in genetic resources. However, individual programs may only utilise part of the various evaluation phases or procedures which are available.

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Collection and Assemblage of Germplasm

The number and range of species which will be included in a forage evaluation program will depend on the objectives of the program, the resources available and the availability of germplasm.

Choice of Genera and Species

The selection of an appropriate set of germplasm is critical to the whole program. The selection of inappropriate species, in relation to soils and climate, can completely jeopardise the success of the program. In programs where prior knowledge is available on species performance in a closely similar region to the target region, then germplasm selection can be more restrictive. Where there is little prior information, however, germplasm selection should include a much wider range of species whilst minimising the number of ecotypes within a species. More information is becoming available in databanks on species adaptation to soils and climate, and consultation should take place with institutions from which germplasm is obtained as to the selection of an appropriate range of species. If resources are very limited, efforts should concentrate on obtaining a collection of commercial cultivars and species which are already used in other tropical countries. Two sources of germplasm are available, viz., introductions from an overseas centre or from collection of indigenous species.

INTRODUCED GERMPLASM

Large germplasm collections of tropical grasses and legumes are held by a few research centres. These include the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia; Centro Internacional de Agricultura Tropical (CIAT), Colombia; and Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA), Brazil (R.J. Williams 1983). These centres are not only maintaining large germplasm collections of forage species but also have active programs of plant collection to further increase the diversity of the world genetic resources of forage species. These organisations are usually willing to give

advice in species selection and provide small seed lots for evaluation in countries of the Southeast Asian and South Pacific region. Currently, a proposal is under consideration to establish a pasture network in the region which will be sponsored by the Australian Development Assistance Bureau (ADAB) and Australian Centre for International Agricultural Research (ACIAR) in association with CSIRO. One of the functions of this network will be to supply germplasm for regional research programs.

In countries where there is a rich diversity of grass or legume species which have some potential as forage species or where native forage species are fed or grazed locally, it is desirable to include these indigenous species in the plant evaluation program. The capacity of an organisation, in terms of expertise, finances and seed storage facilities, to mount an extensive program of germplasm collection may however be limited in the Southeast Asian and South Pacific region. In general terms the Asian region has been underexplored for forage species, and the large genetic resources centres like CSIRO and CIAT are often willing to mount joint collection programs within a country. In 1982, for example, a joint plant collection trip (CSIRO/Indonesian Forage Research Project (FRP)) was undertaken in Sulawesi, Indonesia (Reid and Ivory 1983) and CIAT collaborated with government institutions in Thailand and Malaysia for a collection trip in which 387 legumes were collected (Pattanavibul and Schultze-Kraft 1985). CIAT is planning further collections in Indonesia, and the International Board for Plant Genetic Resources (IBPGR) has stationed a scientist in Indonesia to collect grass and legume species over a three-year period. The Southeast Asian area is of particular important as a rich source of species of *Pueraria* and *Desmodium* and genera closely related to *Desmodium*.

Various practical aspects of collecting tropical forage plants are given in the book of Clements and Cameron (1980) and by Reid and Strickland (1983). However, it is probably more expedient to use the large resources of the established genetic resource centres for collecting local germplasm than to undertake individual collection trips.

Where germplasm is introduced from overseas collections, efforts should be made to include any germplasm which has been collected from that country, or from adjacent regions with similar climates and soils, in the evaluation program.

Storage of Germplasm

It is important for any research group embarking on forage plant evaluation to have a suitable facility for seed storage. Ideally tropical forage seeds should be stored at a temperature of 0–5°C and 30–40% humidity (Harty 1980). For short-term storage, higher temperatures can be used but humidity needs to be controlled in tropical environments. The simplest storage method is to store seeds in paper packets in sealed tins, in which a desiccant such as silica gel is included, and place the tins in the bottom of a refrigerator. A more reliable method is to refrigerate seeds in individual lots in evacuated aluminium foil pouches, following seed drying in a desiccator.

Evaluation Procedures

The choice of evaluation procedures depends on the objectives of the evaluation program. Tropical forages, particularly legume species, have generally been found to exhibit narrow ranges of adaptation to soils and environments. In new environments a coordinated, systematic approach to evaluation has to be adopted. This necessitates a number of stages or phases in evaluation, to establish the suitability of the plant for improved animal performance.

Strategies of Evaluation

The overall objective of any evaluation program must be to select a species which is productive and persistent under cutting or grazing, and when fed as a single forage or in combination with other forages significantly increases animal production over that achieved with existing available forages. In addition, the forage species should produce adequate amounts of seed or be easily vegetatively propagated, where labour is not a limitation. A subsidiary objective of the evaluation program should be to gain some understanding of the reasons why particular accessions succeed or fail in different environments. These reasons may be related to phenological factors, such as flowering and seed production, insect and disease susceptibility, nutritional adaptation, the effectiveness of the *Rhizobium* symbiosis in the case of legumes, or edaphic factors. This information is vital to defining species adaptation, both on a regional and global basis.

Different research groups and individual researchers prefer different schemes of evaluation. However most follow the generalised scheme shown in Fig. 1. This scheme provides a systematic way of decreasing a large number of potential candidates down to a small elite group, with the possibility of recording a wide range of criteria associated with various aspects of species performance at different stages in the evaluation program. The same methodology can also be used in follow-up evaluation of further accessions of an elite species, where only one or two entries were examined in the original evaluation.
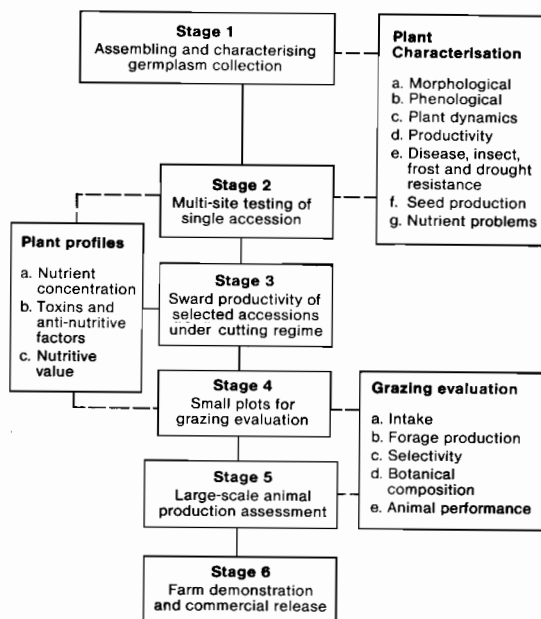
Stage 1
Assembling and characterising germplasm collection

Plant Characterisation
a. Morphological
b. Phenological
c. Plant dynamics
d. Productivity
e. Disease, insect, frost and drought resistance
f. Seed production
g. Nutrient problems

Stage 2
Multi-site testing of single accession

Plant profiles
a. Nutrient concentration
b. Toxins and anti-nutritive factors
c. Nutritive value

Stage 3
Sward productivity of selected accessions under cutting regime

Stage 4
Small plots for grazing evaluation

Grazing evaluation
a. Intake
b. Forage production
c. Selectivity
d. Botanical composition
e. Animal performance

Stage 5
Large-scale animal production assessment

Stage 6
Farm demonstration and commercial release

Fig. 1. General scheme for evaluation of forage species in a new environment.

In order to obtain a good appreciation of species adaptation within a region, the germplasm collection should be tested across major soils and climatic regions. The number of sites that are chosen will depend ultimately on seed supplies, and financial and manpower resources. While it is perhaps easy to recognise major soils, the definition of climatic zones is more difficult. Pattern analysis is one method which can be used to subdivide a region into homoclimates (Russell and Moore 1976). Priorities may have to be assigned to select a manageable number of sites which will maximise the information obtained in the accession × soil × climate interaction.

It is very important to characterise site factors in terms of soil physical and chemical properties and collect climatic information at or near each site during the evaluation program as well as the long-term historical averages.

Experimental Methodology

A wide range of methods has been used for forage evaluation depending on the objective of the program and the resources available.

Glasshouse Evaluation

In Stage 1 evaluation, where the objective is simply to describe the germplasm collection in morphological terms, to quantify the genetic variation within species

or to multiply seed, the accessions can be grown in pots of soil in the glasshouse. If the number of accessions of a particular species is larger than can be easily handled in field trials, all accessions can be grown in the glasshouse, and morphological and agronomic characters can be measured with a view to reducing the total species population to a few like-groups (Burt and Williams 1979). A few representatives of each group can then be used in field trials.

Glasshouse experiments are also useful for studying both the variation in mineral nutrition requirements within and between legume species and the variation in affinities between legume accessions and *Rhizobium* strains (Edye et al. 1974).

Nursery Evaluation

In Stage 2 evaluation the objective is to reduce a large number of plant accessions to a small group of superior species which have some potential for use as commercial forage plants. One of the simplest methods, in terms of time, is simply to broadcast the whole germplasm collection into a prepared seedbed or undisturbed native pasture area and return in two years time to determine the survivors and those accessions which have remained productive and dominant. While this method is very simple it depends on considerable skill in identification of the survivors, particularly if several accessions of the same species are included, and it provides minimum information on why certain accessions were successful or unsuccessful in that particular environment.

The more usual method is to plant seedlings as spaced plants in single or multiple rows or to sow seed in rows or small plots. The seed can be sown or broadcast on prepared or unprepared seedbeds, depending on the objectives of the evaluation. Planting established seedlings in the field is advantageous when seed supplies are very short but gives no information on potential difficulties with establishment from seed under variable environmental conditions in the field. When seed is used, two or three successive sowings may be required to obtain a satisfactory establishment in highly variable environments. Such an approach requires a lot of seed but gives good information on variation within and between species for ease of establishment.

In this preliminary testing phase, information can also be obtained on nutrient and *Rhizobium* requirements. For each accession, separate plots or rows can be included in the experimental design for fertilised and unfertilised treatments. Separate plots can also be included for seed which is inoculated with appropriate *Rhizobium* strains or uninoculated. After some time half of each of these plots can be fertilised

with 50 kg/ha of nitrogen to evaluate the effectiveness of the inoculum used or the effectiveness of native *Rhizobium* strains in the uninoculated legume plots.

The inclusion of these treatments requires larger amounts of seed, land and manpower resources but can provide valuable information at an early stage of assessment particularly where species are being sought for low-input, low-cost situations.

The management of plots in the nursery evaluation can be highly variable. However, in general terms plots are left uncut for a reasonable length of time after establishment, to quantify phenological development and seed production and to allow seeds to fall on the ground to measure subsequent seedling recruitment. In the second part of the nursery evaluation, plots can be cut several times to assess productivity and persistence under a regular defoliation regime. It is advisable to allow the nursery evaluation to proceed for at least two years, unless the environment is very uniform throughout the year, to provide some assurance of an accession's long-term production and persistence.

Small Sward Evaluation

In Stage 3 testing, the objective is to assess the productivity of a select group of accessions from site performance in Stage 2, under conditions similar to their final end use. This is usually done in small sward plots where the legume accessions are tested with one or two standard grasses, or grass accessions are tested with one or two standard legumes under prepared seedbed conditions. Legumes or grasses can also be oversown into native pasture where the objective is to improve native pasture. Tree legumes are usually planted out as seedlings on a square planting arrangement at a suitable density, or seed sown in rows between a sown or native grass. Often a variable cutting regime (frequency and intensity) is imposed so that an assessment can be made of the plant's response to varying degrees of grazing management (or mismanagement) or, in the case of plants grown for cut-and-carry situations, to obtain some indication of optimum cutting management strategies. Different fertiliser treatments can also be imposed at this stage, particularly the application of nitrogen to grasses which are to be used for cut-and-carry situations. These experiments should continue for at least two years in order to assess the longer term production potential of each accession. If there are large differences in performance between the first two years, the experiment should be continued for a longer period.

Forages which are being used specifically for cut-and-carry systems can then move directly into farmer demonstration trials and commercial release from this stage of the evaluation sequence, if optimum cutting and fertilising management has been defined.

Grazing Evaluation

Where species are required for use under grazing, two additional stages are often necessary, unless a single species is clearly superior. In such a case a species could move directly to Stage 5 evaluation. Stage 4 testing is designed to provide additional information on the productivity, persistence and intake of a small group of elite accessions under grazing. Because this stage requires larger areas of land, larger physical and financial resources and larger seed supplies, different methods of evaluation have been utilised to minimise costs and resources. One method is to sow individual swards of all accessions within one paddock and rotationally graze the replicate paddocks (Monzote et al. 1979). This minimises resources but provides for selective grazing of more palatable species, which in the end will result in the most palatable species being the last productive species and the least palatable species being the most productive. The alternative is to have separate small paddocks of individual accessions and rotate animals quickly from paddock to paddock at a reasonably high stocking rate (Jones et al. 1980). This method is more costly, and intake can be affected by grazing behaviour in the previous paddock, but with crossover designs or rerandomisation between replicates this method provides a more realistic method of assessment. An assessment of before and after presentation yields should be made before and after each grazing, with separation into botanical components in mixed grass/legume swards.

In Stage. 5 evaluation, only one or two of the promising species are compared with a currently recommended standard forage or commercial cultivar. The emphasis at this stage is on animal production and pasture stability, and therefore treatments usually include stocking rates and possibly fertiliser treatments in order to develop a commercial recommendation for farmers.

Stage 6 is the interface between the researcher, extension officer and the farmer. It also requires the development of a means to provide adequate supplies of seed for commercial use. The large-scale production of seed may become the responsibility of the government or commercial producers, or rely on the importation of seed from other countries if a market can be guaranteed. Farm demonstration of new forages is a good means of determining and encouraging the adoption and use of new commercial cultivars by farmers.

Data Collection and Performance Evaluation

There is no standard set of criteria which are used universally to assess the performance of forage plants in new environments. The criteria used vary with the

objectives of the evaluation program and the individual researcher. There would, however, be considerable advantage in having an international set of standardised criteria, as proposed by Myers et al. (1974), even if not all criteria were used in an individual evaluation program. This would have immeasurable benefit in comparing species performance across regions and countries.

Information which has been collected on aspects relevant to plant performance and feeding value to animals include phenological, morphological and agronomic criteria; effectiveness of *Rhizobium* symbiosis in legumes; mineral composition and nutritional deficiencies; plant digestibility, palatability and intake; and presence and amount of toxins or antinutrient factors.

Criteria for Assessment

PHENOLOGICAL CRITERIA

In Stages 1 and 2 evaluation there is an opportunity to measure variation in the length of the vegetative and reproductive phases of growth, dates of first flowering and duration of flowering period, seed development and seed production (Edye and Kiers 1966). Simple criteria can be used, such as presence or absence of flowering, immature seed or mature seed, and a simple rating scale for mature seed production.

MORPHOLOGICAL CRITERIA

It would be extremely difficult, if not impossible, to have a standard set of morphological criteria that would cover the range of attributes of interest for a diverse range of legumes and grasses. Measurements of morphological attributes are usually confined to Stage 1 or 2 testing, such as in a characterisation of a genus or species where large numbers of accessions are held. For example, Burt et al. (1971) have used morphological and agronomic attributes to group a large *Stylosanthes* collection into a limited number of like-groups for subsequent regional evaluation (Edye et al. 1985).

AGRONOMIC CRITERIA

Considerable variation is found in the agronomic attributes recorded in different evaluation programs. In Stage 1 or 2 evaluation a wide range of agronomic information can be collected (Burt and Williams 1979) whilst in Stage 3 evaluation, most emphasis is on yield (Edye 1967; Edye et al. 1975; Partridge 1979; Andrews and Gibson 1985; Gibson and Andrews 1985). The objective, however, should be to obtain enough agronomic information in Stage 2 and 3 testing to be confident of the success of selected accessions in terms of productivity, persistence and palatability under a cutting or grazing regime. Ranking procedures have

been successfully used to characterise many agronomic criteria in Stage 2 testing. I believe that the minimum amount of agronomic information should include criteria which quantify plant population dynamics, plant vigour and yield, resistance to pest and diseases, an index of leafiness, drought or frost resistance, as well as phenological criteria mentioned previously to describe plants' reproductive capacity (Ivory et al. 1985). The effectiveness of the *Rhizobium* symbiosis and response to fertilisers can also be scored on a relative ranking scale where treatments are included as described previously.

NUTRITIVE VALUE CRITERIA

The nutritive value of forages is determined by the level of intake, digestibility and chemical composition of the feed. The effect of these factors on animal production is dealt with in detail in other papers in this workshop.

Intake can be assessed indirectly by measurement of the difference between presentation yields before and after grazing during short periods of time, or directly by oesophageal fistulated animals during Stage 4 and 5 evaluation. Some assessment of comparative intake can also be obtained by feeding material produced in Stage 3 evaluation to penned animals (sheep or goats), providing plots are sufficiently large to produce enough material for several weeks feeding.

The presence of toxic or antinutritive substances can affect both intake and digestibility. A detailed review of toxins and methods of assessment is given by Hegarty et al. (these proceedings). Many genera or species containing toxic or antinutritive substances have, however, very desirable agronomic attributes. Often variation exists in the concentration of these substances in ecotypes or species. It is important, therefore, to measure the variation in concentration of specified substances in species or genera of good productive performance that are known to have toxic or antinutritive substances. In some species, however, which are known to be poorly eaten but have a good chemical composition, high in vitro digestibility and good production, antinutritive factors have not been identified. There is a need to identify such substances so that ecotypic variation in the concentrations of these antinutrient factors can be assessed.

Methods of measuring digestibility are given by Egan et al. in these proceedings. Plant digestibility can be measured at all stages of plant evaluation from small samples of forage either in nylon bags suspended in the rumen (Lowrey 1970) or laboratory methods involving the two-stage method (Tilley and Terry 1963) or the cellulase/pepsin enzyme method (McLeod and Minson 1978, 1980). Although intake is not simply related to digestibility, it provides a useful

criterion for eliminating species which have very low values. Proximate analyses which measure crude protein and neutral detergent fibre give valuable additional information.

In vivo digestibility can be measured from feeding trials in pens with goats or sheep.

Plant mineral concentration will vary with plant species, season and soil conditions. Where forages are being sought for use with little or no fertiliser input or on infertile soils, it is important to measure the inherent variation in efficiency of uptake of essential nutrients for plant and animal growth. These measurements will enable selection of species which have sufficiently high levels of essential nutrients for animal growth. Whether fertilisers or mineral supplements have to be used will depend on the economics of the biological response to fertiliser application by the forage plants.

There are no useful laboratory methods for measuring palatability. Palatability can be assessed simply by allowing animals free grazing in plots at the end of the Stage 2 testing and regular assessments made of species which are eaten or rejected. More resources are required to use preference feeding trials with penned animals. In Stage 4 and 5 testing in mixed grass/legume swards it is important to measure any differences in preference (palatability) between species at different times of the year. Such measurements have implications for grazing management, animal productivity and plant performance.

Methods of Information Collection

The most widely used method of recording plant performance information is manually into note books or on to standard information sheets. Manual methods are very cheap and easy to organise but suffer from the disadvantages that data are easily lost and the method is time consuming if information is to be subsequently transferred to a computer for analysis.

Small, low-cost computers are now available which can be carried into the field and used to record data in a standard format either on magnetic tape or in the random access memory. Subsequently, this information can be transferred to a larger memory via a magnetic tape reader or by direct interface through a RS 232 port on the computer. Such a system has been developed in Indonesia and is described by Ivory et al. (1985). Such a system minimises data handling time and allows the direct assembling of information into a data base, which can be interrogated or manipulated in a variety of ways to retrieve or analyse genetic resources information. Information management systems have been reviewed more fully by Clements and Bray (1980) and McMillan and Salhuana (1983).

Methods of Information Analysis

Much of the early evaluation of species performance was done on an ad hoc basis. Similarly the analysis of any information collected was used simply to support the intuitive assessment of relative species performance by the researcher. Where small plots were cut for yield or dry matter or for seed production, analyses of variance could be used in replicated experiments to determine statistical difference between accessions or species. If the data collected is numeric, basic statistical methods can be used. However where morphological, phenological and agronomic data are collected it is often a mixture of numeric, nominal, qualitative and ordered ordinal information. This is very difficult to analyse by conventional statistical methods. In recent years the development of pattern analysis programs has provided a useful means of summarising such information (Burt 1983; W.T. Williams 1983). Briefly, these methods allow the grouping of large numbers of accessions into similar groups in relation to the criteria measured in the evaluation process (Burt et al. 1971; Burt and Williams 1979) and can also provide a summary of the numeric values for each criterion assessed for each of the groups.

Potential Improvement of Evaluation Procedures

The widescale availability and adoption of computers has allowed quick and large-scale storage, manipulation, retrieval, analysis and transfer of data. This is potentially an enormous advantage to plant genetic resource evaluation where very large amounts of data can be collected.

While there have been considerable advances made in Australia on the use of computer programs for analysis of genetic resource information, this has not been widely adopted elsewhere, possibly because programs are complicated and are currently written for a large computer system. More widespread use of these programs could be made if programs were written for smaller main-frame computers and if there was training available for statisticians in countries of the Southeast Asian and South Pacific region in the use of these programs.

There has been less development of programs and systems for data acquisition, manipulation and interrogation of large genetic resource information bases. Such data management systems not only allow interrogation of data bases from individual sites but allow comparison within and between accessions for individual performance characters across sites and regions. Thus more valuable information can be

obtained on the adaptation of species both regionally and globally. The exchange of data between different research groups or organisations requires a compatability with other information storage systems.

In order to allow the comparison of evaluation data across sites and regions and therefore compare species adaptation in different environments, there is a need to standardise evaluation procedures, in terms of both methodology and assessment criteria. In the Central and South American region, CIAT has coordinated an international tropical pastures evaluation network with national research institutions in twelve countries (CIAT 1983). Four regional trials can be utilised in this network, which allow for the introduction, agronomic evaluation and evaluation-under-grazing of the most promising germplasm. The value of such a network is that testing is under standard procedures. If the regional pastures network for this region was established it would prove an ideal organisation to consider and initiate discussion and agreement on a suitable standardised system for the testing of forage germplasm in the Southeast Asian and South Pacific region.

The availability in recent years of a much wider range of germplasm, usually with only small quantities of seed of each accession, has led to the increasing adoption of the method of planting single rows of seed or spaced individual plants, with minimal replication rather than swards as a means of initially evaluating germplasm collections. This has proved a satisfactory method of evaluating large germplasm collections (> 100 accessions) in Kenya and Ethiopia (Ibrahim and Orodho 1981), Colombia (CIAT 1981) Australia (McIvor et al. 1982) and Indonesia (Ivory et al. 1985). This method should be adopted more widely in evaluating forage species for use in the Southeast Asian and South Pacific region, because it allows more widespread testing with limited seed supplies.

References

Andrews, A.C., and Gibson, T.A. 1985. Adaptation of improved pasture species in the highlands of northern Thailand. 2. The 800m zone. Trop. Grassl., 19, 17–24.

Burt, R.L. 1983. Observation, classification and description. In: McIvor J.G. and Bray R.A., ed. Genetic Resources of Forage Plants. CSIRO, Melbourne, Australia, 169–181.

Burt, R.L., and Williams W.T. 1979. Strategy of evaluation of a collection of tropical herbaceous legumes from Brazil and Venezuela. II. Evaluation in the quarantine glasshouse. Agro-Ecosystems, 5, 119–34.

Burt, R.L., Edye, L.A., Williams, W.T., Grof, B., and Nicholson, C.H.L. 1971. Numerical analysis of variation patterns in the genus *Stylosanthes* as an aid to plant introduction and assessment. Aust. J. Agric. Res., 22, 737–57.

CIAT 1981. Annual Report.

1983. Annual Report.

Clements, R.J. and Bray, R.A. 1980. In: Clements, R.J. and Cameron, D.G., ed. Information storage and retrieval in collecting and testing forage plants. CSIRO, Melbourne 52–70.

Clements, R.J. and Cameron, D.G., ed., 1980. Collecting and testing tropical forage plants. CSIRO, Melbourne, Australia.

Edye, L.A. 1967. Yield comparisons of thirty-eight introductions of *Glycine javanica* in swards in three environments. Aust. J. Exp. Agric. Anim. Husb., 7, 342–50.

Edye, L.A., and Kiers, H.J. 1966. Variation in maturity, stolon development and frost resistance of *Glycine javanica*. Aust. J. Exp. Agric. Anim. Husb., 6, 380–7.

Edye, L.A., Burt, R.L., Norris, D.O. and Williams, W.T. 1974. The symbiotic effectiveness and geographic origin, of morphological-agronomic groups of *Stylosanthes* accessions. Aust. J. Exp. Agric. Anim. Husb., 14, 349–57.

Edye, L.A., Williams, W.T., Anning, P., Holm, A. McR., Miller, C.P., Page, M.C., and Winter, W.H. 1975. Sward tests of some morphological-agronomic groups of *Stylosanthes* accessions in dry tropical environments. Aust. J. Agric. Res., 26, 481–96.

Gibson, T.A. and Andrews, A.C. 1985. Adaptation of improved pasture species in the highlands of northern Thailand 1. The 1200 to 1500 m zone. Trop. Grassl., 19, 10–17.

Harty, R.L. 1980. Seed technology: testing and storage. In: McIvor J.G. and Bray R.A., ed., Collecting and testing tropical forage plants. CSIRO, Melbourne, Australia, 1983, 102–113.

Ibrahim, K.M., and Orodho, A. 1981. Test adaptation and evaluation trials of forage plants in major ecological regions of Ethiopia and Kenya. Proceedings, XIV International Grassland Congress, Lexington, Kentucky, USA.

Ivory, D.A., Ella, A., Nulik, J., Salam, R., Siregar, M.E. and Yuhaeni, S. 1985. Assessment of agronomic performance of large numbers of plant accessions using a computerized data management system. XV International Grassland Congress, Japan, 1985 (in press).

Jones, R.M., Jones, R.J. and Hutton, E.M. 1980. A method of advanced stage evaluation of pasture species: a case study with bred lines of *Macroptilium atropurpureum*. Aust. J. Exp. Agric. Anim. Husb., 20, 703–9.

Lowrey, R.S. 1970. The nylon bag technique for the estimation of forage quality. Proc. Nat. Conf. Forage Qual. Eval. Util., Univ. Nebraska, 1969, p. 12.

McIvor, J.G., Williams, W.T., Anning, P., Clem, R.L., and Finlay, M.C. 1982. The performance of introduced grasses in seasonally dry tropical environments in northern Australia. Aust. J. Exp. Agric. Anim. Husb., 22, 373–81.

McLeod, M.N. and Minson, D.J. 1978. The accuracy of the pepsin-cellulase technique for estimating the dry matter digestibility *in vivo* of grasses and legumes. Anim. Feed Sci. Technol. , 3, 277–87.

1980. A note on Onozuka 3S cellulase as a replacement for Onozuka 5S (P1500) cellulase when estimating forage digestiblity *in vitro*. Anim. Feed Sci. Technol., 5, 247–50.

McMillan, C., and Salhuana, W. 1983. Information management systems for forage plant genetic resources. In: McIvor, J.G. and Bray, R.A. ed., Genetic resources of forage plants. CSIRO, Melbourne, Australia, 299–308.

Monzote, M., Funes, F., and Diaz, L.E. 1979. Comparison of *Panicum maximum* cultivar 2 under grazing conditions. Cuban J. Agric. Sci., 13, 93–99.

Myers, L.F., Lovett, J.V., and Walker, M.H. 1974. Screening of pasture plants: a proposal for standardising procedures. J. Aust. Inst. Agric. Sci., 40, 283–289.

Partridge, I.J. 1979. Evaluation of herbage species for hill land in the drier zones of Viti Levu, Fiji. Trop. Grassl., 13, 135–139.

Pattanavibul, S., and Schultze-Kraft, R. 1985. Collecting germplasm of *Desmodium* and *Pueraria phaseoloides* in Thailand and Peninsular Malaysia. XV International Grassland Congress, Japan, 1985 (in press).

Reid, R., and Ivory, D.A. 1983. Forage introduction for the northern tropics. CSIRO Div. Trop. Crops and Pastures Annual Report 1982–83, p. 19.

Reid, R., and Strickland, R.W. 1983. Forage plant collection in practice. In: McIvor, J.G. and Bray, R.A., ed., Genetic resources of forage plants. CSIRO, Melbourne, Australia.

Russell, J.S., and Moore, A.W. 1976. Classification of climatic data for Northern Australia. In: Williams W.T., ed., Pattern analysis in agricultural science. CSIRO/ Elsevier, Melbourne, Australia, 231–241.

Tilley, J.M.A. and Terry, R.A. 1963. A two-stage technique for the *in vitro* digestion of forage crops. J. Brit. Grassl. Soc., 18, 104–111.

Williams, R.J. 1983. Tropical legumes. In: McIvor J.G., and Bray R.A., ed. Genetic resources of forage plants. CSIRO, Melbourne, Australia. 17–31.

Williams, W.T. 1983. Analysis of plant evaluation data. In: McIvor J.G., and Bray R.A., ed., Genetic resources of forage plants. CSIRO, Melbourne, 293–298.

Forage Research Networking in Tropical Humid and Subhumid Environments

J.M. Toledo*

TOGETHER with recognition of plant–environment interactions and the concepts of stability and adaptability, the basic concepts of networking were developed in the agricultural sciences. Several statistical tools were developed to mathematically process data from multilocational series of experiments (Cochran 1937, 1954; Yates and Cochran 1938; Porter 1943; Yates 1954) and to analyse and assess the genotype–environment interactions (Finlay and Wilkinson 1963; Everhart and Russel 1966; Everitt 1974; Mungomery et al. 1974; Shorter et al. 1977).

During the last fifteen years, international research network systems have been actively developed by the Consultative Group for International Agricultural Research (CGIAR) international research centres with the aim of exposing germplasm to different environments and to scientists in national research programs. Several of these networks have also been very effective in establishing successful cooperation among and with national research programs. In addition to the germplasm-environment interaction information being generated, important economies of scale have been gained by participants, especially in methodology development, as well as in broadening the conceptual scope of the research process.

The relative success of several cooperative research systems has resulted in recent proliferation of many so-called 'networks', very often established only on paper without any follow up, or with only minor options for effective contribution to the societies of involved nations. Networks are in fashion; participants (nations, institutions, researchers) of these many, recently developed networks are in danger of entangling in a profuse web of inefficiency.

Several points to be considered in shaping and developing a pasture–forage research network within humid and subhumid ecosystems are discussed in this paper in an attempt to provide a guide for effective networking.

Ecosystems/Farming Systems Framework

The humid and subhumid zones of the world, with total mean rainfall above 1000 mm per year (Garnier 1958), occupy 73% of the tropical lands. Humid and subhumid regions occupy 93% (1450 million ha) of tropical America, 62% (1340 million ha) of Africa and 65% (832 million ha) of Southeast Asia and the South Pacific. Most of these vast tropical subhumid and humid zones of the world are covered predominantly by rainforests, woodlands, savannas and grasslands (Cochrane et al. 1985; Goodall 1983; UNESCO/UNEP/FAO 1978; Walter 1971; Myers 1980). The distribution of the humid and subhumid zones of the world is shown in Fig. 1.

Although the soils throughout this vast area of land are extremely variable, there is a predominance of highly weathered, leached soils (oxisols and ultisols) occupying 69% (2460 million ha) of the humid and subhumid zones of the tropics (Sánchez 1976).

The tropical American continent is the centre of diversity of most commercial tropical pasture–forage legumes, such as *Stylosanthes* spp., *Centrosema* spp., *Macroptilium* spp. and *Leucaena* spp., which have co-evolved with their specialised pests and diseases, creating high negative biotic pressures for these genera. Several important tropical pasture legume genera, including *Desmodium* and *Pueraria* spp., are native to tropical Asia. Several diseases and pests have been observed on these legumes in Asia, but definition of the importance of native biotic factors in this region requires further evaluation. On the other hand, the African continent is the centre of diversity of many important tropical pasture–forage grasses such as *Andropogon gayanus, Panicum maximum, Brachiaria* spp., *Cenchrus* spp., *Setaria* spp., *Pennisetum* spp. and *Hyparrhenia* spp. Specialised pathogens and pests of these grasses are generally restricted to Africa, and few pests and diseases have caused significant problems elsewhere.

Tropical America has the largest livestock resource with 202 million cattle and 56 million sheep. Africa has 141 million cattle and 198 million sheep, most of them in the border between the semiarid and subhumid

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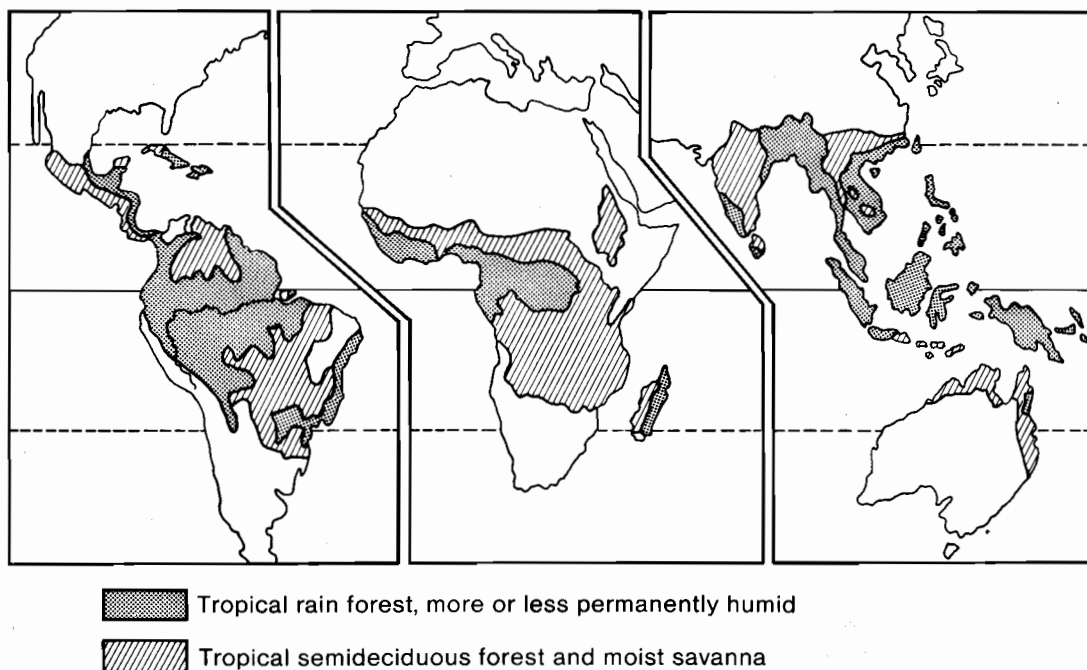
Fig. 1. Humid and subhumid regions of the tropical world. Adapted from Manshard 1974.

zones, due to high trypanosomiasis pressure in the equatorial humid and subhumid zones. Southeast Asia has relatively few cattle (25 million), mostly used as the working force in paddy rice and other crops (FAO 1983). Tropical America's animal production farming systems vary from the cow–calf extensive (0.1–0.15 head/ha) savanna utilisation in isolated areas to semi-intensive (0.5–2.0 head/ha) dual purpose (beef and milk) production systems in areas with better rainfall (humid areas) closer to infrastructure and markets. In Africa, although most of the extensive cattle are restricted to the savanna and semiarid zones, dwarf sheep and goats are commonly raised in humid regions in association with slash-burn farming systems. In Southeast Asia, cattle are mostly working animals in agricultural fields, grazing road sides, communal marginal lands and rice and crop stubbles, while large areas of extensively fire-managed *Imperata* grasslands in Philippines, Indonesia, Thailand and Malaysia are under-utilised. In contrast, highly intensive fattening systems using backyard pastures and ad libitum or force-feeding are common in certain areas of the Philippines (Jones et al. 1984).

The difference in importance of ruminant livestock production among regions of the world should first be recognised. The importance of differences in ecosystems and farming systems should also be recognised to effectively design and implement options and potential solutions for pasture–forages within the many combin-

ations of environmental factors, management and utilisation requirements in an extremely heterogeneous range of situations.

The Network Approach

Basic science does not require multi-effort and multilocational research. It is normally successfully conducted in advanced specialised institutions. Applied research, however, could strongly benefit from a network organisation and structure that would provide coverage, cooperative research effort and efficient exchange of information. Consequently, research networking should aim to help catalyse individual applied research efforts to be successful in their own immediate areas of influence, as well as to summate these efforts at the macro, national or regional level.

Pasture–Forage Research Networking

With the aim of developing a network for applied pasture–forage research, based on adapted plants, the whole of the research structure should be considered within a farming system perspective (Mateo and Li Pun 1983; Mares et al. 1984; Toledo et al. 1984; Biggs 1985; Vera and Sere 1985).

Fig. 2 shows a scheme for applied research in which the basic research components (BRC) such as germplasm, fertilisers, pesticides, machinery and tools, as well as natural and socioeconomic resources (NSR) such as land, climate, human resources, money,
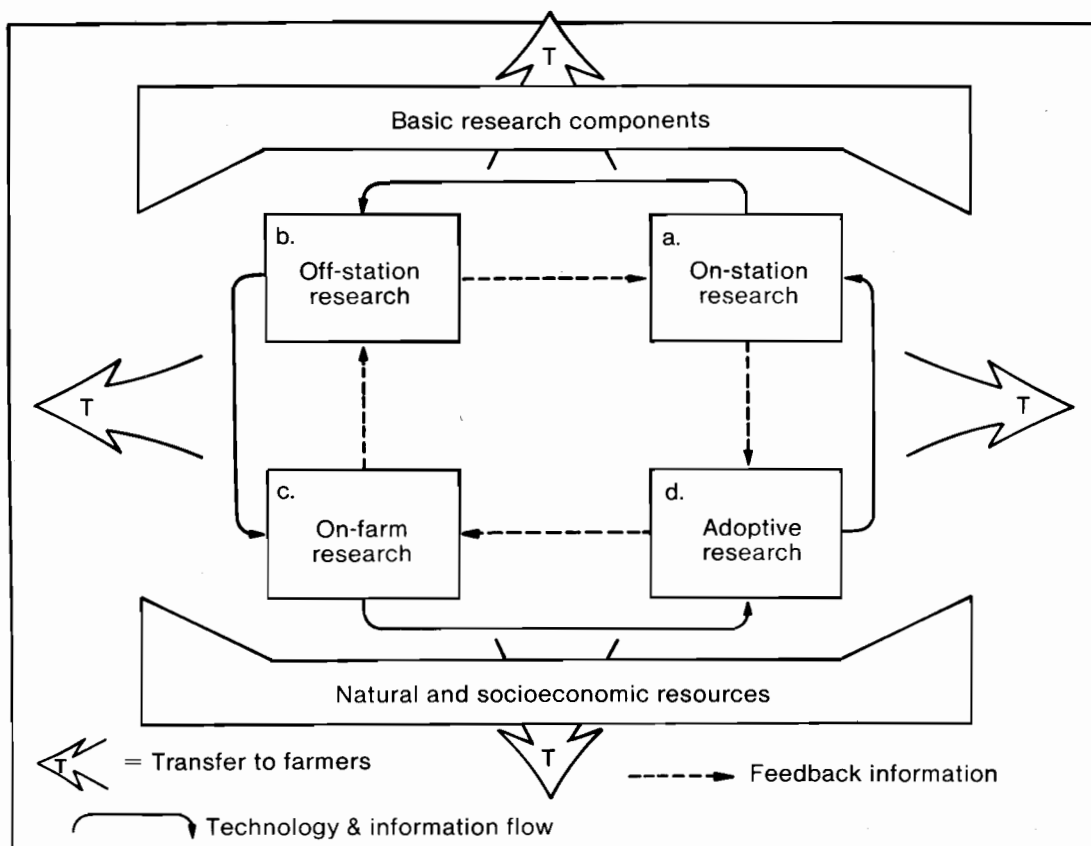
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Fig. 2. Applied research model and participants in the technology development: a. Researchers and extensionists; b. Researchers, extensionists and farmers; c. Extensionists farmers, researchers and developers; d. Developers, researchers and politicians. Adapted from Toledo et al. 1984.

markets, etc. are effectively utilised for technology development. The applied research effort links together the two kinds of available resources to modify and optimise through improved technology the existing production techniques at the farming system level.

The process of applied technology requires on-station research (ON-SR), essentially, factorial research to select from the BRC components that best suit the following research steps toward the target farming system. The selected components should be validated and adjusted under different environmental (soil, climatic, biotic) conditions through off-station research (OFF-SR). The latter is normally conducted in experimental and farmers' fields on a few representative sites. The successfully adapted plant materials together with management techniques should be then exposed to the farmers' management fields through on-farm research (OFR). This research step is particularly important in incorporating the farmer's mentality and capacity to adjust and adapt the new technology within his own natural and economic resources. Finally, adoptive research (AR) should be conducted at the

farmer (micro) and regional (macro) level to assess the adoption, success or failure of the new technology and its social and economic impact, providing important feedback to the research process as well as to national and regional decision makers. This applied research action should be as participative as possible, integrating researchers, extension workers, farmers, developers and politicians. This integrated approach naturally establishes communication channels down to farmers and up to decision makers.

This integrated applied research organisation is often difficult to implement at the institutional and field level; more so when recognising that the main actors, viz., researchers, extensionists and farmers, traditionally are not together in the technology development and transfer process. Networking could be an effective tool to help integrate international and national research efforts within continents and countries. In addition, networking at local levels could also be instrumental in providing the organisation for effective coverage (environmental conditions) and exposure of the new technology to farmers' fields. As
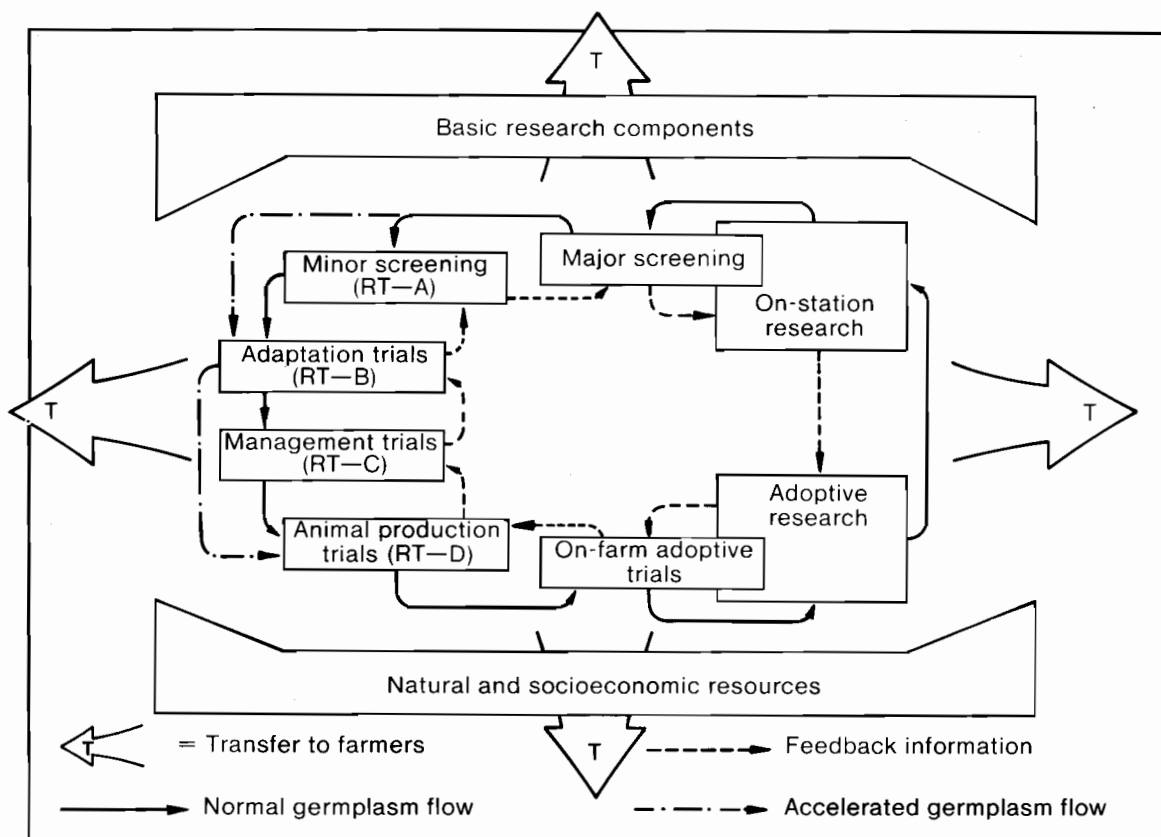
Fig. 3. The networking germplasm evaluation steps as part of the proposed applied research model. Adapted from Toledo et al. 1984.

an example, the steps of Regional Trials A, B, C, D, ... (RT-A, RT-B, RT-C, RT-D) implemented by the International Tropical Pastures Evaluation Network (RIEPT) in tropical America (Toledo 1982), are effectively used at regional and local levels to cover wide ranges of environmental conditions and to implement the new pasture–forage management technology to suit the resources and utilisation scheme at the farming system level. Fig. 3 shows how the minor germplasm screening trials (RT-A), the adaptation and seasonal dry matter productivity trials (RT-B), the grass legume compatibility under grazing management trials (RT-C), the pasture–forage animal productivity trials (RT-D), and the pasture–forage utilisation and productivity at farm level trials effectively cover the OFF-SR and OFR activities within the scheme for pasture–forage applied research (Toledo et al. 1984).

In advancing the environmentally-adapted selected materials into management and utilisation trials, it is very important to clearly define the pasture–forage needs of farmers. The characters to look for in the plants and the design of experiments to select the best pasture–forage plants should be adjusted accordingly.

The first two steps at the agronomic level, RT-A and RT-B, should be standard in evaluation methodology and experimental design, since they are the only means to assess germplasm adaptability to environmental, soil, climatic and biotic factors in several locations. However, after environmentally-adapted germplasm is selected, the experimental designs and methodologies of evaluation for the next steps (RT-C and RT-D) on management/productivity/persistence/utilisation should be carefully considered, clearly defining the range of potential utilisation and management of the pasture–forage in the target farming system. Fig. 4 relates the options of advanced pasture–forage evaluation with the range of intensification of pasture–forage utilisation at the target farm level. After a plant is selected for environmental adaptation, methods used to evaluate the management and productivity of the new pasture–forages often do not relate to the final farm utilisation. One case (X) could be the evaluation of pastures in a rotational and flexible grazing management, when the only alternative for utilisation and management at the farming (ranching) level is extensive and continuous grazing. Another case (Y) could
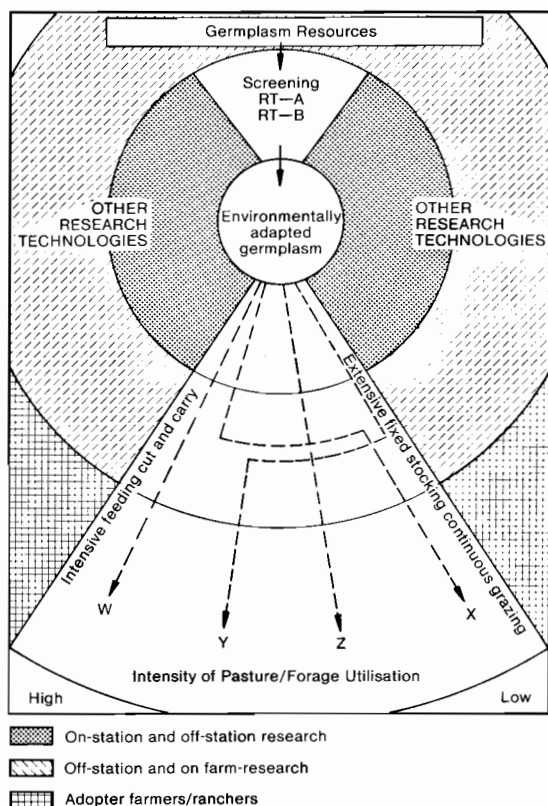
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Germplasm Resources

Screening
RT—A
RT—B

OTHER RESEARCH TECHNOLOGIES

Environmentally adapted germplasm

OTHER RESEARCH TECHNOLOGIES

Intensive feeding cut and carry

Extensive fixed stocking continuous grazing

W

X

Y

Z

Intensity of Pasture/Forage Utilisation

High   Low

▓ On-station and off-station research

▨ Off-station and on farm-research

▦ Adopter farmers/ranchers

Fig. 4. Alternative sequential activities of research on pasture–forage management and utilisation with environmentally adapted germplasm in a farming systems perspective. Adapted from Toledo 1983.

be when methods used to assess management requirements and pasture productivity under grazing are rigid continuous stocking, while target farmers are intensively grazing in a rotational flexible management system, perhaps including different sources of feed stuffs. The results of grazing and utilisation research conducted outside of the range of possible utilisation and management options at farmer-rancher level are irrelevant and often useless. When this happens, the common result is lack of adoption by farmers and/or technical or economic failure of the new technology in the hands of the producers. The straight lines (W and Z) are the ideal ones properly approaching the farmers and adjusting the evaluation methodologies under cut-and-carry or grazing, according to the needs of the farming system.

Networking within the applied research model has been in progress in tropical America since 1979, when RIEPT was organised among national and international pasture research institutions in the region. Since its formation, more than 40 national institutions from 15 countries have become actively involved in the

movement of pasture germplasm efficiently and effectively throughout more than 100 sites. Different germplasm has been selected for its adaptation in different ecosystems, including the llanos of Colombia and Venezuela, the cerrados of Brazil and the humid tropics. The value of *Andropogon gayanus* CIAT 621 as a productive tropical grass was confirmed across ecosystems, while *Brachiaria dictyoneura* CIAT 6133 was selected as highly promising in the llanos and humid tropics. *Stylosanthes capitata* CIAT 10280, together with accessions of *Centrosema macrocarpum*, *C. brasilianum* and *Centrosema* sp.n. have been identified as valuable productive legumes for the llanos. The value of *S. guianensis* var. *pauciflora* CIAT 2243 in the cerrados has been confirmed while *S. guianensis* CIAT 184, accessions of *C. macrocarpum* and *Zornia* spp. have been identified as highly promising in the humid tropics (Toledo et al. 1983; Pizarro 1983; Pizarro et al. 1985). Several of these materials have been released by national programs as commercial cultivars, while others are being advanced into off-station and on-farm grazing evaluation trials.

Pasture–Forage Networking Considerations

In thinking about the organisations, shape and technical structure of a pasture–forage research network for Southeast Asia or elsewhere, several concepts have to be clearly understood:

a) pastures and forages, unlike crops (cotton, corn, rice, beans, etc.), tend to be managed to optimise the use of available natural resources (native soil fertility, rainfall, solar radiation, etc.) under very low input systems, while crops tend to be under higher input management systems (fertilisers, irrigation, weed–diseases–pest control, etc.) to optimise the genetic yield potential of plants.

b) Adaptation to natural environmental soil, climate, and biotic (weeds–diseases–pests) factors is the key character of any pasture–forage plant with potential. Therefore, the wide range of environmental conditions existing in Southeast Asia and the humid and subhumid zones of the world should be recognised. The biotic factor is often the primary determinant of adaptability and stability of a pasture–forage plant. There are important examples of diseases such as anthracnose on *Stylosanthes* spp, *Rhizoctonia* on *Centrosema* spp., as well as pests such as spittlebug on *Brachiaria* spp. that have different importance among regions of the same continent, and more so among continents (Lenné et al. 1985; Calderón 1981). This emphasises the importance of exposing germplasm to as many different environments as possible, and of using a sufficiently broad and variable germplasm base to select material adapted to the specific set of

conditions in each region. The need for moving germplasm as small seed quantities versus large quantities of seed of finished cultivars probably minimises the risk of introduction of exotic pests and diseases. In any case, strict quarantine measures, should be taken during the movement of any seed. Multiplication of experimental and basic seed of promising germplasm should be the responsibility of the national networks.

c) The intensity of utilisation of pastures and forages varies, depending on local external factors such as price of land, density of human population, kind and numbers of animals and input/output price ratios in animal farming systems. Therefore, a good pasture or forage plant for a given farming system, environment and utilisation scheme could be useless and non-adoptable under different socioeconomic environments.

d) The participant national pasture–forage research programs and institutions have different relative importance to the governments and societies whom they serve. The financial support they receive from their respective countries also varies in time and space within a country. These differences in support normally reflect the importance of pastures and ruminant animal production as sources of food and economic growth for the societies involved. On the other hand, technically and financially weak research programs could easily be engaged in irrelevant or poorly oriented research and/or development programs when foreign financial support is offered and made available. The important role of national scientists in defining the orientation and priorities of their own research program should be recognised. Foreign technical advice and financial support should help to enrich the capacity of national programs to effectively meet their goals.

e) Strong and defined common interests should be the basic driving force of a research network. In the case of pasture–forage research, the points of common interest may be germplasm, exchange of information and methodological adjustment and development. In all cases, national research programs are in a hurry and dependent on practical results that will effectively impact on the productivity and economy of farmers. The capacity to respond in time and space to the needs of the different regions and nations involved should be an integral part of the network organisation. This is effectively achieved by including in the management and coordination of the network an advisory committee made up of, for example, national pasture–forage network leaders. This committee in RIEPT meets once a year to review progress, and define methodologies and priorities for the future.

One of the most critical functions in networking is communication. Effective communication mechanisms should be established within the countries to integrate different institutions and disciplines in forages and ruminant production. This is essential for effective international operation of the network. In the RIEPT these mechanisms are a technical bulletin that contains research articles and notes reporting results of the research activities, and a centralised data base for processing and exchange of research results. Annual national meetings are encouraged. Every three years all the participants of the international network meet to exchange information directly. Technical training of young scientists is an important function of a network.

In short, networking could play an extremely important role in catalysing regional forage research activities. An active and effective pasture–forage research network should clearly recognise the role of national scientists and institutions. The points of common interest, such as sufficient germplasm to be multilocationally screened (using a low input approach and simple, reliable and relevant methodologies for selection and advancement of germplasm) must be identified in order to move new, successful pasture–forage options to farmers.

References

Biggs, S.D. 1985. A farming system approach: some unanswered questions. Agricultural Administration. England. 18, 1–12.

Calderon, M.C. 1981. Insect pests of tropical forage plants in South America. In: Proceedings of the XIV International Grassland Congress. Lexington, Kentucky, USA. 778–780.

Cochrane, T.T., Sanchez, L.G., De Azevedo, L.G., Porras, J.A., and Garver, C.L. 1985. Land in tropical America: Vol. I. A guide to climate, landscapes and soils for agronomists in Amazonia, the Andean piedmont, Central Brazil and Orinoco. CIAT-EMBRAPA. Cali, Colombia. (In press).

Cochran, W.G. 1937. Problems arising in the analysis of a series of similar experiments. Jour. Roy. Stat. Soc. Suppl., 4, 102–118.

1954. The combination of estimates from different experiments. Biometrics 10, 101–129.

Everhart, S.A., and Russel, W.A. 1966. Stability parameters for comparing varieties. Crop Science, 36–40.

Everitt, B. 1974. Cluster analysis. Social Science Research Council, London, 122 p.

Finlay, K.W. and Wilkinson, G.N. 1963. The analysis of adaptation in a plant breeding programme. Aust. J. Agric. Res., 14, 742–754.

Food and Agriculture Organisation 1983. FAO Production Yearbook. Rome, Italy. Vol. 37, 320 p.

Garnier, B.J. 1958. Some comments on defining the humid tropics. IITA, Research notes, 2, Ibadan, Nigeria, 9–25.

Goodall, D.W. 1983. Ecosystems of the World. Elsevier Scientific Publishing Co., New York.

Jones, R.M., Tothill, J.C., and Jones, R.J. 1984. Pastures

and pasture management in the tropics and subtropics. Tropical Grassland Society of Australia. Occasional Publication No. 1, 73 p.

Lenné, J.M., Pizarro, E.A. and Toledo, J.M. 1985. Importance of diseases as constraints to pasture legume adaptation in the tropical American lowlands. In: Proceedings of the XV International Grassland Congress, Kyoto, Japan (in press).

Manshard, W. 1974. Tropical Agriculture: A geographical introduction and appraisal. London, Longman. 226 p.

Mares, V., Vera, R.R. and Li Pun, H.H. 1984. La evaluación de pasturas mediante experimentos de pastoreo y su relación con los sistemas de producción animal. In: Metodologías de Evaluación de Pasturas con Animales. CIAT, Cali, Colombia (in press).

Mateo, N., and Li Pun, H.H. 1983. Farming Systems Research Networks in Selected Latin American Countries. Paper presented at the farming systems symposium. Kansas State University. Manhattan, Kansas, Oct. 31st–Nov. 2nd, 1983.

Mungomery, V.E., Shorter, R., and Byth, D.E. 1974. Genotype × environment interactions and environmental adaptation. I. Pattern Analysis. Application to soybean populations. Aust. J. Agric. Res., 25(1), 59–72.

Myers, N. 1980. Conversion of tropical moist forests. Nat. Acad. of Sciences, Washington, D.C. 205 p.

Pizarro, E.A., ed. 1983. Red Internacional de Evaluación de Pastos Tropicales: Resultados 1979–1982. CIAT, Colombia. 460 p.

Pizarro, E.A., Toledo, J.M. and Amezquita, M.C. 1985. Adaptation of grasses and legumes to the humid tropics of America. In: Proceedings of XV International Grassland Congress, Kyoto, Japan (in press).

Porter, R.H. 1943. Cooperative Soybean Seed Treatment Trials, Iowa State University, Seed Laboratory.

Sánchez, P.A. 1976. Properties and Management of Soils in the Tropics. John Wiley and Sons. USA. 618 p.

Shorter, R., Byth, D.E. and Mungomery, V.E. 1977. Genotype × environment interactions and environmental adaptation. II. Assessment of environmental contributions. Aust. J. Agric. Res., 28(3), 223–235.

Toledo, J.M. 1982. Manual para la evaluación Agronómica. Red Internacional de Evaluación de Pastos Tropicales. CIAT, Cali, Colombia. 168 p.

1983. Ensamblaje de germoplasma en pasturas: problemática de experimentación. In: Paladines, O., y Lascano, C., ed., Germoplasma Forrajero bajo Pastoreo en Pequeñas Parcelas: Metodologías de Evaluación. CIAT, Cali, Colombia, 1–10.

Toledo, J.M., Amezquita, M.C. and Pizarro, E.A. 1983. Análisis del comportamiento del germoplasma evaluado por la RIEPT en los ecosistemas de sabana y bosque tropical. In: Pizarro, E.A., ed., RIEPT: Resultados 1979–82. CIAT, Colombia, 429–447.

Toledo, J.M., Li Pun, H.H. and Pizarro, E.A. 1984. The Network approach in pasture research. Tropical American experience. Paper presented at the S.E. African Workshop on Tropical Pastures. Zimbabwe, Sept. 17–21, 1984. IDRC, Canada (in press).

UNESCO/UNEP/FAO. 1978. Tropical forest ecosystems. UNESCO. 683 p.

Vera, R.R., and Sere, C. 1985. Evaluation of tropical pasture species with a farming system perspective. In: Proceedings of the XV International Grassland Congress, Kyoto, Japan (in press).

Walter, H. 1971. Ecology of tropical and subtropical vegetation. Oliver and Boyd, Edinburgh. 539 p.

Yates, F., and Cochran, W.G. 1938. The analysis of groups of experiments. J. Agr. Sci., 28, 556–580.

Yates, F. 1954. The analysis of experiments containing different crop rotations. Biometrics, 10, 324–346.

The Main Varieties of Forages and their Evaluation in Southern China

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GUANGDONG province is located in the most southern part of China. Because the province is mostly a lowland plain and near the ocean, it has a subtropical season with seasonal tropical winds. The special features of the climate of Guangdong province are many sunny days, high temperatures and high rainfall, and a long rainy period. Although the rainfall is less during winter it can provide sufficient water for agricultural crops and for forage production.

The area of native grasslands in the Guangdong province is one million ha. This can be divided into two areas; tropical and subtropical. The tropical native grasslands spread along the southwest coast, and the hills and tablelands of the northern part of Hainan Island, central tableland and mountain area; subtropical native grasslands are found throughout the mainland area, but are considered to be inferior for use as fodder.

Examples of native grasses which can be used to feed animals are *Eremochloa ciliaris* (L.) Beauv., *Heteropogon contortus* (L.) Beauv., *Lachaemum indicum* (Houtt) Merr., *Miscanthus sinensis* (Anderss), *Miscanthus floridulus* (Labill), *Panicum repens* (L.) Warb., and *Cynodon dactylon* (L.) Pers. Normally the native grasses commence growth in the beginning to middle of March after the commencement of spring rains, reaching maximum production in summer. Seed can be harvested in the middle of October, and then pastures enter the dry and dormant stage. The yield of native pastures is between 3000–7500 kg FW/ha/year. If the bushy weed *Dicranoptenis linearis* (Butm.f) Underw. also grows with the native grasses, grass production is lower.

Introduction and Use of Improved Pasture Species

In order to increase animal production, many kinds of forage species were imported in the early 1950s, such as; *Panicum maximum* Jacq., *Pennisetum purpureum* Schumach., *Sorghum sudanense* (Piper)

Stapf., *Calopogonium mucunoides* Desv., *Centrosema pubescens* Benth., *Stylosanthes gracilis* H.B.K. (syn. *S. humilis*), etc. Recently, 300 forage species have been imported from Australia, England, USA, New Zealand, Thailand, Denmark, etc., in genera such as *Lolium, Dactylis, Paspalum, Panicum, Setaria, Cynodon, Chloris, Vigna, Phaseolus, Trifolium, Stylosanthes, Medicago, Desmodium* and *Leucaena*.

Table 1 lists the grasses and legumes introduced from Australia in June 1981. Of the grass species, carpet grass, Japanese millet, urochloa and kikuyu did not germinate, while sionau grass proved difficult to grow. *Leucaena* cv. Cunningham was easily the best legume of those introduced.

All species have been evaluated in small plots or demonstration areas before selection for intensive production. *Pennisetum purpureum* Schumach. has been cultivated in large areas, and several perennial

Table 1. Grasses and legumes introduced from Australia, June 1981.

Grass type	Legume type
Setaria anceps	Verano stylo
cv. Kazangula	Seca stylo
Cynodon dactylon	Hunter River lucerne
Carpet grass	*Lablab purpurens* cv. Rongai
Paspalum plicatulum	*Vigna sinensis* cv. Reeves
cv. Bryan	*Neonotonia wightii* cv. Tinaroo
Paspalum plicatulum	
cv. Rodds Bay	*Desmodium*, cv. Greenleaf
Sudan grass	*Desmodium*, cv. Silverleaf
Panicum maximum	Siratro
cv. Hamil	Graham stylo
Paspalum dilatatum	Cook stylo
Bahia grass	Endeavour stylo
Green panic	Townsville stylo
Samford Rhodes grass	*Centrosema pubescens*
Para grass	*Leucaena*, cv. Cunningham
Katherine millet	
Bioela buffel	
Gayndah buffel	
Paspalum broad-leaf	
Japanese millet	
Urochloa	
Sionau grass	
Molasses grass	
Kikuyu grass	

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tropical species introduced from Australia have been established for grazing. Some perennial temperate species, from genera such as *Lolium, Trifolium, Medicago, Dactylis* etc., are able to be planted during autumn and can grow normally during winter and spring. A small area of these species can yield around 25 000 kg FW/ha, but they have difficulty surviving summer because they are intolerant of high temperature and humidity, they have low seed production, and thus cannot be used for general purposes.

Forages for Cutting

Pennisetum purpureum came to the Guangdong province at the end of the 1950s. Now it is widely grown and is the most important feed for dairy cows. In some areas it is even used to feed rabbits and fishes. *P. purpureum* has a long stem, high regenerative characteristics, can be cut 4–8 times per year and at

each harvest can produce 30 000–45 000 kg FW/ha. Each year it can produce 150–300 t FW/ha, which is enough to feed 15 dairy cows. Its leaves and stems are soft and contain approximately 10.9% crude protein, and it is palatable to animals. Its root system is extensive, and so it can withstand drought and high summer temperatures. It is also able to overwinter, it can be cut regularly for 3–6 years, and is easy to establish and manage. Because of this it has become the most popular forage for dairy cows. Until now there is no other forage which is superior.

Not only is it used to feed dairy cows, but also to feed fish. Fish farmers in Sunte regency plant *Pennisetum* on the side of fish ponds, roadsides, the side of rice fields or anywhere there is unused land. It is cut and fed to the fish. In 1982, 1100 ha of *Pennisetum* was planted in the Sunte regency, giving a total yield of 600 t/ha/year at each harvest.

Forages for Grazing

Many forages available for grazing have been introduced from Australia. Mostly they are tropical or subtropical types which can survive for several years, such as molasses grass, paspalum, broadleaf paspalum, kikuyu, siratro and stylo, which are grown in several areas to improve the quality of native pastures that are normally used to feed grazing animals. The area sown to introduced species is now approximately 5000 ha. These introduced species have several advantages:

HIGH PRODUCTIVITY

In small experimental areas, grasses have produced 40-50 t FW/ha/year, (Table 2) and legume species, such as siratro and stylo have produced 20-30 t FW/ha/year (Table 3). By growing several good species together, yields of 15–35 t/ha/year can be obtained. Compared to the native pasture before improvement, this represents a significant 6.7–26 fold increase in yield.

Table 2. Tropical grass production

Grass type	Fresh grass yield (t/ha)		
	Year 1	Year 2	Year 3
Kazangula setaria	55.0	62.2	72.5
Paspalum broad-leaf	49.8	52.8	
Molasses grass	14.6	31.8	31.2
Samford Rhodes grass	25.6	29.0	16.4
Para grass	24.5	51.6	
Biloela buffel	15.3	21.0	12.8
Paspalum plicatulum cv. Bryan	48.3	60.6	
Paspalum dilatatum	31.9	58.8	
Bahia grass	37.2	48.8	
Hamil grass	64.5	80.0	
Green panic	49.0	69.7	
Gayndah buffel	17.3	29.6	
Cynodon dactylon	12.5		
Sudan grass	38.9		
Katherine millet	52.3		

Note: All species grow year-round, except Sudan grass, which is an annual.

Table 3. Tropical legume production

Legume type	Fresh legume yield (t/ha)			Remark
	Year 1	Year 2	Year 3	
Siratro	24.1	13.2	33.8	Grows year round
Centrosema pubescens	29.3	30.7	37.7	Grows year round
Seca stylo	24.5			Frost-sensitive
Graham stylo	31.6	22.1		Frost-tolerant
Cook stylo	33.8	25.1		Frost-tolerant
Endeavour stylo	35.6			Frost-sensitive
Verano stylo	37.4			Annuals
Townsville stylo	35.0			Annuals
Neonotonia wightii	7.5			Planted during autumn; still being assessed
Desmodium cv. Greenleaf	38.7			Planted during autumn; still being assessed
Desmodium cv. Silverleaf	48.7			Planted during autumn; still being assessed

Amongst the grasses, kikuyu is more palatable than molasses grass. Paspalum is not as palatable as others but is still superior to native species. Cattle like siratro and stylo the best.

GRAZING PERIOD EXTENDED

Native grass species begin seeding in early September, senesce in the middle of October and begin to grow again in the following March. They remain dormant for five months. Growth of improved pastures is also influenced, but the dormant period is at least one month shorter than for native pastures.

ADAPTATION

Several forage species grow well, give good seed production and high forage yields on Hainan Island. Plants are also well adapted in Southern Guangdong, but in the central region stylo, siratro and molasses grass are damaged by light frosts during winter, with partial or complete death of shoots. But in spring they regenerate and form a new sward. Leaves of paspalum species turn yellow during winter and have low cold resistance. The most cold-resistant species is *Setaria spacelata* cv. Kazungula. In the northern region, the winter season is much longer with lower temperatures, and although tropical species grow well in summer, their seed production is low and winter survival is generally poor in most species except *Setaria*.

Use of Native Pastures

The Animal Husbandry Research Institute in Guangdong Province has collected and evaluated native forage species. Collection and investigation of forage plant species on Hainan Island commenced in 1980. From this initial testing, 30 grass species and 14 legume species were selected for further evaluation by the Research Institute, and two species which grew very well and had high yields were selected for wide-scale use, viz., *Alysicarpus vaginalis* and *Pennisetum polystachyon* (Linn) Schult. After testing for yield, digestibility and methods of planting, *P. polystachyon* was further tested in regional trials.

Alysicarpus vaginalis var. *diversifolius* This is an annual herbaceous legume, belonging to the family Papilionaceae. It is an erect plant with many branches and with 2–3 cuttings per year has produced 26 250 kg FW/ha. The stem is soft with light green leaves. The foliage is nutritious and suitable for feeding to cattle and rabbits. It has the following nutritive composition in dry matter:

7.5% moisture, 15.7% crude protein, 3.6% ether extract, 35.7% nitrogen free extract, 29% crude fibre, 9.2% ash, 0.95% calcium and 2.9% phosphorus. In

the feeding study the digestible crude protein was 79%. The value of digestible crude protein is similar to lucerne. When fed to cattle no incidence of bloat was recorded.

Germination is good above 20°C. The growth of seedlings is slow. In mixtures with grass its growth is easily suppressed and it is difficult to establish. It grows well in light, acidic, sandy loam soils. It is observed that this species is planted in monoculture as a forage for cattle and rabbits.

Pennisetum polystachyon (Linn) Schult This species has a tufted growth habit, forming clumps. After three years of observation trials it has been shown that seedling growth is rapid and vigorous. Tillering ability is good. It can be grazed or cut 3–4 times a year. The stem is erect and thick with a height of 2–3 metres. The growth is vigorous and yields are high. In the Sisue Cattle Farm in Baisha district of Hainan Island, 10 hectares of this species have been planted. Fresh forage yield is 133 600 kg/ha/year. In Gaopo Demonstration Farm of Dongfang district, when this species was planted with equal rates of *Panicum maximum*, *Setaria* sp., *Chloris* sp, and *Paspalum* sp., there was a doubling of forage yield.

The palatability, nutrient content and digestibility of *P. polystachyon* is similar to *P. purpureum*. In 1984, 100 ha of *P. polystachyon* was planted in Guangdong province. It showed good adaptation, fair growth in general and was not very selective in respect to soil type. Seed production was comparatively high, with a seed yield (unprocessed) of about 600 kg/ha. The seeding rate for sowing is 6–8 kg/ha. Further studies on the utilisation of this species need to be carried out.

In regard to native forage species, there is a need to continue their collection and subsequent evaluation. In addition to selecting and the direct utilisation of promising native species their collection provides a valuable germplasm resource for future research.

Experimental research and extension activities, associated with native and introduced pastures in the Guangdong Province, have been jointly carried out by the Livestock Section of the Department of Agriculture of the Guangdong Province, the Department of Veterinary Science, Wah Nam Agricultural University and the Guangdong Provincial Livestock Research Institute. In addition, Wah Nam Botany Research Institute and the Biological Department of Wah Nam Teaching University also carry out some aspects of forage research.

Use of Cultivated Forages and Crop Residues

Most of the cattle farmers graze their livestock on public grazing lands, river banks, unused land, rice bunds and roadsides. Rice straw is dried and kept as

feed for the whole year. Sugar cane tops, maize stalks and sweet potato vines are also harvested to feed animals. Traditionally, there is no planting of pastures for animal feed. Cultivated forages are found around the dairy farms next to towns.

Besides the planting of 'elephant grass' as a major green forage for dairy farms, farmers also plant crops for silage. Where irrigation is available in rice growing areas, oats and wheat are planted in winter to solve the feed requirements of animals during spring and winter. Oats and wheat can be cut twice. Generally the fresh yield is around 30 000 kg/ha. Corn and sweet potato are good silage crops. Corn, when sufficiently manured and planted at an adequate density, with high input and optimum conditions gives 60 000 kg FW/ha of stems and leaves 70 days after planting. During summer and autumn, when growth is rapid, the leaves and stems of sweet potato can be cut several times and give high yields. In winter, the tubers can be harvested and stored or ensiled, and are an excellent source of feed.

In Guangdong Province, more than 20 000 ha are planted with sugar cane every year. During harvesting time in autumn and winter, the sugar cane tops, and by-products from the factory such as bagasse, which was previously burned as fuel, are now being assessed for silage making. The bagasse is being treated with salt and molasses additives.

Traditionally, rice fields are interplanted with vetch, *Astralagus sinicus*, as harvesting begins on the last crop of rice. This usually produces 15 000–30 000 kg FW/ha. The crop is used partly as a green feed for cattle and pigs, and partly as a green manure.

Future Research Emphasis

On the basis of past experience with native and introduced forages the following points can be made:

● Different regions of the Guangdong Province have different climates. The most suitable forage species must be selected for different areas. This is especially important for legumes species, and the system in which forages are to be used must be chosen carefully. Equal emphasis should be placed on the use of introduced and native species.

● A good mixture of forage species can not only increase yield and quality but also increase the productive life of the pasture. For this reason there is a need to further strengthen research and select suitable species mixtures.

● In the mountainous areas of Guangdong Province, temperatures are relatively low, and low rainfall occurs during winter, so that there is a longer period when the leaves of tropical species die back. It is necessary to select pasture species which can withstand cold and drought.

● At present the production of forage species is restricted by different degrees of damage by pests and diseases. The selection of forage species which are resistant to pests and diseases should received equal attention.

Forages in Indonesia

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THERE are 14.4 million agricultural holdings in Indonesia which are primarly concerned with crop production, but animals play an important economic and social role in the agriculture of the various areas. In 1982, there were 6.6 million cattle, 2.5 million buffalo, 7.9 million goats and 4.2 million sheep in Indonesia.

Sources of Forage for
Animal Production

Native Pastures

Livestock are fed on a range of native grasses, leaves of trees, farm wastes, by-products such as crop residues, and weeds or grasses under plantation crops. The amount of forage available is often very low and of poor quality.

Because of the agricultural green revolution and good irrigation practices, nearly all of the rice fields are occupied by crops throughout the year, with sometimes three crops a year. This increase in crop area and cropping intensity has meant that there are fewer opportunities for farmers to graze their livestock after harvesting rice, which was the common practice for village people who were not necessarily the rice producers. This is not a written regulation but a custom, and the effect has been a marked limiting of sources of forage for village people in intensive cropping areas.

The livestock in Indonesia, especially in Java, are primarily owned by the smallholder farmers. The size of the farm is very small (0.5–1.0 ha), so there is very little space to plant forages.

According to Schwaar (1973) there are approximately 21 million hectares of grassland area in various parts of Indonesia. This land is being used by villagers who normally free-graze their stock on native grasses and plants. The native grasses are the main feed source for livestock in the eastern part of Indonesia, especially Nusa Tenggara.

In Sumatra, Kalimantan and Sulawesi, *Imperata*

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cylindrica is the dominant species in most native grassland areas. There are about 6 million hectares of various plantation crops in Indonesia. The main plantation crops are rubber (2.3 million hectares) and coconuts (2.2 million hectares) (Harimurti and Martojo 1979), which grow in monospecific estates. In these plantations there is generally a range of high density native grasses and broad-leaved weeds. It is believed that plantation areas provide good prospects for livestock production if proper management systems can be devised.

Besides the above sources of forage, a wide range of leguminous and non-leguminous trees are used as sources of forage in Indonesia, and Nitis et al. (1980) reported various tree species that can be used for forage.

Cultivated Forages

The practice of growing forage crops is still in its infancy in Indonesia and is not practiced by a significant portion of the farming community. However the few existing examples, such as Lembang and Pangalengan and at the Citanduay River Basin Project, indicate that the cultivated forages *Pennisetum purpureum, Setaria splendida* and *Brachiaria brizantha* can contribute to dairy cattle, sheep and goat production. Cultivated improved forages are grown on a few commercial dairy farms and in some government schemes.

In various parts of the river basins in Java, farmers already plant improved grasses on the edge of the bench terraces. *Brachiaria brizantha* and *Setaria splendida* are the main species, and these are cut as a source of forage for their livestock.

In certain areas of teak forest in Java, the Indonesian Forest Company has interplanted trees with *Pennisetum purpureum* and a forage yield of 3.5 t/ha/year has been recorded (Narsum 1983).

Improved pastures have been introduced on government stations and to a limited extent on private land. To date the response from farmers to government schemes to encourage improved forage production has been focused on seed production.

The most commonly used species for cut-and-carry in Indonesia are *Pennisetum purpureum* (Elephant grass), *Brachiaria brizantha*, *Setaria splendida*, *Leucaena leucocephala* and *Gliricidia sepium*.

Past Evaluation of Native and Introduced Forage

Native Forages

There have been very few studies conducted in Indonesia where native forages have been evaluated. Bonnemaison (1961) has surveyed the botanical composition of savanna areas on the larger islands in the Nusa Tenggara region, and reported that the best grazing lands were dominated by the grasses *Paspalum* sp. and *Axonopus compressus*, with only a few legumes such as *Desmodium heterophyllum* being present. The tall savannas were dominated by *Themeda* sp., *Sorghum* sp., and *Heteropogon* sp.

In South Sulawesi, Prawiradiputra et al. (1979) reported the botanical composition of three grasslands and found that the dominant species were *Paspalum conjugatum* and *Axonopus compressus*.

Siregar (1972) reported that the main native species in Irian Jaya were *Andropogon acciculatus*, *Imperata cylindrica* and *Axonopus compressus*.

In Kalimantan, Sulawesi and Sumatra, *Imperata cylindrica* is the main species covering the open areas on the undulating terrain. All these areas are normally grazed heavily by cattle in the vicinity of the villages, but undergrazed away from the villages and in some areas occasionally burnt to stimulate early growth in the rainy season.

The introduction of improved species has been the major step in forage development in Indonesia, and many important forage species have already been introduced from Australia and other countries.

Introduced Forages

The evaluation of forage in Indonesia has been spasmodic, and since 1950 the emphasis has been on plant introduction and management practices, with very little co-ordination and lack of continuity. These evaluations have mainly been conducted by scientists from LPP (now BPT) and officers of Dinas Peternakan.

The effects of fertiliser, cutting height and cutting interval on forage production have been evaluated in a series of trials with a number of grasses, herbaceous legumes and tree legumes in West Java (Siregar 1985).

The productivity and erosion control capability of selected grasses and legumes in upland cropping systems of Java are being evaluated in the Citanduy River Basin in West Java as part of the Forage Research Project. During 1983/84, after eight regrowth periods over a 48-week period, *Brachiaria brizantha* (38.1 t DM/ha) gave 24% higher yields than *Setaria splendida* (Table 1).

Table 1. Annual dry matter yields (t/ha) of grasses and legumes grown on the risers of bench terraces in upland cropping systems of west Java.

Treatment	1983–84	1984–85
Brachiaria brizantha	38.10	22.49
Setaria splendida	30.70	11.63
Digitaria decumbens	19.22	—
Panicum maximum cv. Petrie	31.85	—
Centrosema pubescens	3.60	5.95
Stylosanthes guianensis cv. Cook	—	9.98

The production from *Setaria splendida* is lower than *Brachiaria brizantha* because growth is restricted in the dry season.

Vigna lutiola gave good initial yields but failed to persist. Productivity was low from *Trifolium semipilosum* and *Centrosema pubescens* persisted but gave low production. In the second phase of this experiment *Vigna lutiola* and *Trifolium semipilosum* were replaced by better adapted species of *Stylosanthes guianensis* cv. Cook and *Desmodium heterophyllum*, and productivity measures are still being made for these species.

Water runoff and soil loss measurement were made over two 6-week regrowth periods on selected treatments in 1983/84. Soil losses were found to be higher from the unplanted (control) risers (32.5 t/ha for 12 weeks) than from risers planted with *Brachiaria brizantha* and *Setaria splendida* (2.0 t/ha for 12 weeks).

Current and Future Research in Forage

Current Research

Forage research brings together the disciplines of plant collection and introduction, forage agronomy, forage nutritive value, rhizobiology and socioeconomic studies on forage. The Agrostology Section of BPT Ciawi has been given the national mandate for forage research in Indonesia and is assisted in this task by the UNE/ADAB (Australia) Forage Research Project (FRP).

The highlights of current research activities are summarised as follows:

● A collection of local plant species with forage potential has been undertaken in Sulawesi and Sumatra by the FRP. The International Board for Plant Genetic

Resources is also collecting native or naturalised forage grasses in many regions of Indonesia. The native species are being compared with a wide range of introductions of grasses, herbaceous legumes, and tree legumes from Australia and other countries.

• The nutrient limitations to forage production and means of amelioration of problem soils are being studied under glass-house and field conditions. At the present time considerable emphasis is being placed on tree legumes for use in intensive animal/cropping systems. Besides the evaluation of a wide range of tree legumes in regional nurseries, a multisite evaluation of forage production of the more promising tree species has been undertaken.

Most activities are concentrated in the lowland areas of Indonesia, but two activities are being undertaken in highland areas to examine the productivity of herbaceous legumes, tree legumes and grasses at higher altitudes. One project is concerned with the use of mixtures of forage grasses and legumes to provide high quality feed for ruminants and control soil erosion and run-off in upland cropping systems.

• An effective rhizobium–legume symbiosis is very important to forage production by legumes and to soil fertility improvement. The main activities of this program have concentrated on the collection of local strains and culturing, multiplication, preparation of *Rhizobium* strains for inoculum production, development of laboratory facilities and importation of *Rhizobium* strains from overseas for testing.

• The nutritive value and chemical composition of various forages in the plant introduction and evaluation programs is being measured in vitro and in vivo in selected experiments. Grazing experiments are being conducted in South Sulawesi and Sumba. In both locations, experiments are measuring animal productivity on native grasslands oversown with legume species and fertilised. In addition, one experiment is being conducted to examine the effects of using various supplements on liveweight gain and reproductive performance of young female cattle.

• Research has been undertaken to identify the biological, social and economic constraints to forage and animal production in Java and South Sulawesi. This will enable forage research programs to be problem-oriented. Data from existing reports on agroclimatology, soil surveys, land use and animal and human population density have been used in pattern analysis programs to subdivide Java and South Sulawesi into 'homologous' subregions which are likely to produce similar animal and forage production systems. It is hoped that subsequent surveys of these subregions will establish their particular biological,
social and economic constraints to forage and animal production.

Future Research

Increasing population pressure and decreasing farm size have meant that farmers must become more competitive and more efficient in the utilisation of natural resources to fulfil their needs. The more efficient utilisation of these resources can be facilitated by the development of appropriate new or improved technologies or new or improved plant and animal species. Any developments in this respect require high level research, carried out by research scientists who are attuned to the problems of small farmers.

Technologies and developments from this research must be simple, effective and inexpensive if they are to be implemented.

Future research programs to increase forage production and efficiency of animal production in Indonesia should include:

• co-ordination and extension of systematic collection and evaluation of plant genotypes adapted to specific soils, climates and production systems;

• production of forages to supplement crop residues, i.e. species capable of growing after the rice harvest or on unused land;

• evaluation of genotypes and production systems to integrate forages into plantation crops and for the stabilisation of erodable land;

• introduction of forage crops to rehabilitate degraded land and increase forage production;

• studies on seed production and establishment methods.

Such research requires a group of well trained forage scientists. The number of such scientists in Indonesia must be increased urgently if national needs are to be satisfied. This requires a training for existing researchers and a strengthening of university courses in forage science. In universities, the subject of forage science at present falls between the subject areas of animal husbandry and crop agronomy, which are taught in separate faculties. Thus, forage science is generally poorly serviced by both groups.

In addition, if research findings are to be implemented, strong links must be developed between research and extension agencies and farmers.

References

Bonnemaison, P. 1961. Report to the Government of Indonesia on grassland and fodder development. ETAP Report No. 1448, FAO, Rome.

Harimurti, and Martojo 1979. Possibility of integrating animals with plant crops in Indonesia. Proc., Seminar on Integration of Animals with Plantation Crops. Pulau Penang, 34–40.

Narsum 1983. Eksplorasi budidaya tanaman pakan dalam ekosistem hutan jati. Universitas Pajadjaran, Bandung.

Nitis, I.M., Lana, K., Sudana, I.B., Sutji, N., and Sarka, I.G.N. 1980. Survey data makanan ternak persediaan dan kebutuhan hijauan makanan ternak di Bali, FKH, UNUD, Denpasar.

Prawiradiputra, B.R., Siregar, M.E., and Manurung, T. 1979. Komposisi botanis padang rumput alam di tiga daerah penggembalaan di Sulawesi Selatan. Bull. L.P. Peternakan, 22, 1–17.

Schwaar, D.C. 1973. Land capability appraisal–land use appraisal. FAO, Bogor, Indonesia.

Siregar, M.E. 1972. Hasil survey inventarisasi forage dan pasture crops untuk pengembangan peternakan di Irian Barat. Laporan, LPP, Bogor.

    1985. Forage and pasture production in Indonesia. Trop. Agric. Res. Series No. 18, Japan.

Forages in Malaysia

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A SIGNIFICANT constraint to improved animal production in developing countries is efficient nutritional management. While breeding and selection are necessarily long term, immediate results can be achieved by feeding methods that will supply chosen feedstuffs in adequate amounts. At present, the ruminant population in Malaysia is generally fed on roadside forages and between rows in plantation crops, on by-products and sometimes on fodder supplements cut from rice fields, bunds and drains (Table 1). Few inputs are spent to improve forage or feed supply.

In the early seventies, exotic forages were introduced and evaluated for the development of large ranches. Currently there are 25 519 hectares of land cultivated with improved pastures mainly in government institutions (17 429 ha) and two commercial farms (8010 ha). At the same time, the greatest potential for increasing forage supply and animal production is from the interrow forages of tree crops such as rubber, oil palm and coconut estimated at 0.67 million hectares (Table 1). Research by the Rubber Research Institute of Malaysia and the Malaysian Agriculture Research and Development Institute has shown the feasibility and practicability of rearing ruminants on the natural pastures under rubber and oil palm. This paper presents the evaluation and role of forages in ruminant production in Malaysia on smallholdings of plantation crops and rice and on commercial livestock farms.

Forage Resources of Smallholdings

Natural pastures in Malaysia exist mainly under a variety of agricultural tree crops. Dry matter yield ranges from 3 to 7 t/ha/annum; under partial shade between tree crops, the productivity has been estimated at 5 t/ha/annum (Devendra 1982).

Feeding systems practised by the smallholders are classified as intensive, semi-intensive and extensive grazing. In the intensive system, the animals are stall-fed at all times from cut natural fodder plus concen-

trates. In the extensive grazing system the animals are let out to graze and no cut fodder is given, although some concentrates are provided in the evening. In the semi-intensive system, the animals have limited areas to graze and cut fodder is given at night (Hassan and Devendra 1982).

The pastures grazed are a mixture of native grasses and some leguminous cover crops of the plantations. The native grasses are mainly *Paspalum conjugatum*, *Axonopus compressus*, *Ischaemum muticum*, *I. timorense* and *Ottochloa nodosa*. The legumes are mainly *Centrosema pubescens*, *Pueraria phaseoloides* and *Calopogonium* spp. However, a small percentage of smallholders feed their animals with improved grasses, namely napier and para grass and to a lesser extent guinea, signal grass and *Digitaria* species from their home plots. Yusoff et al. (1982) found that grasses such as *Brachiaria mutica*, *Ottochloa nodosa* and *Paspalum conjugatum* grew well on rice bunds, roadsides and drains under cutting or grazing. Other weed species utilised are *Asystasia invisa*, *Mikania cordata*, *Ageratum conyzoides*, *Nephrolepis bisserata*, *Stenochlaena palustris* among others. The nutritive value of the herbage consumed by cattle and sheep is comparatively high but variable. Crude protein of grasses was measured at 6.7–11.4%.

Evaluation of Improved Forages

Forage evaluation was initiated by the Department of Agriculture, Malaysia in the early 1930s. From 1972 onwards, improved tropical grasses and legumes were introduced and evaluated for forage production on several different soil series (Wong et al. 1982).

The more productive grasses produced yields of up to 30 t dry matter/ha/annum under appropriate management and fertiliser inputs (Wong 1980). This is comparable to yields obtained in other tropical environments (Grof and Harding 1970; Edye 1975). The performance and chemical composition of the promising grasses at three different sites are given in Table 2. It should be noted that the sodium values are very low.

Liveweight gains from beef cattle grazing improved pastures range from 350 to 850 kg/ha/annum (Chen 1985).

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Table 1. Estimated availability of forages from natural pastures in Malaysia (1984).

Areas	Total area '000 ha	Area for ruminants %	Area for ruminants '000 ha	Dry matter production t/ha/y	Dry matter production '000 t/y	Contribution %
Rubber	1610[b]	25[a]	402.5	5	2012.5	42.1
Oil Palm	847	25[a]	211.8	5	1058.8	22.1
Coconut	246[b,c]	25[a]	61.5	4	258.3	5.4
Roadside verges	6[a]	100	6.3	7	44.1	0.9
Rice fields	377[b]					
bunds		2.5	9.4	7	65.8	1.4
fallow[d]		50.0	188.5	7	1319.5	27.6
Grazing reserves[e]	39	11	4.3	5	21.5	0.5

a. Devendra 1982.
b. Arshad Ayub 1982.
c. Ministry of Agriculture 1978.
d. Anuwar Mahmud and Yusof Basiron 1982.
e. Mustaffa 1982.

Table 2. Average mineral composition, nitrogen and crude protein (as % dry matter) of grasses evaluated at Serdang and/or Jalan Kebun.

Grass species	% Crude Protein	% N	% Ca	% P	% Mg	% K	% Na	% DMD
Brachiaria brizantha	10.8	1.73	0.26	0.16	0.18	1.41	0.02	56.9
Brachiaria decumbens	10.6	1.69	0.30	0.15	0.19	1.35	0.02	59.8
Brachiaria ruziziensis	11.6	1.86	0.31	0.16	0.20	1.80	0.02	60.7
Cynodon plectostachyus	10.9	1.74	0.16	0.14	0.10	1.46	0.02	50.5
Digitaria sp. H-10	10.7	1.71	0.37	0.17	0.23	1.55	0.02	61.9
Digitaria sp. X-125-1	11.5	1.84	0.38	0.14	0.23	1.61	0.04	63.6
Digitaria sp. X-46-2	11.1	1.77	0.36	0.16	0.22	1.51	0.03	60.6
Digitaria	11.1	1.78	0.27	0.15	0.21	1.55	0.06	59.3
Digitaria setivalva	11.0	1.76	0.39	0.15	0.26	1.54	0.03	63.3
Panicum maximum cv. Coloniao	12.9	2.07	0.29	0.16	0.18	1.63	0.02	53.7
Panicum maximum cv. Gori	10.5	1.68	0.23	0.13	0.14	1.25	0.02	52.3
Panicum maximum cv. Hamil	13.5	2.16	0.27	0.15	0.15	1.88	0.02	53.6
Panicum maximum cv. Sigor	13.4	2.15	0.26	0.14	0.18	1.69	0.03	54.3
Panicum maximum cv. Tanganyika	10.5	1.68	0.39	0.13	1.17	1.38	0.02	51.3
Paspalum dilatatum	12.3	1.97	0.29	0.18	0.24	1.75	0.03	54.9
Paspalum plicatulum cv. Rodd's Bay	11.1	1.78	0.43	0.13	0.25	1.55	0.02	51.5
Paspalum plicatulum cv. Hartley	11.1	1.78	0.44	0.13	0.25	1.50	0.02	50.8
Pennisetum purpureum cv. Local	11.1	1.77	0.41	0.36	1.02	0.62	—	62.5
Pennisetum purpureum cv. Uganda	10.3	1.65	0.51	0.50	1.13	0.77	—	64.1
Setaria sphacelata cv. Kazungula	11.7	1.88	0.25	0.15	0.22	1.79	0.08	61.7
Setaria sphacelata cv. Nandi	12.6	2.01	0.24	0.15	0.16	1.76	0.09	58.2
Setaria sphacelata var. *splendida*	12.4	1.99	0.21	0.15	0.21	1.73	0.06	59.7
Tripsacum laxum	9.6	1.54	0.35	0.25	0.84	0.44	—	55.5

Source: Wong 1980.

Generally, it can be concluded that *Pennisetum purpureum* (Napier), *Brachiaria decumbens, Panicum maximum* (guinea), *Setaria sphacelata* cv. Kazungula and *Digitaria setivalva* are the most vigorous, persistent and highly adapted species that can tolerate short dry periods. These species are commonly recommended for smallholdings and in commercial enterprises. Napier, guinea grass and *Digitaria setivalva* are normally recommended for well drained and fertile soils, while *Setaria sphacelata* cv. Kazungula and *Brachiaria decumbens* are well suited for well drained soils of lower fertility. For poorly drained soils, para grass is recommended and for sandy soils such as bris soil, *Digitaria pentzii* cv. slenderstem and pangola grass are recommended (Chen 1980).

The performance of introduced and local tropical

legumes indicates that the promising species are from the genera *Calopogonium, Centrosema, Desmodium, Leucaena, Pueraria, Stylosanthes* and *Zornia*. The failure of many other introduced species was due to poor growth and survival, severe pest and disease damage. The chemical composition of the promising legumes is given in Devendra (1979). Many legumes are very susceptible to defoliation and die out under frequent cutting or grazing (Wong and Mannetje 1981; Wong et al. 1982).

Centrosema pubescens cvs Local and Belalto are the most persistent legumes. They nodulate readily but yield is generally low as they are prone to severe leaf damage from *Epilachna indica* (ladybird beetle). *Calopogonium caeruleum* and *C. mucunoides* are widely grown in the interrow of rubber and oil palm. *C. caerruleum* is very shade tolerant and persists under rubber for 10–15 years. These two species were productive and persistent under cutting but unpalatable to stock (Wong 1982). Seed production was good for *C. mucunoides* but poor for *C. caeruleum*. Their potential as forage legumes remains much in doubt unless genotypes with better palatability can be identified.

Desmodium heterophyllum, D. triflorum and *D. ovalifolium* are the three species that can colonise and associate effectively with closely grazed or low growing grasses (Wong and Mannetje 1981; Wong 1982). They are moderately palatable and persistent but *D. heterophyllum* and *D. triflorum* had poor seed yield. *D. ovalifolium* was shown to be the most shade tolerant species producing 5 t dry matter/ha/annum (Chen and Othman 1984).

Pueraria phaseoloides is a more vigorous legume species which achieves good ground cover in a period of three months. It is highly palatable but does not persist under frequent close cutting, shading or heavy grazing (Eng et al. 1978). It is grown widely in the interrow of rubber and oil palm and its rapid growth at establishment makes it a potential pioneer legume.

Of the *Stylosanthes* species evaluated, *Stylosanthes guianensis* cultivars Schofield, Endeavour and Cook produced higher dry matter yields than the other species. Generally they did not persist long and died out three to five years after sowing. *Stylosanthes hamata* cv. Verano has persisted well on bris soils. Similarly *Zornia diphylla* is low-growing, flowers profusely and rapidly colonises bare areas. It appears suitable to sustain high grazing pressures.

Other genera such as *Glycine, Macroptilium, Aeschynomene, Medicago, Lotononis* and *Vigna* are unsuitable for legume forage production in the Malaysian environment because of their susceptibility to *Rhizoctonia solani* and other diseases.

Besides evaluation studies on forages, the potential of fodder shrubs such as *Leucaena, Cassava* and *Gliricidia maculata* has been evaluated. Research indicates that leucaena needs liming and *Rhizobium* inoculation for successful establishment and good growth on acidic soils (Tham et al. 1977). Dry matter yields of 13–22 t/ha/annum have been recorded from some of the promising leucaena accessions. Grazing studies with leucaena and grass pastures were promising, and liveweight gain of 400 g/head/day was obtained (Wong and Devendra 1983). However, *Brachiaria decumbens* is not recommended for goat grazing because of photosensitivity problems (Abas et al. 1983).

Forages in Plantation Crops

The areas of forages under plantation crops like rubber, oil palm and coconut are the most extensive and underutilised in Malaysia (Devendra 1982). In the planting of these crops, the wide interrow occupies more than 75% of the land and this vast area offers great potential for forage and pasture integration from the second year after establishment and until the canopy closes. The integrated use of such extensive areas under plantations would make a considerable contribution towards the need for livestock products, maximisation of land use and intensification of agricultural diversification.

In the first two years, it is recommended that maize, groundnut, bananas and vegetables or leguminous cover crops, such as *Calopogonium caeruleum, C. mucunoides, Centrosema pubescens, Mucuna cochinchinensis, P. phaseoloides* and *D. ovalifolium* are interplanted. These legume cover crops are good forage resources for ruminants (Chee and Devendra 1981). However, due to either physical, economical or social constraints, these agronomic practices are not usually undertaken by smallholders and thus the interrows are invaded by weeds. With canopy closure and the increasing shade the leguminous covers disappeared. Thus under mature rubber, the interrow is bare or occupied by shade tolerant grasses or other forms of undergrowth. Investigations by Wan Mohamad (1977) showed that 60–70% of the ground vegetation on rubber plantations was highly nutritious and could be utilised to support sheep rearing successfully without much supplementary feeding.

The ground vegetation can be broadly classified as grasses, broadleaved weeds, ferns and others. The grasses are *Axonopus compressus, Paspalum conjugatum, Ottochloa nodosa* and *Imperata cylindrica*. The weeds are *Mimosa pudica, Mikania cordata, Melastoma malabathricum* and *Eupatorium odoratum*. The ferns are *Nephrolepis biserrata, Gleichaenia linearis, Lygodium* spp. and others. The ground vegetation species *Imperata cylindrica, Melastoma malabathricum* and most ferns are not palatable. The

nutritive values of some of these weeds have been reported to be comparable to some of the cultivated grasses (Devendra 1979).

Chee and Devendra (1981) showed that in rubber areas, three systems of herbage cover were feasible under trees less than 3 years old (Table 3). System 1 was found in smallholdings of about 2 hectares while systems 2 and 3 were found in estates of more than 45 hectares of rubber trees. The vegetation under rubber trees can support goats and sheep. On the basis of 3% intake of dry matter on a body weight of 20 kg for indigenous sheep, the daily intake is 0.6 kg (Devendra 1976). Thus, it has been calculated that the carrying capacity is 2, 6 and 12 animals for systems 1, 2 and 3 respectively (Table 3), an increase of 3–6 times more animals, due to increased availability of feed from natural cover plus legumes and pure legumes respectively.

In the oil palm areas, Chen et al. (1978) found that similar plant species occurred and the vegetation can support cattle. Under oil palm, the available forage diminished rapidly during the third year from planting on both grazed and ungrazed plots. However, the cover at 27 months was 10 000–13 500 kg dry matter/ hectare, indicating the potential for earlier grazing by sheep. After a year's grazing at a stocking rate of 2 cattle/ha the cover was 2000 kg dry matter/ha (Chen and Othman 1983).

Conclusions

Most research emphasis in Malaysia has been directed to replacement of existing vegetation, but little improvement has been achieved in practice. Ashby (1941) suggested that grasses adapted to low fertility, such as *Axonopus* and *Ischaemum* species, would be more relevant as forages than high producing and high fertility demanding exotic grasses. Greater efforts should be made to collect more local pasture and legume species to fit into Malaysian farming systems.

However, the potential of grasses in the genera *Brachiaria, Cynodon, Digitaria, Panicum, Paspalum, Setaria* and legumes such as *D. ovalifolium, S. guianensis* needs further research and development. Legumes need to be incorporated to enhance the nutritional quality of herbage. In this respect when grasses are being planted, seeds of *D. ovalifolium* and *D. heterophyllum* should be included as these legumes can withstand competition from compatible grasses and, because of lower palatability to stock, will not be overutilised. Two other fodder shrubs with a potential for ruminant production are *Gliricidia sepium*, presently used as a shade tree for cocoa, and the rapidly growing forestry tree, *Acacia mangium*.

In Malaysia, the integration of forages into plantation crops has the greatest potential for the further expansion and development of the livestock industry.

Suggestions for future research are:
1. evaluation of plant genetic resources to attain more productive forage species for use in different farming systems;
2. evaluation of adaptive species to problem soils e.g. bris, peat and acid sulfate soils;
3. investigation of efficient use of fertilisers in mixed cropping systems including nutrient cycling in such systems;
4. identification of nutritional and disease problems influencing forage production;
5. economic analyses of the various production systems.

Table 3. Chemical composition of undergrowth in rubber plantations and some cultivated grasses

| Location | Herbage | Chemical composition (%) | | |
		Crude protein	Crude fat	Crude
Rubber smallholding[a]	Grasses	9.4	1.5	33.3
	Broad leaves	13.2	1.9	32.9
	Ferns	11.4	1.8	31.9
Rubber estate	Grasses	11.4	1.9	33.1
	Broadleaves	14.1	1.8	33.1
	Ferns	13.9	1.9	27.2
Cultivated grass[b]	*Panicum maximum*	12–16	—	31–33
(cut six weekly)	*Pennisetum purpureum*	15–18	—	26–30
	Brachiaria mutica	14–18	—	24–36

a. Wan Mohammad 1979.
b. Tan et al. 1973.

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References

Abas Mazni, O., Mohamad Khusahry, Y., and Sheik Omar, A.R. 1983. Jaundice and photosensitisation in indigenous sheep of Malaysia grazing on *Brachiaria decumbens*. Malaysian Veterinary Journal, 7, 254–263.

Anuwar Mahmud and Yusof Basiron 1982. The oil palm as a resource: current and prospective opportunities. Proceedings of the National Conference on Development of Resource-based Industries, 1982. Serdang, Malaysia.

Arshad Ayub 1982. Policy issues and implications for the future development of resource-based industries with special reference to agro-based industries. Proceedings of the National Conference on Development of Resource-based Industries, 1982, Serdang, Malaysia.

Ashby, H.K. 1941. Development of cattle grazing grounds in Kelantan. Malayan Agriculture Journal, 29, 399.

Chee, Y.K. and Devendra, C. 1981. The role of legumes and animals in the nitrogen cycling in rubber cultivation. Proceedings of Workshop Nitrogen Cycling in South-East Asian Wet Monsoonal Ecosystems. 5–10 November 1979. Chiang Mai, Thailand.

Chen, C.P. 1980. Feed Resource and Nutrition Branch Annual Report, Malaysian Agriculture Research and Development Institute, Malaysia.

1985. The research and development of pastures in Peninsular Malaysia. Tropical Agricultural Research Series No. 18. TARC, Ministry of Agriculture, Forestry and Fisheries, Japan.

Chen, C.P., and Bong, J.I. 1983. Performance of tropical forages under the closed canopy of the oil palm. I. Grasses. Malaysian Agriculture Research and Development Institute Research Bulletin, 12, 248–263.

Chen, C.P., Chang, K.C., Ajit, S.S. and Wahab, H. 1978. Pasture and animal production under five year old palm at Serdang. Proceedings of Seminar on Integration of Animals with Plantation Crops. Pulau Pinang, Malaysia.

Chen, C.P., and Othman, A. 1983. Effect of cattle production on forage under oil palm — a preliminary report. Proceedings of the Seventh Annual Conference, Society of Animal Production. Port Dickson, Malaysia.

1984. Performance of tropical forages under the closed canopy of the oil palm. II. Legumes. Malaysian Agriculture Research and Development Institute Research Bulletin, 12, 21–37.

Devendra, C. 1976. Goat production on small farms in South East Asia. Proceedings, Integration of Livestock with Goat Production at Small Farm Level. Food and Agriculture Organisation Expert Group Meeting on Livestock for Small Farms. Bangkok, Thailand, 176–210.

1979. Malaysian Feeding Stuff, Malaysian Agriculture Research and Development Institute, Malaysia.

1982. The feed requirements for animal production in Peninsular Malaysia: an assessment of the feed resources, implications and strategies for efficient utilisation. Proceedings of the Conference on Exotic and Crossbred Livestock Performance in Malaysia. September 11–12, 1981. Genting Highlands, Malaysia.

Devendra, C., and Chee, Y.K. 1980. The utilisation of pigeon pea (*Cajanus cajan*) by goats and sheep in Malaysia. Proceedings, International Symposium of Legumes in the Tropics: Serdang, Selangor, Malaysia. University of Agriculture, Malaysia, 1979.

Edye, L.A. 1975. A comparison of twenty-seven introduced grasses in two dry-tropical environments in Northern Queensland. Australian Experiment Agriculture and Animal Husbandry, 15, 788–94.

Eng, P.K., Kerridge, P.C., and 't Mannetje, L. 1978. Effect of phosphorus and stocking rate on pasture and animal production from a guinea–legume pasture in Johore, Malaysia. I. Dry matter yields, botanical and chemical composition. Tropical Grasslands, 12, 188–97.

Grof, B., and Harding, W.A.T. 1970. Dry matter yields and animal production of Guinea grass (*Panicum maximum*) on the humid tropical coast of North Queensland. Tropical Grasslands, 4, 85–95.

Hassan, W., and Devendra, C. 1982. An assessment of feed resources, feeding systems and problems concerning smallholder dairy cattle production in the milk collecting centre, Jasin, Malacca. Malaysian Agriculture Research and Development Institute Report 77.

Izham, A., and Hassan, A.W. 1982. Oversowing of pasture legumes into native pastures. Comparison of oversowing techniques. Malaysian Agriculture Research and Development Institute Research Bulletin, 10, 33–42.

Ministry of Agriculture 1978. Statistical Digest. Ministry of Agriculture, Kuala Lumpur.

Mustaffa, B.A. 1982. The livestock industry — its role in national development. Proceedings of the National Conference on Development-based Industries. Serdang, Malaysia.

Tan, H.T., Yeow, H.K. and Pillai, K.P. 1973. Potential pasture production and development. Proceedings of the Symposium on National Utilisation of Land Resources, Serdang, Malaysia.

Tham, K.C., Wong, C.C. and Ajit, S.S. 1977. Establishment of *Leucaena leucocephala* on the acidic inland soils of Peninsular Malaysia. I. Effects of lime, inoculation, pelleting and phosphorus on the establishment of *L. leucocephala*. Malaysian Agriculture Research and Development Institute Research Bulletin, 5, 10–20.

Wan Mohamad Bin Wan Embong 1977. Utilisation of ground vegetation in rubber plantations for animal rearing. Proceedings Rubber Research Institute Malaysia Planters' Conference, Kuala Lumpur, Malaysia, 265.

Wong, C.C. 1980. Productivity and chemical composition of twenty improved tropical grasses in the humid tropics. Malaysian Agriculture Research and Development Institute Research Bulletin, 8, 163–173.

1982. Evaluation of ten pasture legumes in mixture with grasses in the humid tropical environment. Malaysian Agricultural Research and Development Institute Research Bulletin, 10, 299–308.

Wong, C.C., Chan, C.P., and Ajit, S.S. 1982. A report on pastures and fodder introductions in MARDI. Malaysian Agriculture Research and Development Institute Report 70.

Wong, C.C., and Devendra, C. 1983. Research on leucaena forage production in Malaysia. Proceedings Leucaena Research in the Asian–Pacific Region. November 1982, Nitrogen Fixing Tree Association and International Development Research Centre, Singapore, 55–63.

Wong, C.C., and 't Mannetje, L. 1981. Productivity and compatability of pure grasses and legumes in Peninsular Malaysia. Malaysian Agriculture Research and Development Institute Research Bulletin, 9, 1–13.

Yusoff, M.A., Basary, M., Dahlan, I., Shukor, Y., and Rahim, A.H. 1982. Performance of Droughtmaster cattle under smallholder conditions. Proceedings, Conference on Exotic and Crossbred Livestock Performance in Malaysia. September 1981. Genting Highlands, Malaysia.

Forages in the South Pacific and Papua New Guinea

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Regional Description

COUNTRIES that will be considered in this paper are Papua New Guinea, Fiji, Solomon Islands, Vanuatu, and Western Samoa. All have significant cattle populations. They may be found between the latitudinal ranges of 5°N to 23°S, support a total population of about 4 million, occupy approximately 525 000 km² and are spread over 1200 islands (Ward and Proctor 1980). Papua New Guinea is the largest country, with 88% of the land area and 71% of the population.

This paper will briefly describe salient environmental features, as well as the development of the cattle industries in those countries. The objective is to identify the role of pasture improvement in the South Pacific physical and socioeconomic environment, to describe existing development activities and current research findings, and to make recommendations for future emphasis. We wish to acknowledge the contribution of I.J. Partridge, who contributed significantly to information on Fiji.

Geology and Soils

The countries being considered span the zone of interaction between the Indian and Pacific tectonic plates. Both historical and recent volcanic and earthquake activity have contributed to present landforms and geologic features from which the soils of the region have been derived (Ward and Proctor 1980). Common soils are those formed on uplifted coral reefs, but sometimes improved with deposits of volcanic ash. Soils formed on the older volcanic deposits are often steep and eroded or highly weathered, and therefore of limited fertility. Recent volcanic activity gives rise to very fertile soils such as occur on the southern Vanuatu island of Tanna. Fertile alluvial soils may be found on river deltas such as the Guadalcanal Plains in the Solomon Islands and on Viti Levu and Vanua Levu in Fiji.

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Steep dissected mountains of volcanic, metamorphic and sedimentary materials form the spine of Papua New Guinea and the Solomons, and in most Pacific countries render a large proportion of the land mass unsuitable for agriculture (Ward and Proctor 1980). Fiji has the highest proportion of land (32%) with slopes under 19° (Twyford and Wright 1965). Only Papua New Guinea has high altitude (1500–2000 m) intermontane basins supporting high human populations.

Climate

Temperature maxima and minima at coastal stations at low latitudes average 32/29°C in January and 29/23° in July. Further south, equivalent temperatures are 29/22°C and 25/18°C for January and July respectively (Ward and Proctor 1980). The main variations from these generally uniform temperatures occur at higher elevations, principally in Papua New Guinea. Pasture production will clearly be affected by temperature in these areas, but rainfall is generally the more significant climatic influence due to orographic and rainshadow effects. Extremely high rainfalls of 4500 mm/annum occur on the southern flanks of the central mountains of Papua New Guinea and Solomon Islands. In rain shadow areas, mainly on the north-western side of islands, precipitation may be as low as 1200 mm/annum, with water deficit occurring between the months of May and October. In wetter areas, heavy cloud cover significantly reduces radiation and pasture growth.

Livestock Industries

Background

Cattle, mainly dairy breeds, were first introduced into the South Pacific region by early settlers and missionaries late last century and early this century. Subsequently, cattle became important for weed control in expatriate-managed coconut plantations. The Second World War had a devastating effect on cattle numbers, particularly in Papua New Guinea and the Solomons, but numbers began to increase rapidly in these countries during the 1960s and 1970s with

government and international funding. Assistance was given, firstly to finance establishment of government-controlled nucleus cattle ranches, and secondly to promote indigenous smallholder ownership of cattle. The smallholders were assisted with cheap credit, training, subsidies, and supervision by enthusiastic expatriate extension officers. Historical development was somewhat different in Vanuatu, where cattle population increased through the efforts of private European ranch and plantation owners; and in Fiji where large numbers of cattle were owned by Indian cane farmers for draught purposes.

Present Cattle Numbers and Distribution

Present estimated cattle numbers are shown in Table 1. Fiji (156 000 head) and Papua New Guinea (153 000) have the highest beef cattle populations, followed by Vanuatu with 98 500. Approximately one third of these populations are held by indigenous smallholders. Government involvement in the cattle industries of most countries has meant that significant herd numbers are under government control.

In almost all cases, the present national cattle population represents a substantial shortfall on projected numbers following implementation of development plans in the 1970s. This may be attributed to a number of factors:

- indigenous smallholders had no prior experience with management of cattle with the result that their standards of animal husbandry and productivity were lower than expected;
- smallholders were encouraged into commercial cattle production too quickly and on too large a scale, and there was no opportunity for the industry to evolve and consolidate;
- many projects were located at great distance from potential markets, and sometimes on islands remote from abattoirs;
- it was difficult for buyers to achieve regular and

substantial numbers of cattle from smallholders, who tend to have many small herds in inaccessible areas;
- Brahman cattle obtained from government ranches were sometimes wild and difficult to control;
- there was social status attached to ownership of cattle, and farmers were sometimes reluctant to sell, i.e. they were not commercially oriented;
- land disputes which occurred over the ownership of customary land interfered with management;
- some smallholders encountered serious soil nutrient deficiencies which affected both pasture growth and animal nutrition.
- there was significant slaughter of breeding cows which finally had to be limited by legislation.

As a result, some smallholder projects were abandoned and many had loan repayment difficulties. Projects were poorly managed and overstocked, resulting in loss of improved pasture species and serious weed infestation. Smallholder numbers have therefore declined in Papua New Guinea and the Solomon Islands. Nevertheless, there have been impressive achievements when one considers that these countries have no history of large animal management. Experiences were somewhat different in Vanuatu where smallholders were able to obtain cattle from abandoned French estates in Espiritu Santo following independence; and in Fiji where many of the smallholders are Indian migrants.

Role and Importance of Pasture Improvement

Historically, establishment and management of productive improved pastures have not been given high priority by cattle owners in the region. Managers of the large plantations in the Solomon Islands and Vanuatu viewed cattle primarily for grass control under coconuts. Little attention was given to improved methods of husbandry or pasture improvement. Similarly, smallholders constrained by a range of economic, social, marketing and expertise limitations had neither the will nor the resources to seriously consider pasture improvement.

Government and aid donors, on the other hand, gave priority to pasture improvement, and supported substantial research programs in Papua New Guinea, Solomon Islands, Fiji and Western Samoa. Unfortunately, adoption of pasture technology by primary producers has been disappointing for the reasons given. However, the livestock industries in many countries are currently being consolidated, and increasing awareness of the importance of improved animal management and feeding will mean greater interest in pasture improvement in future. Currently, low level of adoption is the major problem in the Pacific, not inadequate research effort.

Table 1. Estimated cattle numbers in countries of the South Pacific, 1985.

| Country | National herd total | Distribution by sector | | |
		Government	Estate, plantation, mission	Smallholder
Fiji	156000	—	—	—
Papua New Guinea	153000	7500	96000	49500
Vanuatu	98500	500	66000	32000
Western Samoa	26300	9200	—	—
Solomon Islands	23000	6000	8400	8600

Forage Resources and Evaluation

Natural Grasslands

Extensive natural grasslands may be found in Papua New Guinea (5 million ha), Fiji (300 000 ha) (Ward and Proctor 1980) and to a lesser extent in the Solomon Islands (approximately 10 000–15 000 ha). Vanuatu and Western Samoa have only small areas. The principal species are kunai (*Imperata cylindrica*), kangaroo grass (*Themeda* sp.), and mission grass (*Pennisetum polystachyon*) and they are maintained by regular burning.

The grasslands are recognised as an important resource available for extensive low-cost feeding of cattle (Falvey 1981; Smith and Whiteman 1985a; Ward and Proctor 1980).

Limitations to the successful use of these grasslands are associated with low productivity, low digestibility (Holmes et al. 1980), susceptibility to overgrazing, and sometimes inadequate protein and mineral levels as found in the grasslands of the East Sepik region of Papua New Guinea. Susceptibility to overgrazing and therefore instability is their major problem. All three major species, but especially *Themeda* spp. are replaced by unwanted weeds when overgrazed (A.E. Charles 1975 pers. comm.; I.J. Partridge pers. comm.; Smith and Whiteman 1985a). M. Raurela (unpublished data) found that degraded *Themeda* grasslands in the Markham Valley of Papua New Guinea did not recover after a three-year rest period from grazing.

However, the grasslands have been successfuly improved, usually by oversowing *Stylosanthes* spp. following burning and application of appropriate fertiliser (Clancy 1972; Partridge 1977). In the Solomon Islands, Smith and Whiteman (1985a) recorded mean liveweight gains on the fertile Guadalcanal Plains of 0.38 kg/head/day or 273 kg/ha/annum over a two-year period from three stocking rates (1.3, 2.0 and 2.7 beasts (b)/ha), but the period of test was short and weeds such as *Sida* sp. and *Stachytarpheta* sp. were becoming a serious problem at the end of the trial. In addition, *Themeda* sp. was rapidly disappearing.

A significant development was the recognition by I.J. Partridge in Fiji (pers. comm.) that a stable grazing-tolerant grass species was of even higher priority than an adapted legume. He found that the introduction of Nadi blue grass (*Dicanthium caricosum*) into natural grasslands provided a stable base for grazing, despite its low productivity (Roberts 1970). Following consolidation of smallholder pastures by introduction of this grass, it was found that productivity could be improved by application of superphosphate to promote the growth of the naturally occurring legume hetero (*Desmodium heterophyllym*).

This has become the development strategy for the Yalavou project in Fiji. A similar experience was noted in Papua New Guinea when *Dicanthium annulatum* was inadvertently introduced to the Markham Valley where it began spreading naturally under frequent defoliation. Work of Holmes (1981a) demonstrated moderate live weight gains (0.3 kg/head/day at 1.82 b/ha) but more importantly, the species supported continuous grazing for five years without deterioration. Its dense sward structure inhibited the ingress of the weed species *Sida cordifolia* and *Digitaria insularis*. Holmes concluded it was a persistent productive grass suited to simple management systems.

Pastures under Coconuts

The other major grazing resource in the Pacific region is pastures under the ubiquitous coconut plantations. Cattle ownership by smallholders is largely under coconuts (especially in the Solomon Islands, Vanuatu and Western Samoa), therefore programs designed to assist smallholders must direct their attention to this sector. The contribution of cattle to weed control, the lower pasture establishment costs, and the availability of cash from copra sales to offset the cost of setting up a small livestock enterprise, are special advantages of the coconut/cattle system.

In the Solomon Islands, Watson and Whiteman (1981a) measured average liveweight gains over three years of 0.34 kg/head/day and 292 kg/ha/annum at three stocking rates (1.5, 2.5 and 3.5 b/ha) on naturalised mat grass (*Axonopus compressus*), mimosa (*Mimosa pudica*) and centro (*Centrosema pubescens*) pastures under a coconut density of 175 palms/ha and light transmission of 60%. The improved sown species signal grass (*Brachiaria decumbens*), para grass (*B. mutica*), and koronivia grass (*B. humidicola*), did not persist at any stocking rate even when rotationally grazed (Smith and Whiteman 1985b). But the naturalised legumes centro and puero (*Pueraria phaseoloides*) remained productive.

Species evaluation (Reynolds 1978) and animal production studies have been conducted in Western Samoa and reviewed by R.C. Gutteridge (pers. comm.) who estimated liveweight gains on local pastures of mat grass and mimosa pastures under well spaced coconuts (light transmission >50%) at 180 kg/ha compared to 350 kg/ha on improved pastures (Cori grass (*Brachiaria miliiformis*), para grass and Batiki blue grass (*Ischaemum aristatum*) with centro and puero).

Unpalatable weed invasion is a major problem in frequently overgrazed smallholder pastures under coconuts. Weeds such as *Cassia tora*, *Stachytarpheta*, *Elephantopis*, *Psidium*, *Nephrolepis* and *Sida* are

common (Macfarlane and Shelton 1986, Litscher and Whiteman 1982).

As for the grassland areas, a simple robust and easy to manage pasture system is required for smallholders under coconuts, even if productivity is somewhat lower. Experience in Vanuatu has shown the value of buffalo grass (*Stenotaphrum secundatum*) for this purpose. It is shade-tolerant (Smith and Whiteman 1983), resistant to heavy grazing, and sufficiently vigorous to prevent ingress of unwanted weed species (Macfarlane and Shelton 1986). Work in the Solomon Islands showed vigorous growth under *Eucalyptus deglupta* (<40% light transmission) even when stocked at 3 b/ha; however, live weight gain was only 0.2 kg/head/day and this may be related to low digestibility. Chemical composition data indicated adequate supply of all essential minerals although sodium levels of 6000 ppm were high (Shelton 1984).

In Vanuatu, estimated liveweight gain on buffalo grass under old coconuts (>50% light transmission) was 175 kg LWG/ha/year (Macfarlane and Shelton 1986). However, many of the smallholder coconuts were extremely dense (>200 stems/ha) due to lack of a soundly based thinning policy and random establishment of new seedlings from fallen nuts. The heavy shading in these plantations precludes the establishment of more productive species and reduces the productivity of even buffalo grass.

A related topic is pastures under reafforestation. In the Solomon Islands, a grazing trial was commenced in 1978 to test the productivity and viability of improved pastures and cattle under *Eucalyptus deglupta* (initially 330 stems/ha) on Kolombangara Island. Para grass, signal grass, koronivia grass, batiki grass, centro and puero were grazed at three stocking rates (1, 2 and 3 b/ha). Data showed, with increasing age of trees, disappearance over five years of all sown grasses, invasion by the ubiquitous T grass (*Paspalum conjugatum*), and a slower decline in the sown legume component. Animal production similarly declined to one-fifth of the estimated productivity of unshaded pastures (495 kg/ha/annum) (Macfarlane and Whiteman 1983; Shelton 1984). This was associated with a fall in light transmission over five years to 30–40% of incident light. Thinning made little difference because of the capacity of *E. deglupta* to increase canopy size, and light profiles remained poor.

Fully Improved Unshaded Pastures

Highly productive, fully improved unshaded pastures are of greater relevance to large scale ranch style operations than to smallholders; these may be government-sponsored or privately managed. Many species evaluation cutting trials, to study adaptation of grasses and legumes, have been conducted in all countries and at sites with a range of soil and climatic conditions, especially in Papua New Guinea. We see little value in summarising these results; rather we will describe some successful experiences with commercial development of improved pastures in the Pacific region.

J.H. Schottler and the managers of the Cattle Under Trees Project in the Solomon Islands have developed an effective method of establishing open fully improved pastures. It involved felling of previously logged rainforest, followed by a good burn prior to the broadcast sowing of seed of the pasture species signal grass, puero and centro. Puero was the pioneer species and its vigorous early growth was essential to control regrowth. Subsequently, with grazing, signal and centro became dominant. No fertiliser was applied. However, legume content has declined, probably due to low available phosphorus levels (Shelton 1984); fertiliser application was uneconomic on this phosphorus-fixing volcanic soil. Short term liveweight gains were approximately 450 kg LWG/ha/annum at a stocking rate of 2.7 b/ha (unpublished data).

In Vanuatu, J. Earnst of Rentabao ranch has developed highly productive signal grass/glycine (*Neonotonia wightii*) pastures on fertile volcanic soils, following bulldozer clearing of rainforest. Macfarlane and Shelton (1986) estimated the productivity of those pastures at 525 kg LWG/ha/annum when stocked with growing cattle at 2.5 b/ha. In this case, *Sorghum almum* was used as a pioneer species to control regrowth and provide early grazing.

These data compare favourably with cattle liveweight gains on the Guadalcanal Plains of the Solomon Islands over four years. Mean animal production was higher on para grass/centro pastures (0.47 kg/head/day; 607 kg/ha/annum) than on signal grass/centro pastures (0.38 kg/head/day; 442 kg/ha/annum) both stocked at 3.6 b/ha (Watson and Whiteman 1981b).

Naturalised Legumes in the Pacific Region

The Pacific area has several naturalised leguminous species which have considerable potential for exploitation as fodder species.

Leucaena leucocephala occurs naturally, especially on limestone soils, throughout the Pacific. It colonises disturbed areas along roadsides and may form a dense thicket. The vegetation on Lelepa Island in Vanuatu is almost entirely leucaena. At present, its fodder value is not widely recognised and many people are concerned about its weed potential if widely used in pastures. Despite these concerns, some smallholders in Eastern Efate, Vanuatu, have fenced small areas of leucaena thicket and daily cut saplings so that their canopies can be fed to their cattle. Some of the best smallholder

cattle encountered in a recent Vanuatu pasture survey (Macfarlane and Shelton 1986) had leucaena in their diet. Plucked leaf material showed higher protein and phosphorus concentrations than other legumes sampled (e.g. from Lelepa Island — 5.85% N and 0.42% P).

Elsewhere in the Pacific, Partridge and Ranacou (1974) found it to be an excellent supplement to Nadi blue grass; liveweight gains were more than doubled when cattle had access to 20% leucaena on a grazed area basis. However, in Papua New Guinea Holmes (1981b) found that when leucaena grew vigorously in the wet tropics it was toxic to cattle. But recent research by R.J. Jones in Australia has demonstrated the existence of rumen microorganisms capable of degrading the toxic goitrogenic metabolite of mimosine, DHP (Bray et al. 1984). This offers scope for increased utilisation of this highly productive and persistent legume. Urine samples taken from ruminants feeding on leucaena in the Morobe Province of Papua New Guinea (M. Raurela, unpublished data), Solomon Islands and Vanuatu (Shelton, unpublished data) indicate that the microorganisms may be present in these countries. Further investigation is necessary. The experience in Timor, where leucaena thickets are managed in a slash-and-burn rotation with upland crops (Piggin and Viator Parera 1984) may also be relevant to the Pacific area.

Other naturally occurring legumes which warrant further investigation and possible transfer within the region are hetero (*Desmodium heterophyllum*), which is very successful in Fiji, *Desmodium canum*, in Vanuatu, and the ubiquitous *Desmodium triflorum* and *Mimosa pudica*. This latter species is often considered to be a serious weed pest.

Soil Fertility and Chemical Composition of Pastures

Soil fertility and associated chemical composition of pastures vary widely within the region. Vanuatu is well endowed with fertile soils by Pacific standards. The majority of pasture development has occurred on coastal coralline and uplifted calcareous/volcanic ash soils. The coastal soils may be deficient in nitrogen and potassium, while the older weathered plateau soils have low available phosphorus levels (Macfarlane and Shelton 1986). Sodium concentrations of many of the pastures sampled were below recommended level for growth (0.07% Na in dietary intake), except koronivia grass (0.19% Na) and buffalo grass (0.65% Na) which are clearly sodium accumulators.

In the Solomon Islands, the following deficiencies have been recorded: potassium on coastal coralline soils (Gutteridge and Whiteman 1978); potassium, phosphorus and sulfur on the mission grass (*Themeda*

sp.) foothills of Guadalcanal (Smith 1985; Gutteridge and Steel 1985); and sulfur on the alluvial soils of the Guadalcanal Plains (Watson and Whiteman 1981c).

In Fiji, deficiencies have been recorded of nitrogen and phosphorus on all hill soils; potassium in latosol, humic latosol and alluvial soils; and nitrogen, phosphorus, potassium and to a lesser extent molybdenum in nigrescent soils (T.R. Evans pers. comm.).

In Papua New Guinea, responses have been recorded to phosphorous, nitrogen and sulfur in the Markham Valley; and to phosphorus, potassium, sulfur, molybdenum and boron on the poor soils of the Sepik Plains.

It must be concluded that, in all Pacific countries, further work is necessary to clarify the extent of soil nutrient problems and the establishment and maintenance of fertiliser requirements to ameliorate nutrient deficiencies. In economic terms, the viability of extensive fertiliser application is doubtful (J.H. Schottler pers. comm.), but soil fertility studies should be conducted to provide a basis for sound decision making regarding choice of pasture species and pasture and cattle management, and particularly the need for direct supplementation of cattle. For instance, responses have been obtained to supplementation of cattle with sodium (Leche 1977) in the Papua New Guinea highlands and with phosphorus on the Sepik Plains (Holmes 1981c). No response was obtained to salt supplementation of low sodium (0.01% Na) signal ' grass pastures on Kolombangara Island in Solomon Islands (unpublished data).

Conclusions and Future Directions

Cattle numbers have increased dramatically in the Pacific region this century. Over the past 20 years indigenous smallholders have become increasingly involved, but with variable success. Significant pasture research has been carried out, but the level of successful adoption of permanent improved pastures remains disappointingly low, although awareness of the importance of improved pastures to animal productivity is increasing. The outlook for the cattle industries is relatively optimistic, with the possible exception of Solomon Islands, and governments are proceeding with plans for further inputs to the industry to achieve self-sufficiency and, in some cases, develop export markets. As the Pacific economies improve, demand for beef can be expected to increase.

There is a need for assistance and progress in several sectors of the industry, to ensure that the incentive for pasture improvement is not limited by other factors. For instance, herd management and cattle husbandry, also marketing infrastructure and credit facilities, are often limiting and should receive appropriate attention. In Vanuatu, there is opportunity to structure the

industry, with smallholders from more remote areas supplying weaners and store cattle for fattening on expatriate and commercially run Ni-Vanuatu properties more centrally located near abattoirs. This suggestion is appropriate to their respective resources, expertise and physical location. In Lae, Papua New Guinea, short term protection from beef imports has been provided as an interim measure to get the industry established.

It is clear from experiences to date, that future research should aim to provide simple and robust systems suitable for indigenous smallholders with only recent experience of pasture and cattle management. Systems such as those developed with *Dicanthium caricosum* in Fiji, *D. annulatum* in Papua New Guinea and *Stenotaphrum secundatum* in Vanuatu should be tested more widely in the region. There is a need to collate and integrate all existing, often fragmented, information on species performance and soil fertility data for the benefit of all countries in the region. Species introduction and evaluation and soil fertility testing will both continue to be research priorities, as management of poorer soils is likely to involve choice of adapted species rather than fertiliser addition, at least in the short term. Further investigation of naturalised legumes such as leucaena is given high priority because of its demonstrated productivity and persistence in Australia.

The problem of poor adoption of improved pastures by primary producers must be faced. Research workers must work more closely with extension officers and innovative farmers to ensure that research emphases are realistic and that extension recommendations are practical and appropriate.

The low number of nationals in pasture agronomy and their lack of expertise are serious limitations to further research development. There is clearly justification for direct technical assistance to meet short term needs and for training assistance to increase local competence. This may take the form of workshops, study tours, regional seminars or tertiary study. The proposed Pacific pasture network to promote interchange of information within the region will be of great benefit. Many personnel from institutions in several countries have indicated their support for this concept.

References

Bray, R.A., Jones, R.J. and Probert, M.E. 1984. Shrub legumes for forage in tropical Australia. In: Craswell, E.T., and Budi Tangendjaja, ed., Shrub Legume Research in Indonesia and Australia. ACIAR Proceedings Series No. 3.

Clancy, J.F. 1972. Pasture work in the grasslands of the northern district — Part II. Harvest, 2, 122–6.

Falvey, J.L. 1981. *Imperata cyclindrica* and animal production in Southeast Asia: A review. Tropical Grasslands, 15, 52–56.

Gutteridge, R.C., and Whiteman, P.C. 1978. Potassium fertilizer studies on *Brachiaria mutica/Centrosema pubescens* pastures grown on soils derived from coral limestone, Malaita, Solomon Islands. 1 — Effect of rates of potassium on yield and botanical composition. Tropical Agriculture (Trinidad), 55, 215–224.

Gutteridge, R.C. and Steel, R.J.H. 1985. Fertilizer requirements for *Stylosanthes guianensis* oversown into the grassland foothills of Guadalcanal. *Tropical Grasslands*, 19, 40–43.

Holmes, J.H.G. 1981a. *Dicanthium annulatum:* a persistent pasture for cattle in the Papua New Guinea Lowlands. Tropical Grasslands, 15, 56–58.

  1981b. Toxicity of *Leucaena leucocephala* for steers in the wet tropics. Tropical Animal Health and Production, 13, 94–100.

  1981c. Phosphate deficiency in cattle on the Sepik Plains, Papua New Guinea. Tropical Animal Health and Production, 13, 169–176.

Holmes, J.H.G., Lemerle, C., and Schottler, J.H. 1980. *Imperata cylindrica* for cattle production in Papua New Guinea. Papua New Guinea Agricultural Journal, 31, 51–62.

Leche, T.F. 1977. Effects of sodium and phosphorus supplements for steers on native pastures in the tropical highlands. Papua New Guinea Agricultural Journal, 28, 19–25.

Litscher, T. and Whiteman, P.C. 1982. Light transmission and pasture composition under smallholder coconut plantations in Malaita, Solomon Islands. Experimental Agriculture, 18, 383–391.

Macfarlane, D.C. and Shelton, H.M. 1986. Pastures in Vanuatu. Report to the Australian Centre for International Agricultural Research. ACIAR Technical Reports, 2.

Macfarlane, D.C., and Whiteman, P.C. 1983. Report on grazing studies under *Eucalyptus deglupta* reafforestation on Kolombangara Island. University of Queensland report to Solomon Islands Government and the Australian Development Assistant Bureau.

Partridge, I.J. 1977. Results of beef pasture research in Fiji. Proceedings, Regional Seminar Pasture Research, Min. Agric. and Lands, Honiara, Solomon Islands.

Partridge, I.J., and Ranacou, E. 1974. The effects of supplemental *Leucaena leucocephala* browse on steers grazing *Dicanthium caricosum* in Fiji. Tropical Grasslands, 8, 107–112.

Piggin, C.M. and Viator Parera 1984. The use of leucaena in Nusa Tenggara Timur. In: Craswell, E.T. and Budi Tangendjaja, ed., Shrub Legume Research in Indonesia and Australia. ACIAR Proceedings Series, No. 3.

Reynolds, S.G. 1978. Evaluation of pasture grasses under coconuts in Western Samoa. Tropical Grasslands, 12, 146–151.

Roberts, O.T. 1970. A review of pasture species in Fiji. 1. Grasses. Tropical Grasslands, 4, 129–137.

Shelton, H.M. 1984. Transcript of seminar on pasture research on cattle under trees project. Quarterly report No. 5 to Australian Development Assistance Bureau.

Smith, M.A. 1985. Preliminary studies with fertilizer and legumes for improving the natural grasslands of the Aruligo Land System, Guadalcanal. Tropical Grasslands, 19, 35–40.

Smith, M.A. and Whiteman, P.C. 1983. Evaluation of

tropical grasses in increasing shade under coconut canopies. Experimental Agriculture, 19, 153–161.

1985a. Grazing studies on the Guadalcanal Plains, Solomon Islands. 3. Comparison of existing mixture with Koronivia *(Brachiaria humidicola)* and with natural pastures. Journal of Agricultural Science, Cambridge, 104, 181–189.

1985b. Animal production from rotationally-grazed natural and sown pastures under coconuts at three stocking rates in the Solomon Islands. Journal of Agricultural Science, Cambridge, 104, 173–180.

Twyford, I.T. and Wright, A.C.S. 1965. The soil resources of the Fiji Islands. Published by Government Printer, Suva.

Ward, R.G. and Proctor A. 1980. South Pacific Agriculture — Choices and Constraints. South Pacific Agriculture Survey 1979. Published by Asian Development Bank.

Watson, S.E. and Whiteman, P.C. 1981a. Animal production from naturalized and sown pastures at three stocking rates under coconuts in the Solomon Islands. Journal of Agricultural Science, Cambridge, 97, 669–676.

1981b. Grazing studies on the Guadalcanal Plains, Solomon Islands. 2. Effects of pasture mixes and stocking rates on animal production and pasture components. Journal of Agricultural Science, Cambridge, 97, 353–364.

1981c. Grazing studies on the Guadalcanal Plains, Solomon Islands. 1. Climate, soils, and soil fertility assessment. Journal of Agricultural Science, Cambridge, 97, 341–351.

Forages in Thailand

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ALTHOUGH livestock production in Thailand is considered one of the more important farming activities, most of the available arable land is used for crop production, which is by far the largest agricultural activity.

Of the 20 million hectares designated as farm land in the country in 1982, 18 million hectares (92.5%) were used for cropping, while only 0.7 million hectares (3.4%) were classified as grassland or idle land (Anon., 1983).

The large ruminant population of Thailand in 1983 was 6.3 million water buffaloes and 4.8 million cattle with the northeast region being the major producer. Sheep and goats form a minor proportion of the total but their numbers are increasing, particularly in the southern region (Table 1).

Table 1. Ruminant animal population in Thailand 1983. (Unit = 1000 head)

Region	Buffalo	Cattle	Goats	Sheep
Northeast	4270	1864	1	1
North	1287	1127	5	2
Central Plain	574	992	—	—
South	223	847	27	7
Total	6354	4832	33	10

In Thailand, extensive grazing systems are not used to any great extent, and for the most part livestock are raised in small numbers by smallholder village farmers, who are engaged in subsistence agriculture based on rain-fed rice and upland crops. Cropping patterns, therefore, have a marked influence on forage supply, and crop residues form an important component of the diet of livestock.

Because livestock production is so closely linked with cropping in Thailand, it is difficult to estimate just how much land area is available for forage production. In addition, cropping patterns and therefore forage resources change from region to region throughout the country. Thailand can be divided into four major

regions, based broadly on physiographic characteristics and climate. The four regions are the central plain, the north, the northeast and the south. In this paper the role and evaluation of forages in each region will be reviewed separately.

The Southern Region

This area lies between 6° and 11°N latitude and experiences a humid tropical climate (Köppen Af). Rainfall ranges from 2100–4725 mm/annum falling mainly from April–May to November–January. A 3–4 month dry season occurs from December to April (Van den Eelaart 1973).

The soils in the region are derived from a variety of parent materials such as limestone, bedded sediments and granites, and vary in texture from clay loam to sandy loam. There are also large areas of alluvial soils, beach sands and acid peats.

The southern region accounts for most of Thailand's plantation agriculture; rubber, coconuts and oil palm are the main crops, occupying almost 2 million hectares. Livestock are often raised in conjunction with plantation crops, and in this situation are grazed on sown and volunteer pastures under coconuts and rubber.

A range of grasses and legumes have been evaluated under coconuts, and species such as *Brachiaria decumbens*, *Panicum maximum*, *Centrosema pubescens* and *Macroptilium atropurpureum* have exhibited superior productivity (Boonklinkajorn 1978). However, only a very small area of the total of 110 000 hectares under coconuts has been specifically sown to forage species, and for the most part livestock graze volunteer species including *Axonopus compressus*, *Paspalum conjugatum* and *Imperata cylindrica*.

Legumes such as *Centrosema*, *Calopogonium* and *Pueraria* are sown as cover crops in rubber plantations, and these provide a high quality source of fodder for livestock until about year 7, when canopy closure markedly reduces productivity.

Livestock raised in association with paddy rice production are often grazed on upland communal areas dominated by *Digitaria* sp., *Chrysopogon* sp. and *Eragrostis* sp. In a number of instances where grazing

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has been controlled, species such as *Stylosanthes hamata* cv. Verano, *S. guinanensis* cv. Endeavour, *Brachiaria decumbens* and *Paspalum plicatulum* have been used successfully (T. O'Sullivan, pers. comm.).

Browse trees and shrubs, such as leucaena, form an important component of the diet of goats in southern Thailand (B.W. Norton, pers. comm.). Future research on the evaluation and utilisation of browse species appears warranted, not only for goats but also for other ruminants, which are often fed under a cut-and-carry system heavily reliant on browse.

The Central Plain

The central plain consists of the lower watershed of the Chao Phraya River system, lying between 13° and 15°N latitude and experiencing a tropical savanna climate (Köppen Aw) with a regional average rainfall of 1259 mm (Van der Eelaart 1973). The alluvial soils in the flood plain of the Chao Phraya are among the most fertile in the country, and this, together with the almost flat topography, makes the area ideally suited to paddy rice production.

More than 93% of the farm holdings in the region are devoted to crop production, with very few areas available for grazing. Livestock in the region rely heavily on crop residues, and rice straw in particular. This is often supplemented by naturalised or planted forage, cut and carried from areas inaccessible to livestock.

Para grass (*Brachiaria mutica*) has been in use in Thailand for many years, and is commonly found in lowland seasonally flooded areas in the central region. It is often cut and fed as a supplement to rice straw. Other introduced forage species which are used predominantly on the upland areas are Guinea grass (*Panicum maximum*) and Napier grass (*Pennisetum purpureum*). These species have been shown to be the most versatile species for both grazing and cut-and-carry systems. More recently, Ruzi grass (*Brachiaria ruziziensis*) and Cori grass (*B. miliiformis*) have been introduced, and are currently being evaluated for use under moderate grazing pressures.

The use of forage legumes in the central region is not as widespread as in other areas. This may be associated with the higher fertility status of the alluvial soils. Verano stylo has been used to some extent on the more infertile upland soils of areas bordering the region, while leucaena is used in cut-and-carry systems and as a supplement to rice straw.

The Northern Region

Northern Thailand comprises 16 provinces lying between 15° and 20°N latitude and covering 170 000

km^2. The area can be divided into 3 physiographic zones:

1. The lowlands, occupying 16% of the area, are relatively flat and fertile alluvial basins which produce mainly paddy rice.
2. The uplands (45% of the area) consist of undulating or hilly terrain to about 500 m above sea level, where the principal land use is swidden agriculture for upland rice, maize, grain legumes and other field crops.
3. The highlands (40% of the area) range in altitude from 500 to 2500 metres above sea level, and are rugged, inaccessible masses varying from flat plateaux to steep-sided mountains. A variety of crops including upland rice, maize and opium are cultivated in swiddens.

The climate of the region is tropical savanna, with annual rainfall varying from 950 to 2000 mm. The wet season extends from May to October–November. There is a cool season from November to February, followed by a hot season until the rains commence. At Chiang Mai (300m altitude) maximum and minimum temperatures vary from 29°/13° in January, to 36°/21°C in April. Within this general pattern many different microclimates occur, due to the mountainous terrain. Temperature decreases with altitude at about 0.5°C for each 100 m, and in sheltered highland locations frosts do occur. Soils of the uplands and highlands are mostly of a residual nature, weathered from parent materials of granite, gneiss, shales, limestones and sandstones.

The Lowlands

In the lowland areas most livestock are raised in the traditional manner by farmers primarily engaged in the production of paddy rice.

The Uplands

In the uplands, large areas of fenced pastures have been established by the Department of Public Welfare in their Nikhoms or resettlement stations. Verano stylo, Townsville stylo, Siratro, Green Panic (*Panicum maximum* var. *trichoglume*) and Sabi grass (*Urochloa mosambicensis*) have been the most successful species. The pastures are grazed at controlled stocking rates by village cattle from the resettlement stations. Inputs such as seed, fertiliser and machinery are supplied by the Department. In addition to the activities of the Department of Public Welfare, the use of leucaena and other forage species for 'backyard' plantings has been widely promoted in the upland areas by the Forage Division of the Department of Land Development.

The Highlands

Ruminant livestock in the highlands occupy an

important position in the culture of some of the hill tribe groups (Falvey 1977), and are kept as a capital reserve, for draught, and for sacrifice and special occasions. The main forage resources in this area are the grasslands (dominated by *Imperata cylindrica*) which have developed largely because of the shifting cultivation of the opium-growing hill tribes. The productivity of these grasslands is low and they support a stocking rate of less than 0.1 beasts per hectare (Falvey 1981). Continuous grazing at higher stocking rates leads to a decline in vigour of *Imperata* and invasion by unpalatable weeds.

Most of the forage research in the highlands of Northern Thailand has been undertaken by the Thai-Australian Highland Agricultural Project over the period 1972–80. This project was associated with Chiang Mai University and the Department of Public Welfare, and was initially designed to rehabilitate the *Imperata* grasslands by the introduction of improved forage species.

A range of forage species was introduced and tested at various locations. *Desmodium intortum* cv. Greenleaf and *Macrotyloma axillare* cv. Archer were found to be the best legumes for grazed pastures above 1200 m (Gibson and Andrews 1978). *Desmodium uncinatum, Trifolium repens, T. semi-pilosum* and *Lotononis bainesii* were also productive, but were not persistent and did not thrive at all sites. At lower elevations, 600–1200 m, perennial stylo *S. guianensis* and Greenleaf were most productive, and all legumes except stylo responded to fertiliser. Fertilised Greenleaf was favoured because of its persistence, palatability, high production, ease of establishment, long growing season and ability to compete with weeds and native grasses. Leucaena was not widely adapted to the highlands but grew well at altitudes below 1000 m, yielding up to 5 t leaf/ha (Andrews 1979a).

Of the grasses the most productive species irrespective of altitude were Nadi setaria (*S. sphacealata* var. *sericea*), *Panicum maximum* cv. Hamil, *Paspalum plicatulum* and *Brachiaria decumbens*, of which *B. decumbens* gave the best dry season performance. Greenleaf and setaria are considered the best mixture for cut-and-carry systems, and yields of 6–10 t dry matter/ha were obtained (Andrews 1979b).

Sulfur was identified as one of the main nutrient deficiencies in the highlands, and responses of up to 70% have been obtained with additions of sulfur. Phosphorus fertiliser was also found to be essential for good growth of most legumes, and an initial fertiliser recommendation of 500 kg of rock phosphate and 100 kg of gypsum/ha was developed for legume-based pastures on the common granite soils.

Weed invasion, especially by *Chromolaena* sp., was the main technical problem of grazed pastures. Studies indicated the importance of improved grasses, adequate fertilisation of legumes and frequent slashing for control of weeds.

Grazing trials showed that highland cattle would gain approximately 100 kg/head/annum on improved pastures at a stocking rate of 1.5 beasts/ha (Falvey and Andrews 1979). This represented a 30-fold increase in production compared to native range.

Because of economic limitations, land tenure problems, pasture management difficulties and social constraints, fenced, grazed improved pastures were not seen as a viable production system for existing hill tribe communities. The utilisation of small areas of improved pasture, cut and fed to animals as a supplement to the native range, was likely to be more profitable.

The Northeast Region

The northeast region has the highest ruminant population of the four major regions, and hence has the greatest potential for forage improvement. As a consequence, most of the research and development on forages in Thailand has occurred in this region. The region can be described as a slightly elevated plateau of 17 million hectares, 100–300 m above sea level. It lies between 14° and 19°N and experiences a tropical savanna climate with pronounced seasonal distribution of rainfall. At Khon Kaen (central northeast Thailand) more than 85% of the annual total of 1250 mm falls from mid April to mid October, through the influence of the southwest monsoon. Average monthly day and night temperatures range from a maximum of 36/24°C in April to 30/17°C in December.

Upland soils in the region are largely podzolics, latosols and regosols and are characterised by sandy texture, acid reaction, low organic matter content, low cation exchange capacity and a low level of plant nutrients, particularly nitrogen, phosphorus and sulfur.

Vegetation in areas more remote from villages is open dipterocarp forest with an understory of bamboo grass (*Arundinaria* sp.). In heavily grazed and disturbed areas around villages, the bamboo grass has been replaced by low-growing, grazing-tolerant species, including *Eragrostis viscosa, Dactyloctenium aegypticum, Digitaria adscendens, Perotis indica* and *Chrysopogon aciculatus*. The legumes *Desmodium triflorum* and *Alysicarpus vaginalis* are also common in this association.

A typical northeastern rural household cultivates 1–4 hectares of croplands, and raises 1–3 head of buffalo. Fewer than 50% of households own cattle, and individual holdings seldom exceed 7. Buffaloes are

kept mainly for draught, while cattle are kept as a capital reserve, for draught and for meat.

There are distinct seasonal livestock management patterns which influence feed supply. During the wet season much of the paddy land and some upland is cropped, so that livestock are grazed on communal areas, along roadsides, forest margins and fallow lands. In the late wet season forage is often cut and carried from areas inaccessible to livestock. During the dry season, after rice harvest, rice stubble forms the principal diet. Rice straw, which is conserved after threshing, is fed after standing stubble is exhausted. Rice straw available per head per year in the northeast has been estimated at 3.13 t, compared to a national average of over 4.4 t, indicating the higher stock numbers and lower rice productivity in this region (Anon. 1983).

A study of land utilisation patterns in northeast Thailand (Table 2) indicates that if the area of grassland, idle land, other land, half the forest land and three-quarters of the unclassified land can be assumed to be available for grazing during the wet season, then the average stocking rate for the northeast is approximately 1 animal/ha. In the dry season, this figure is 0.52 animal/ha. These stocking rates approximate those obtained by Rufener (1971) who conducted surveys in a number of villages in the region and calculated wet season stocking rates of 1.2–2.8 animals/ha and dry season rates of 0.48–0.67 animal/ha.

By any standards these stocking rates are high, particularly for an area with a monsoonal climate and inherently infertile soils, so that improvements in forage quantity and quality are vital to the maintenance of a viable livestock industry in the region.

The main institutions involved in forage research and development in the region have been Khon Kaen University (through the Pasture Improvement Project and the Ley Farming Project), the Department of Livestock Development (through the Northeast Livestock Development Project), the Land Development Department, the Department of Public Welfare, the National Security Command and the Northeast Agricultural Centre. The University and the Northeast Centre have mainly been involved in forage research, while the other institutions have concentrated on forage development and extension.

The traditional, low-cost, integrated system of ruminant production in the region has been considered quite sound, given the available resources (Rufener 1971; Shelton 1976). Improvements have therefore been developed which, as far as possible, do not require radical change to present methods and take into account the economic and cultural capabilities of the local farmers.

Research efforts have largely occurred in the fields of species evaluation, pasture establishment, animal production, soil fertility assessment and seed production.

Species Evaluation

WET SEASON FORAGE SUPPLY

The communally grazed upland areas are an important source of forage for livestock in the wet season, and one of the major thrusts of species evaluation programs was to identify legume species which could tolerate heavy grazing and were suitable for oversowing into these areas.

Townsville stylo (*Stylosanthes humilis*) demonstrated a capacity to grow and persist in most village situations without fertiliser or special management (Robertson 1975). However, in 1975–76 it was devastated by anthracnose disease (*Colletotrichum gloeosporioides*) and alternative species were sought. Caribbean stylo (*S. hamata* cv. Verano) also proved to be well adapted, and under managed conditions forage yields of Verano were almost double those of Townsville stylo (Topark-Ngarm 1976). In 1976, this species became the mainstay of pasture development activities in the region, and to date about 50 000 hectares of private and communal grazing land have been oversown (Anon. 1984).

New cultivars of *S. hamata* have been tested, and a number have shown potential with respect to forage yield and anthracnose disease resistance. Disease resistance has also been found in a number of *S. humilis* lines, such as CPI 61674 (Khon Kaen stylo) which has also demonstrated satisfactory dry matter production under heavy defoliation and good seed yields (Table 3). *Cassia rotundifolia* is another species which may have potential in the heavily grazed communal areas and is currently being evaluated.

Although a large area has been oversown to Verano stylo and other species, the actual effectiveness of the

Table 2. Land utilisation in northeast Thailand 1982 (unit = 1000 ha)

	Paddy rice	Field crops	Fruit + tree crops	Vege- tables	Grass- land	Idle land	Other land	Forest	Unclas- sified land	Total
Area	5801	1827	98	14	70	380	114	2606	5822	16885
Proportion %	34	11	>1	>1	>1	2	1	15	34	

legume contribution has not been gauged. Plant densities are often quite high in these situations (Shelton and Wilaipon 1984) but the biological contribution of the legumes to the system may be very small, because the plants are constantly being defoliated. The true value of this oversowing practice may not be realised in communally grazed areas until a workable system of grazing management is devised and implemented.

Table 3. Agronomic performance of *S. humilis* CPI61674 in comparison with Verano stylo

	S. humilis CPI61674	S. hamata cv. Verano
Highest dry matter yield under cutting kg/ha/yr	7230	9840
Highest seed yield kg/ha/yr	1100	1255
Highest anthracnose rating (1 = least, 5 = greatest)	0.7	2
Plant density at establishment (communal area) plants/m^2	146	92
Plant density second year (communal area) plants/m^2	143	24

A number of legumes such as *Macroptilium atropurpureum*, *Centrosema* sp. and *S. guianensis* have shown promise for use in mixed pastures under more controlled grazing conditions, or in cut-and-carry systems such as backyard pastures (Topark-Ngarm and Moolsiri 1981). Siratro demonstrated superior productivity and persistence when oversown. In grassland dominated by the tall *Arundinaria ciliata*, Siratro demonstrated superior productivity and persistence in comparison to three other *Stylosanthes* species (Gutteridge 1985). Siratro and Verano stylo have also been used successfully as ley pastures in an upland monocropping system. A well grown ley pasture fertilised with phosphorus and sulfur has doubled the yields of subsequent cassava or kenaf crops (Gibson 1984).

During the ley phase the pasture can be grazed, and this system has formed the basis of a small village dairy industry in a number of locations in the northeast.

Evaluation of grasses has received less attention than legumes, mainly because of the low nitrogen status of most of the upland soils and the difficulty of introducing grasses into the communal grazing areas. In more controlled grazing situations, as occur on livestock stations and in backyard cut-and-carry systems, grasses such as *Brachiaria decumbens* and *Panicum maximum* have shown superior productivity (Table 4).

Table 4. Forage yield (tonnes/ha) and in vitro dry matter digestibility (IVDMD) of some pasture grasses at Khon Kaen University

Species	Total yield (3 cuts)	IVDMD (%)
Panicum maximum cv. Hamil	15.78	—
Panicum maximum cv. Common	14.26	—
Brachiaria decumbens cv. Basilisk	13.07	47.5
Melinis minutiflora	11.32	—
Paspalum plicatulum cv. Hartley	10.95	38.5
Cenchrus ciliaris cv. Gayndah	9.36	41.6
Setaria sphacelata var. *sericea* cv. Nandi	7.99	45.0
Panicum maximum var. *trichoglume*	7.36	—
Urochloa mosambicensis	6.70	39.8
Chloris gayana cv. Katambora	2.21	39.2

DRY SEASON FORAGE SUPPLY

The long dry season and the poor quality of forage available over this period is one of the major causes of low animal productivity in the region (Rufener 1971; Gutteridge et al. 1983). This period has become the focus of attention for many researchers, and strategies have been developed to help overcome this problem. The use of browse trees and shrubs is important in this

Table 5. First year yield and chemical composition of leaf material of shrub legumes at Khon Kaen

Species	Wet season leaf yield g/plant	Dry season leaf yield g/plant	Crude protein %	IVDMD %
Sesbania sesban var. *nubica*	683.4	377.0	21.3	67.8
S. sesban	541.6	167.8	26.4	69.1
Enterolobium cyclocarpum	518.3	302.5	21.7	68.6
Albizia falcataria	321.8	101.7	19.5	61.5
Sesbania formosa	311.7	87.8	21.5	57.9
Leucaena leucocephala	236.6	168.6	19.7	52.7
Calliandra calothyrsus	215.9	82.5	15.7	48.0
Sesbania grandiflora	156.9	25.0	26.5	66.9
Albizia lebbek	130.6	97.0	28.8	54.5
Cassia siamea	90.5	83.6	18.8	65.5
Samanea saman	35.4	51.2	23.4	59.9
Pithocellobium dulce	28.1	39.0	19.1	59.6
Adenanthera pavonina	22.1	42.2	16.7	66.9

context, as their deep-rooted nature enables them to exploit moisture at depth and thus maintain green leaf for a longer period into the dry season. Leucaena has been the most successful species used to date, and yields of 11–13 tonnes of edible material per hectare have been recorded (Topark-Ngarm, unpublished data). However, slow establishment and poor growth on the more acidic soils have limited its widespread use, and a range of possible alternative species are currently being evaluated. *Sesbania sesban, S. formosa, Albizia falcataria* and *Enterolobium cyclocarpum* appear quite promising, with high yields and reasonable leaf retention over the dry season and high nutritive values (Table 5).

The growing of fodder crops on stored moisture in paddy fields following rice harvest is another dry season strategy which has received some attention. Shelton (1980) demonstrated that *Crotalaria juncea* (sunnhemp) had the ability to grow quickly, could be cut a number of times and produced reasonable yields (1590 kg/ha) of high quality fodder which could easily be mixed with rice straw. Establishment and growth of sunnhemp was markedly improved if the paddy was ploughed before sowing. A further resource, which is potentially available for improvement with forage species, is the extensive paddy bund areas between the rice bays. Estimates place the area of bund at 5–10% of total area, depending on slope (Gutteridge 1981a). Forage species are oversown early in the wet season and allowed to grow in a grazing-free environment during the rice growing season. After rice harvest the accumulated material is grazed in conjunction with rice straw. Verano stylo, *S. scabra* cv. Seca and *S. viscosa* were the most productive species tested, with average yields of 3.9, 5.1, 2.5 t/ha/annum over three years (Gutteridge 1981a).

Pasture Establishment

In heavily grazed commercial pastures, improvements in legume establishment, yield and persistence have been achieved by prior cultivation, by buffalo ploughing and by deferring grazing for the first wet season after oversowing. Cultivation increased oversown Verano yields from 1.2 to 2.7 t/ha while grazing deferment produced a tenfold increase in yield (Wilaipon and Pongskul 1983).

Roadsides are an important source of fodder for livestock in the northeast. It has been found that seeds simply thrown from the window of a moving vehicle are washed to the sides, where they germinate in the lateritic verges. Townsville stylo, Verano stylo, Siratro and *S. scabra* have been the most successful species in this situation. Since 1976, over 6000 km of roadsides have been oversown in this manner by the

Department of Livestock Development. This technique not only improves forage supply in an important grazing area, but also helps familiarise farmers with new species with which they may have had little contact.

Animal Production

A number of grazing experiments have been conducted in the region. They have provided information on animal production from unimproved native pastures and improved fertilised grass legume pastures, and demonstrated the effects of mineral supplementation on the productivity of these pastures. On unimproved bamboo grass pastures, liveweight gain was 35 kg/ha/annum at a stocking rate of one animal/ha. These low production levels were primarily associated with very heavy dry season losses. On improved pastures of *Brachiaria decumbens, Urochloa mosambicensis,* Verano stylo and Siratro fertilised with phosphorus and sulfur, liveweight gains were 213 kg/ha/annum at 3.2 animals/ha (Gutteridge et al. 1983). Supplementation with common salt increased liveweight gain on native pastures from 31 to 77 kg/head and substantially reduced dry season losses. Supplementation with a range of other minerals including P, S, Cu, Zn, Co and I did not substantially affect liveweight gains (Gutteridge and Aitken 1979).

Soil Fertility Assessment

Detailed studies of the nutrient status of the major soils used for forage production in the northeast have been undertaken by a number of institutions. Widespread deficiencies of nitrogen, sulfur and phosphorus have been identified, while potassium, copper and molybdenum are limiting in some soils (Aitken 1979; Shelton et al. 1979; Gutteridge 1981b).

Although fertiliser application is not an economic option for forages in most circumstances in the northeast, a knowledge of the fertility status does permit rational choice of species to suit the fertility. For instance, *Stylosanthes* sp. are reasonably productive in soils of low P status.

Seed Production

The seed production of forage species has received considerable attention in the northeast, and a local seed production industry is now in operation.

Under northeastern conditions, time of planting was found to be more important than seeding rate with respect to seed production. Depressions in seed yield occurred in *S. hamata, S. humilis, S. guianensis* and *Macroptilium atropurpureum* when crops were sown later than July (Wickham 1977; Wilaipon 1976) while

Calopogonium caeruleum should not be sown later than June (Jewthagoon 1984). Seedbed preparation is another factor leading to good seed production. Land levelling and cultivation before sowing not only improved vegetative growth and seed yield but also increased seed recovery at harvest. The use of fertilisers on pastures for seed is more economical than on pastures for grazing, and may be the most significant factor in determining the efficiency of seed production. Fertiliser applications of 125 kg/ha of both double superphosphate and gypsum have been recommended for seed production of Verano in the region (Wickham et al. 1977).

Other management techniques such as the use of trellises for the seed production of *Macroptilium* and *Calopogonium*, the use of irrigation in the dry season and the use of growth retardents have been shown to have beneficial results on seed production in this environment (Wickham 1977; Moolsiri et al. 1980; Kowithayakorn pers. comm.).

Adoption of Improved Techniques

Forage research programs throughout Thailand have produced many relatively simple technological developments, which have been shown in most instances to provide substantial benefits to livestock production. However, the level of voluntary adoption of these techniques by local farmers has been very low. Most of the development has been undertaken by government agencies such as the Livestock Development Department and the Department of Public Welfare, where all the inputs have been supplied.

Effective extension programs lag behind research efforts, and it appears that the main barriers to implementation are sociological and economic.

Farmers are primarily crop growers and livestock production is usually of secondary importance. In most instances, livestock are kept for non-cash purposes such as draught so it is very difficult for the average farmer to determine the return from efforts expended on improving forages. Rufener (1971) points out that farmers have not planted extensive areas to forage largely because the economic return from forages is generally far below that from alternative cash crops.

Research personnel need to work more closely with extension officers and innovative farmers to ensure applicability of results by testing recommended strategies on farms. In this way, an increase in the level of voluntary adoption may be achieved.

Future Directions

Future research on forages in Thailand needs to be directed towards the evaluation and incorporation of persistent, productive species into existing production systems. In this context, more emphasis should be placed on the evaluation of leguminous browse species as these species can make significant contributions to forage supplies under unsophisticated management conditions.

There is also a need to develop a simple method of assessing the biological impact of oversown legumes in heavily grazed communal areas. This strategy has been widely promoted in many regions, but its value in terms of improving forage availability has not really been assessed.

There are areas in Thailand, such as the northeast, which are close to the upper limit in terms of the animal production that can be achieved from currently available forage resources. Expansion of the livestock industry in these areas will depend on the incorporation of improved techniques to increase the quality and quantity of available forage. Many suitable techniques now exist, but the low level of adoption by farmers is a serious problem which needs to be addressed.

An overriding requirement to all these proposals is the need for a national policy to coordinate the activities of all agencies involved in forage research and development throughout the country.

If these proposals can be implemented, significant advances in forage production throughout Thailand can be anticipated.

References

Aitken, R.L. 1979. Soil analyses for predicting sulphur responses in pasture soils from Northeast Thailand. Khon Kaen Pasture Improvement Project Annual Report. Faculty of Agriculture, Khon Kaen University, Thailand, 72–77.

Andrews, A.C. 1979a. Pasture species adaptation trials at Phabujom in the highlands of northern Thailand. Thai–Australian Highland Agricultural Project Fourth Report. ADAB, Canberra.

1979b. The production of grass legume mixed pastures involving *Desmodium intortum*, *Trifolium repens* and *Trifolium semipilosum*. Thai–Australian Highland Agricultural Project, Fourth Report. ADAB, Canberra.

Anon. 1983. Agricultural Statistics of Thailand. Crop Year 1982–83. Centre for Agricultural Statistics, Office of Agricultural Economics, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.

1984. Project Summary Report. Northeast Livestock Development Project, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.

Boonklinkajorn, P. 1978. Herbage production of grasses under coconuts in Southern Thailand. Paper presented at Seminar for Integration of Animals with Plantation Crops. Penang, Malaysia.

Falvey, J.L. 1977. Ruminants in the highlands of Northern Thailand. An Agrosociological Study. ADAB, Canberra.

1981. *Imperata cylindrica* and animal production in South East Asia: A Review. Tropical Grasslands, 15, 52–56.

Falvey, J.L. and Andrews, A.C. 1979. Improved pastures in the Thai highlands. Tropical Grasslands, 13, 154–157.

Gibson, T.A. 1984. Implications for upland land use from pasture/crop rotation experiments of the ley farming project. Proceedings, Seminar on viable farming systems for the infertile uplands of North East Thailand. Khon Kaen University, Thailand.

Gibson, T.A. and Andrews, A.C. 1978. Pasture research in the northern Thailand highlands. Proceedings, Australian Society of Animal Production, 12, 203.

Gutteridge, R.C. 1981a. Productivity of forage legumes on rice paddy walls in Northeast Thailand. Proceedings of XIV International Grasslands Congress. Lexington, Kentucky, USA, 226–229.

1981b. Effect of phosphorus and sulphur fertilizers on establishment and growth of two *Stylosanthes* species on a red latosol soil in Northeast Thailand. Tropical Agriculture (Trinidad), 58, 23–30.

1985. The productivity of native grasslands oversown with legumes and grazed at five stocking rates in north-east Thailand. Journal Agricultural Science, Cambridge, 104, 191–198.

Gutteridge, R.C. and Aitken, R.L. 1979. Mineral supplementation of cattle grazing native pastures. Khon Kaen Pasture Improvement Project Annual Report. Faculty of Agriculture, Khon Kaen University, Thailand, 62–66.

Gutteridge, R.C., Shelton, H.M., Wilaipon, B. and Humphreys, L.R. 1983. Productivity of pastures and responses to salt supplements by beef cattle on native pastures in Northeast Thailand. Tropical Grasslands, 17, 105–114.

Jewthagoon, P. 1984. A preliminary study on some factors affecting growth and seed production of *Calopogonium caeruleum*. M.Agr.Sc. Thesis, Faculty of Agriculture, Khon Kaen University.

Moolsiri, A., Lorwilai, P. and Wickham, B. 1980. Effect of planting method and dry season irrigation on Siratro seed production. Khon Kaen Pasture Improvement Project Annual Report. Faculty of Agriculture, Khon Kaen University, Thailand, 70–72.

Robertson, A.D. 1975. A realistic approach to pasture improvement in Northeast Thailand. Thai Journal Agricultural Science, 8, 69–85.

Rufener, W.H. 1971. Cattle and water buffalo production in villages of Northeast Thailand. Ph.D. Thesis, University of Illinois.

Shelton, H.M. 1976. The physical and socio-economic environment for pasture and beef production in Northeast Thailand. Khon Kaen Pasture Improvement Project Annual Report. Faculty of Agriculture, Khon Kaen University, Thailand, 7–15.

1980. Dry season legume forages to follow paddy rice in N.E. Thailand. I. Species evaluation and effectiveness of native rhizobium for nitrogen fixation. Experimental Agriculture, 16, 57–66.

Shelton, H.M., Gutteridge, R.C., Wilaipon, N., Wickham, B., Kratzing, D.C. and Waring, S.A. 1979. Nutrient studies on pasture soils of Northeastern Thailand. Thai Journal of Agricultural Science, 12, 235–247.

Shelton, H.M. and Wilaipon, B. 1984. Establishment of two *Stylosanthes* species in communal grazing areas of Northeast Thailand. Tropical Grasslands, 18, 181–185.

Topark-Ngarm, A. 1976. Effects of seeding rate and cutting frequency on forage yields of four *Stylosanthes* species. Khon Kaen Pasture Improvement Project Annual Report. Faculty of Agriculture, Khon Kaen University, Thailand, 27–32.

Topark-Ngarm, A. and Moolsiri, A. 1981. Forage yield and perenniality of new introduced twining pasture legumes. II. Performance in the second year. Khon Kaen Pasture Improvement Project Annual Report. Faculty of Agriculture, Khon Kaen University, Thailand, 13–16.

Van den Eelaart, A.L.J. 1973. Climate and crops in Thailand. Report SSR-96, Soil Survey Division, Ministry of Agriculture and Co-operatives, Bangkok, Thailand.

Wickham, B. 1977. *Stylosanthes hamata* seed production. Khon Kaen Pasture Improvement Project Annual Report. Faculty of Agriculture, Khon Kaen University, Thailand, 81–82.

Wickham, B., Shelton, H.M., Hare, M.D. and De Boer, A.J. 1977. Townsville stylo seed production in northeastern Thailand. Tropical Grasslands, 11, 177–187.

Wilaipon, B. 1976. Seeding rate effects on growth and seed production of *Stylosanthes humilis* cv. Lawson. Khon Kaen Pasture Improvement Project Annual Report. Faculty of Agriculture, Khon Kaen University, Thailand, 107–111.

Wilaipon, B. and Pongskul, V. 1983. Pasture establishment in the farming systems in Northeast Thailand. In: Asian Pastures. FFTC Taiwan Series No. 25, 127–152.

Production Limitations of Intake, Digestibility and Rate of Passage

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UNDER most conditions where animals are fed forage diets, the ability of the animal to obtain nutrients, rather than the genetic potential of the animal to produce milk or tissue, is likely to limit productivity. In utilisation of plant materials by ruminants, plant, animal and environmental factors influence the level of intake and the efficiency of extraction of nutrients.

Any description of plant attributes can only provide an approximate guide to the amount of plant material which will be voluntarily ingested by the animal, and the animal performance which can be supported. However, it is clear that feeding value of forages is affected by morphological, anatomical, and chemical characters, which vary between species, vary with stage of maturity and with the temperature, water balance, and nutritional conditions of plant growth. These characteristics can influence the acceptability, edibility and digestibility of the plant materials and the amount and balance of nutrients derived.

It is important at the outset to point out that while high digestibility and high intake may be essential in some animal production systems based on forage, strategies in livestock management do not always require this. In the bid to improve forages in terms of yield, species stability in mixtures and persistence under cutting or grazing, characteristics which help in achieving these objectives may not be consistent with the achievement of maximum feeding value. Trade-offs can only be made when the forage is evaluated in relation to its role in a system, or in relation to the changes in the system which will take advantage of its attributes. The aim of this paper is to highlight those plant characteristics which have important effects on intake and digestibility.

In Fig. 1, the overall pattern of interactions between intake, digestibility, and rate of passage are shown as processes affected by plant structure and composition and by the physiology and behaviour of the animal. The subject of nutritional balance and metabolism by

the animal are addressed by Leng (these proceedings). If a broad view is taken, some characteristics of plants can be seen as favouring long or short retention times; slow or fast rates of digestion; and low or high intakes. The rank order of plant materials for these criteria probably does not alter with changing physiological state of the animal though amount of work done in controlled experiments to look at such possible interactions is slight.
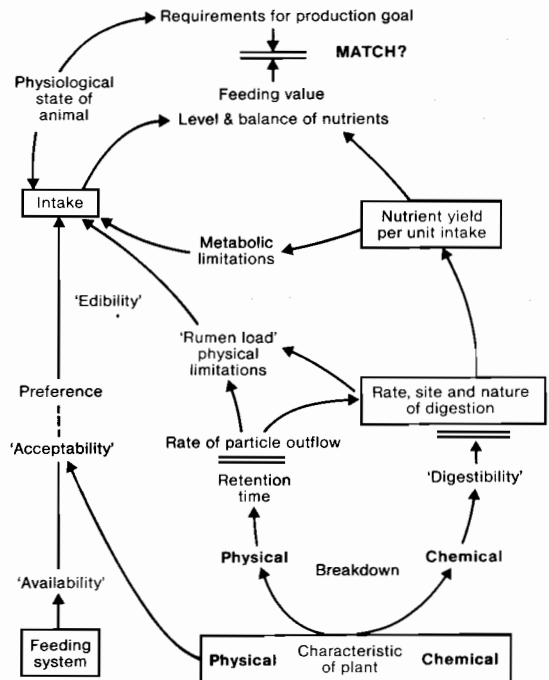

Fig. 1. Relationships between digestibility, intake and retention time.

Intake

Availability, Digestibility and Intake

Of the variables influencing nutrient intake, digestibility can vary over a twofold range; efficiency of metabolism varies over a less than twofold range; and intake varies (under conditions of unrestricted feed

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availability) over a fivefold range. Factors which contribute to the huge range in intake include ease of prehension and selection preferences as influenced by the herbage density and the geometry of its presentation (Allden and Whittaker 1970; Stobs 1973; Hodgson 1982; Black and Kenney 1984). These 'plant availability' factors interact with intake limitations imposed within the animal by nutritional inadequacies and by resistance to chemical and physical breakdown of plant structures once the feed is ingested (Minson 1982). Plant structural and compositional differences affect digestibility, and this, in turn, may contribute to the effect on intake.

If herbage availability (defined by Allden and Whittaker 1970; Hodgson 1982; Black and Kenney 1984) is removed as a variable as at low stocking rate or in 'cut-and-carry' ad libitum feeding, intake by an animal is positively correlated with digestibility. This broad correlation (Table 1) arises because the characteristics of plant composition which lead to high rates of fermentation are the same as, or relate strongly to those which result in removal of rumen digesta load by fermentation and by particle size reduction and rate of passage of digesta. Rate of passage of plant residues from the reticulo-rumen is thought to be a major factor in setting the level of intake possible. The model (e.g. Weston and Kennedy 1985) says that amount eaten is related to the space available to be filled. The faster that space is made available by digestion or passage of space-occupying solids, the greater will be the intake. However, the factors that increase passage rate involve both chemical and physical attributes of the feed and the physiological responsiveness of the animal. As discussed below, a given feed does not have a set 'rate of passage'. Removal of both fluid and particulate matter from the rumen are variable.

Table 1. Correlations of forage analysis data with intake and digestibility for 187 forages

Component	Intake	Digestibility in vivo
Digestibility in vivo	0.61	1.0
Digestibility in vitro	0.47	0.8
Lignin	− 0.08	− 0.61
ADF	− 0.61	− 0.75
NDF	− 0.76	− 0.45
Hemicellulose	− 0.58	− 0.12

However, variation in any factor such as anatomical distribution of fibre which can (for example) increase 'brittleness', or susceptibility to comminution by chewing can result in faster rate of passage with an associated increase in intake but a decrease in digestibility. Limited studies with treated rice straw suggest that the effect on intake can be much greater

than any effect on digestibility (A. Djajanegara and P.T. Doyle, unpublished).

Essential Nutrients and Animal Requirements

The physiological state of the animal (pregnant, lactating, growing) its condition (fat or thin) and state of health (parasite, acute or chronic infection), and the environment (temperature, water availability) affect intake. Changes in nutrient requirements, ability to process digesta and metabolites, and problems with homeostasis all contribute. On the other side of the balance sheet, inappropriate balances in provision of nutrients affect intake. The ingested feed provides the substrate, but nutrient yield is largely the product of microbial activity in the rumen.

The net effect of all processes of fermentation, microbial growth, and flow of microbial and dietary components to the small intestine results in a nutrient balance pattern which may be deficient in some essential nutrient for the animal. Thus low protein: energy ratio (Egan 1978) or low vitamin B_{12} yield (Marston et al. 1973) can suppress intake.

Acceptability and Edibility

Animals ingest some plant materials in quantities which are much greater or smaller than might be predicted (see correlation coefficients, Table 1) from comparison with other materials of similar chemical composition and digestibility. Some of the reasons may lie in specific nutrient deficiencies or in the physical/structural attributes of the plant. Relative 'preferences' exhibited for different plant species or cultivars by grazing animals have been listed by Arnold (1981). However, the degree to which 'preference ranking' relates to ranking of absolute intake either from swards of single species or of mixed species, or when animals are pen fed cut herbage, is poorly explored. It is possible to identify chemical components such as alkaloids and polyphenols which seem to depress the relative acceptability of plants in terms of choice between alternatives or of absolute intake (Arnold 1981). However, there is no simple 'correction factor' to be applied on account of these secondary plant components when attempting to predict intake, or evaluate those plant attributes conferring a characteristic 'edibility' (McClymont 1968) to the feed material. Hegarty (1982), and in these proceedings, has discussed chemical components in forages which are deleterious to animal health and production. In brief, some plant compounds are toxic; others appear not to be directly toxic to the animal, but depress intake; while others alter the extent and site of digestion and have less direct consequences for intake and metabolism.

From work discussed by Black (1984), it can be proposed that edibility and acceptability, as gauged by rate of eating, are broadly related. In simplistic terms, rate of eating is a function of the ease of prehension and the enthusiasm of the animal to work at eating. Plant materials can be ranked on the rate at which they are eaten when offered in similar forms or, within a forage type, when offered in different physical form or 'architectural arrangements'. Such studies (Kenney and Black 1984) reveal that animals generally eat fastest those materials which have high bulk density (Baumgardt 1970) and do not require a great effort in biting or chewing during ingestion. These characteristics again are broadly associated with immature forages; as a plant matures, characteristics become less favourable. Coincidentally with growth towards maturity, cell wall content is increasing, and protein content digestibility and intake are decreasing. Some forages are eaten less rapidly, and voluntary intake is lower than might be expected from the physical form and the macro-chemical attributes of the plant materials. Subterranean clover, for example, is of relatively low acceptability (Doyle 1985; Black 1984) possibly because of the presence of coumarols or bitter-tasting components. Tannins may also influence acceptability of forage plants (Barry 1980). Arnold (1981) states categorically that the plant components measured in conventional proximate analysis cannot directly influence preference, though the tactile characteristics associated with fibre structures cannot be dismissed. However, minor components active at a molecular level do influence preference (Arnold 1981) and this can carry over to influence absolute intake (edibility). The problem of acceptability is complex, as it involves the potential for the animal to adapt but also the possibility of reinforcement of aversiveness if other properties of the feed are detrimental (Egan and Rogers unpublished). Toxicity or metabolic disturbance caused by any component in the diet can lead to a learned rejection of any feed which contains a recognisable cue. Conversely, in a grazing system, high acceptability and edibility because of 'pleasant' components may be, overall, detrimental to the maintenance of a pasture.

Digestibility

Digestibility is perhaps more readily predicted than is intake (Table 1). However chemical analyses or 'simulated' digestion tests do not take account of the fact that amount digested is a product of the rate of digestion, and also the time of exposure to the digestive forces which is affected by rate of passage. In the ruminant, rumen digestion is accomplished by microbial fermentation, involving rapid utilisation of those plant components entering solution, with a slower in situ enzymic erosion of particle surfaces. Digestibility, therefore, is a complex function of plant form, anatomy and physico-chemical characteristics of the components. The components of plant material which are soluble in a neutral detergent solution (neutral detergent solubles, NDS) are normally rapidly and almost completely fermented in the rumen. The two major components contributing to NDS are proteins and non-structural carbohydrates. Water soluble sugars, pectin and some fructosans are readily available sources of fermentable energy for microorganisms in the rumen. Starch, depending on granule type and amylopectin content, is of variable solubility. The fermentation of less soluble forms of starch may be incomplete within the mean retention time of plant fragments in the rumen. Starch accumulated in the leaf and stem fractions of C-4 grasses and tropical legumes is often of low solubility (Smith 1972).

Protein in forage represents 75% or more of total N, the balance being nucleic acids, organic acids, amino acids, nitrates and ammonium salts. The non-protein N and a major part of the protein N is contained in forms that are in solution or are readily soluble and rapidly fermentable (Aii and Stobbs 1980). Membrane lipoproteins, cell organelle N, protein bound by secondary metabolites such as tannins and other polyphenols, or protein denatured by dessication or high temperatures is less readily fermentable (Lyttleton 1973). The soluble fraction not only contributes to the rapid disappearance of organic matter during fermentation, but provides NH_3 and peptides as products which in turn support microbial growth and activity in fermentation of the other soluble and cell wall constituents. The less accessible N forms provide a slower release of N, which can help to sustain the N conditions for continuing fermentation of the cell wall constituents remaining after the first rapid burst of fermentation. Some of the more slowly degraded protein fractions may flow with plant particles from the reticulo-rumen, and become available for intestinal digestion. Solubility of forage protein is widely variable (Aii and Stobbs 1980), is higher in immature than mature plants, sometimes higher in stem than in leaf, and decreases with decreasing total N content of the plant material. If protein solubility is low, as in some forages, this may improve the protein provision for digestion in the intestines, and may be of benefit in some production systems (Egan 1985).

The residue after neutral detergent extraction, though contaminated to varying degrees with less soluble membrane and possibly starch components, is largely cell wall material (G.R. Pearce and S. Kent, unpublished). Extraction with acid detergent solution removes most of the contaminants and a fraction

referred to as 'hemicellulose'. The composition of the latter fraction is under examination (B.A. Stone, pers. comm.) as it represents a component of secondary cell wall material which probably alters in the degree of bonding and the cross-linking with lignin as the plant grows and matures. At least with cereal stem material this appears to be true (G.R. Pearce and S. Kent, pers. comm.). Lignification, or silica accumulation, while increasing with maturity, may only reflect a pattern of chemical and physical changes which contribute to the decrease in digestibility and growth towards maturity, rather than be a sole cause of the decline. They may be major causes of the decline in some species but not in others. Certainly lignin content and silica content are not very good bases for prediction of digestibility across forage materials (Minson 1971). Again, differences in plant anatomy in terms of where lignin and silica are accumulated must be considered.

The structural carbohydrates of the cell walls are of variable digestibility. The contribution of cell wall to plant organic matter is higher in stem than in leaf, particularly in legumes, and increases during growth to maturity. At maturity grasses usually have higher cell wall contents than do legumes, and this is especially true of C-4 grasses where there is a higher proportion of vascular tissue than in C-3 grasses. The digestibility of cell wall material varies between species, and decreases with increasing maturity at rates which differ for different species. There is a broad correlation between cell wall content and digestibility for two reasons: (1) as cell wall content increases as a proportion of organic matter, the readily fermentable cell contents component falls; and (2) as cell wall content increases, the cell wall becomes increasingly refractory, and is being fermented in a decreasingly satisfactory environment of other nutrients required for microbial growth.

Norton (1982) has made the point that forage species which maintain moderate high digestibility for long periods during growth up to maturity will have a higher feeding value for animal production than do those with very high digestibility at early growth but with a rapid decline as growth continues. The rate of fall of digestibility with maturity is very broadly correlated (r^2 = 0.16) with digestibility at an immature stage (Reid et al. 1973). However, different species and growth conditions contribute to wide variability in the pattern of decline in digestibility. Most tropical legumes and many grasses (e.g. genera *Brachiaria, Setaria* and *Digitaria*) decrease only slowly in digestibility when compared with others (e.g. genera *Desmodium, Panicum, Chloris,* and *Hyparrhenia*). Most of these differences can be traced, within a particular forage, to changes in plant morphology, and to content and chemical composition of cell wall and cell contents.

The use of leaf: stem ratio, NDS, NDF, ADF, lignin content, silica content, etc. to predict digestibility across diffferent plant materials is not effective. Temperature during growth has a major influence on digestibility of a forage (Wilson 1982), but again changing plant morphology may be the source of much of the effect. High growth temperature accelerates stem development and reduces digestibility in grasses particularly. Digestibility of legume material is less affected.

Digestibility in vitro either by use of rumen fluid/ pepsin (Tilley and Terry 1963) or pepsin/crude cellulase mixture (Jones and Hayward 1975) is useful in revealing inherent differences between forage materials. The digestibility of the same materials in vivo may not be the same, however, because of differences in the form of presentation of the plant material in the more complex mastication/rumination/ mixing/fermentation, particle outflow relationships in the animal. Similar limitations are encountered with the nylon bag method (Ørskov et al. 1980) of evaluation of degradation rate of forage materials. However, these methods do allow ranking of materials on potential usefulness for animal utilisation.
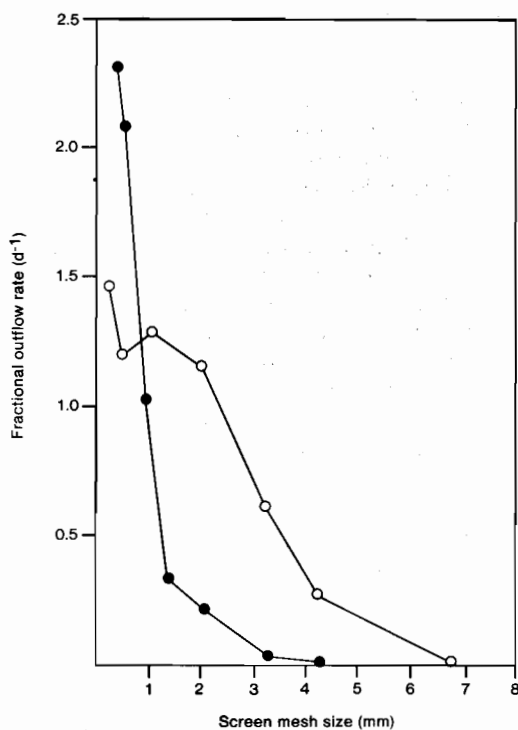

Fig. 2. Relationship between particle size and fractional outflow rate from the particulate pools in ruminal digesta for ● sheep, ○ cattle fed long roughage (from Dixon and Mora 1983; Dixon and Milligan 1985).

Rate of Passage

Plant fragments isolated from the abomasum of sheep include few particles greater than 2 mm in any dimension (Weston 1983) and very little material is retained on a 1.2 mm sieve (McLeod et al. 1985). The maximum dimensions of particles which have cleared the rumen are not grossly different between feed materials of different chemical composition or physical form (Dixon and Milligan 1985; Kennedy and Poppi 1985).

The fractional outflow rate from the reticulo-rumen of particles of various sizes (i.e. the ease with which particles of a given size can participate in flow) is inversely and approximately linearly related to the particle size (Fig. 2). The low probability that large particles will pass from the rumen has led to a simplified concept that large particulate matter in the rumen must be reduced in size before it can pass to the omasum, or that small particles only are eligible to enter the omasum. Such a concept has been used to explain much of the variation in rate of passage of feed materials through the rumen. Particle size is usually defined by those particles retained on a sieve of given screen size, and thus will depend on the sieving method used. With the sieving technique of Dixon and Mora (1983), particles retained on the 1.4 mm screen and on the 3.2 mm screen constituted the large particle pool, which contributed little to passage from the rumen in sheep and cattle respectively.

This should not be taken to imply that the pool size of small particles in the rumen is small or constant between forages. Up to 60% of the particulate material present in the rumen may be small enough to pass a 1.2 mm sieve (Evans et al. 1973). With chopped forages, voluntary feed consumption appears to be limited more by the rate of clearance of small particles from the reticulo-rumen than by rate of large particle breakdown (Poppi et al. 1981).

Small particles are removed from the rumen by transfer processes involving complex muscular contractions and relaxations of the rumen and reticulum, and possibly pressure differences favouring flow to the omasum (Stevens et al. 1960). Only a small volume of fluid containing suspended fine particles passes through the reticulo-omasal orifice at each contraction, and these occur at intervals of 1–2 minutes. For example, in sheep with a rumen digesta load of about 6 litres of fluid containing 500 g of organic matter, on average only 10-20 ml of fluid containing only 0.5–1.5 g of solids is transferred per contraction. Rate and strength of contractions are both variables, the amount of fluid moving per contraction is a variable, and the amount of particulate material supported in the flowing fluid is probably affected by particle geometry, particle specific gravity, fluid viscosity, and reticular shape during contraction. There is probably a host of other poorly investigated variables which are involved. The amount of digesta present in the reticulo-rumen, the physical characteristics of the fibre providing stimuli for contractions and for rumination, and the pH and possibly other chemical characteristics of the digesta, not only in the rumen but in the small intestine, all influence contraction rate and strength of contractions.

As already indicated, despite the complicated mode of particle transfer, material which is finely divided or which is rapidly reduced in particle size by chewing has a faster rate of passage (Weston and Kennedy 1985). Localised microbial activity can remove organic matter at points in structural elements and weaken the plant particles, but most particle breakdown occurs during rumination (Murphy and Nicoletti 1984). Observations on particle size reduction during rumination (Ulyatt 1983) and on the effects of prevention of rumination on particle size in rumen digesta and retention time of fibrous material (Pearce 1967) support this.

For some plant materials, or in some circumstances which are as yet undefined, anaerobic fungi can become established in the rumen digesta (Orpin 1981; Bauchop 1984). These may have a role, not only in the fermentation of plant organic matter, but in physical disruption of structure (Gordon et al. 1984). This area will draw more attention from those interested in the physico-chemical aspects of rumen digestion, and may prove to have more significance for certain classes of forage than for others.

Compartmental models in which particle size features as a variable in estimation of intake and digestibility are being developed. The rate at which particles are divided and pass through the various pools (Fig. 3) on their way to the 'passage-participating' pool (Gill et al. 1985) must be affected by plant characteristics such as inherent resistance to scission, crushing or splitting, but this is by no means translated to a simple routine assessment. Stem fractions of some immature plants have shorter retention times than leaf fractions. This can change with advancing maturity and is not true of some legumes at any stage. Different plant parts will have different rates of particle size reduction and so contribute differentially to the rumen pools of particles and the outflow. This means that contribution to the overall digestibility figure will alter with differences in both rate of degradation and mean retention time in the rumen. This can mean that any slowly fermented carbohydrate or denatured or bound protein will flow from the rumen more extensively if it is associated with plant parts that are rapidly broken down to small particles. However, there is a counter-balancing factor in this, in that particle size reduction also exposes a greater surface area and particularly
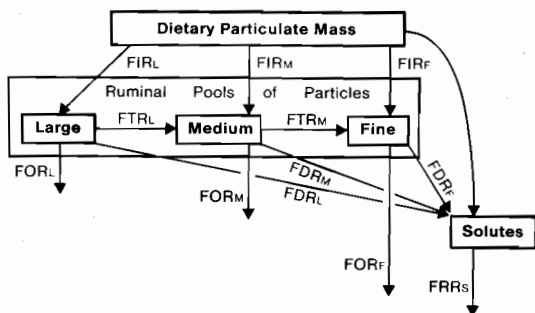
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FIR = Fractional intput rate from diet
FER = Fractional entry rate ( = FIR + FTR)
FTR = Fractional transfer rate of larger to smaller particle
      pools
FDR = Fractional digestion rate
FOR = Fractional outflow rate
FRR = Fractional removal rate ( = FDR + FTR + FOR).
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Fig. 3. The processes contributing to the fractional removal rate of particulate material from the reticulo-rumen.

new surfaces which alters accessibility to cell contents or lipoprotein membranes which might be rapidly fermented once exposed. For structural carbohydrates the decreased retention time associated with rapid reduction in particle size often outweighs the potential for increased surface area to favour higher digestibility, so there will be a net reduction in digestibility. This, however, does not necessary apply to all slowly digested components present in particles. The complexity of the interactions between plant characteristics, and the performance of the material as a degradable and comminutable substrate for microbial growth has called for quite sophisticated modelling (Faichney and Black 1979; Gill et al. 1985; Mertens et al. 1985). Rate of passage, or flow rates for 'compartments' within particulate pools, remains the most difficult to predict, but is an input needed for prediction of intake (Weston 1982), of digestibility and of site of digestion. Rates of passage (including the component flows from the successive compartments) are only measurable in the animal, and for a given forage are only partly determined by physico-chemical properties of the plant. Some of those properties which result in increased rate of particle size reduction and rate of passage are related to those which result in increased digestibility. Grinding energy, i.e. energy used to mill plant material to pass a fine screen (Chenost 1966) and tensile strength measurements (Brougham 1972) may be one indicator of acceptibility and can give a guide to resistance to particle size reduction (C.S. Reid, pers. comm.). However, the rate of particle size reduction is not the sole factor determining retention time or intake.

Research Necessary

Forage materials need to be selected on their ability to sustain high digestibility as they mature. The changes in anatomical and chemical characteristics of plants during maturation need to be examined in relation to intake under standard conditions. Those forage materials showing significant positive or negative departures from broad correlations of intake or rate of eating with major chemical components need to be used to study relationships between 'preference' and 'edibility'. For grasses, legumes, and other shrubs and herbs grown as ruminant feed, the identification of physical or chemical properties reducing acceptability and edibility is particularly important if this is linked to pest and disease resistance on the one hand or, on the other, to nutritional improvement objectives such as 'natural' protection of protein against rumen fermentation. For example, pursuit of possible gains through reduced rates of protein fermentation may produce net production losses if intake is depressed (Ulyatt and Egan 1979).

Most useful plant measurements for screening for nutritional value are digestibility of organic matter (in vitro or in sacco) and N concentration. At an early stage, comparative rates of consumption by test animals (calling for an adaptation of the Black and Kenney, 1984, procedure), need to be evaluated. Though there may be emphasis on the period of growth over which high digestibility and favourable animal intake performance is observed, the changes with time and advancing maturity will be critically important. Measurement of solubility (Aii and Stobbs 1980) or rate of degradation of protein is useful for forage materials of high and moderate protein content. With materials of low protein content ($<1.0\%$ N) supplemental sources of N will be needed, and it is these that will most influence intra-ruminal NH_3 concentration. With the attention being given now to factors influencing rate of passage, particularly those associated with rate of particle size reduction, new measurement methods allowing prediction of intra-ruminal behaviour of the plant material may be developed. However, intake remains the most important variable for maturing forages and will not be readily predicted from digestibility or from characteristics which correlate with rate of passage where edibility is influenced by physical or chemical characteristics monitored during ingestion.

References

Aii, T., and Stobbs, T.H. 1980. Animal Feed Science and Technology, 5, 183–192.

Allden, W.G., and Whittaker, I.A. McD. 1970. Australian Journal of Agricultural Research, 21, 755–766.

Arnold, G.W. 1981. In: Morley, F.H.W., ed., Grazing

Animals. World Animal Science, 1, 79–104. Elsevier, Amsterdam.

Barry, T.N. 1980. Proceedings, N.Z. Society of Animal Production, 38, 82–86.

Bauchop, T. 1984. Reviews in Rural Science V, University of New England Publishing Unit, Armidale, NSW. 38–47.

Baumgardt, W.W. 1970. In: Phillipson, A.T., ed., Digestive Physiology and Metabolism in the Ruminant. Oriel Press, Newcastle-upon-Tyne, 321–337.

Black, J.L. 1984. In: Gilchrist, F.M.C., and Mackie, R.I., ed., Herbivore Nutrition in the Subtropics and Tropics. Science Press, Craighall, S. Africa, 648–671.

Black, J.L., and Kenney, P.A. 1984. Australian Journal of Agricultural Research, 35, 563–578.

Brougham, R. 1972. Proceedings, N.Z. Society of Animal Production, 30, 46–49.

Chenost, M. 1966. Proceedings, 10th International Grassland Congress, Helsinki, Finland, 406–411.

Dixon, R.M., and Milligan, L.P. 1985. British Journal of Nutrition, 53, p. 347.

Dixon, R.M., and Mora, M. 1983. Tropical Animal Production, 8, p. 254.

Doyle, P.T. 1985. In: Baker, J., Gawthorne, J., MacIntosh, J.B., and Purser, D.B. ed., Ruminant Physiology — Concepts and Consequences. University of Western Australia, 138.

Egan, A.R. 1978. Australian Journal of Agricultural Research, 29, 631–642.

1985. In: Dixon, R.M., ed., The utilization of fibrous agricultural residues for ruminant nutrition. Proceedings of 5th Workshop of IDP Fibrous Agricultural Residues Research Network.

Evans, E.W., Pearce, G.R., Burnett, J., and Pillinger, S.W. 1973. British Journal of Nutrition, 29, 357–365.

Faichney, G., and Black, J.L. 1979. In: Black, J.L., and Reis, P.J., ed., Physiological and environmental limitations to wool growth. University of New England Publishing Unit, Armidale, 179–182.

Gill, M., France, J., Siddons, R.C., and Dhanoa, M.S. 1985. In: Kennedy, P.M., ed., Techniques in particle size analysis of feed and digesta in ruminants. Canadian Society of Animal Science, Edmonton, 142–153.

Gordon, G.L.R., Akin, D.E., and Hogan, J.P. 1984. In: Baker, S.K., Gawthorne, J.M., Mackintosh, J.B. and Purser, D.B., ed., Ruminant Physiology — Concepts and Consequences: A Tribute to R.J. Moir. University of Western Australia, Nedlands, W.A., p. 174.

Hegarty, M.P. 1982. In: Hacker, J.B., ed., Nutritional Limits to Animal Production from Pasture. Commonwealth Agricultural Bureaux, Farnham Royal, 153–166.

Hodgson, J. 1982. In: Hacker, J.B., ed., Nutritional Limits to Animal Production from Pasture. Commonwealth Agricultural Bureaux, (CAB) Farnham Royal, 133–150.

Jones, D., and Hayward, M.V. 1975. The effect of pepsin pretreatment of herbage on the prediction of dry matter digestibility from solubility in fungal cellulase solutions. J. Sci. Food Agric., 26, 711–718.

Kennedy, P.M., and Poppi, D. 1985. In: Kennedy, P.M., ed., Techniques in particle size analysis of feed and digesta in ruminants. Canadian Society of Animal Science, Edmonton, 170.

Kenney, P.A., and Black, J.L. 1984. Australian Journal of Agricultural Research, 35, 557–563.

Lyttleton, J.W. 1973. In: Butler, G.W., and Bailey, R.W.,

ed., Chemistry and Biochemistry of Herbages, 1, 63–103, Academic Press, N.Y. and London.

McClymont, G.L. 1968. In: Australian Journal of Experimental Agriculture and Animal Husbandry, 8, 302–310.

McLeod, M.N., Kennedy, P.M., and Minson, D.J. 1985. In: Kennedy, P.M. ed., Techniques in particle size analysis of feed and digesta in ruminants. Canadian Society of Animal Science, Edmonton, p. 168.

Marston, H.R., Smith, R.M., and Childs, J. 1973. British Journal of Nutrition, 30, 207–216.

Mertens, D.R., Strawn, T.L., and Cardoza, R.S. 1985. In: Kennedy, P.M., ed., Techniques in particle size analysis of feed and digesta in ruminants. Canadian Society of Animal Science, Edmonton, 134–144.

Minson, D.J. 1971. Australian Journal of Agricultural Research, 22, 589–598.

1982. In: Hacker, J.B., ed., Nutritional Limits to Animal Production from Pasture, CAB, Farnham Royal, 168–182.

Murphy, M.R., and Nicoletti, J.M. 1984. Journal of Dairy Science, 67, 1221–1227.

Norton, B.W. 1982. In: Hacker, J.B., ed., Nutritional Limits to Animal Production from Pasture, CAB, Farnham Royal, 89–110.

Orpin, C.G. 1981. In: Agricultural Science Seminar: Degradation of plant cell wall materials. ARC, London, 37–46.

Ørskov, E.R., Hovell, F.E.B., and Mould, F. 1980. The use of the nylon bag technique for the evaluation of feedstuffs. Tropical Animal Production, 5, 195–213.

Pearce, G.R. 1967. Australian Journal of Agricultural Research, 18, 119–128.

Poppi, D., Norton, B.W., Minson, S.J., and Henricksen, R.E. 1981. Journal of Agricultural Science, Cambridge, 94, 275–284.

Reid, R.L., Post, A.J., Olsen, F.J., and Mugerwa, J.S. 1973. Tropical Agriculture, Trinidad, 50, 1–15.

Smith, D. 1972. In: Biology and utilization of grasses. Academic Press, N.Y. and London, 318–332.

Stevens, C.E., Sellars, A.F., and Spurrell, F.A. 1960. American Journal of Physiology, 198, p. 449.

Stobbs, T.H. 1973. Australian Journal of Agricultural Research, 24, 821–829.

Tilley, J.M.A., and Terry, R.A. 1963. Journal, British Grasslands Society, 18, 104–111.

Ulyatt, M.J. 1983. In: Wallace, G., and Bell, L., ed., Fibre in human and animal nutrition. Bulletin 20, Royal Society of N.Z., 103–117.

Ulyatt, M.J., and Egan, A.R. 1979. Journal of Agricultural Science, Cambridge, 92, 605–614.

Van Soest, P.J. 1985. In: Proceedings of the 3rd AAAP Science Congress, Seoul, Korea, p. 103.

Weston, R.H. 1982. In: Hacker, J.B., ed., Nutritional Limits to Animal Production from Pasture. CAB, Farnham Royal, 183–198.

1983. Proceedings, Nutrition Society of Australia, 8, p. 181.

Weston, R.H., and Kennedy, P.M. 1985. In: Kennedy, P.M., ed., Techniques in particle size analysis of feed and digesta in ruminants. Canadian Society of Animal Science.

Wilson, J.R. 1982. In: Hacker, J.B., ed., Nutritional Limits to Animal Production from Pastures, CAB, Farnham Royal, 111–131.

Determining the Nutritive Value of Forage

R.A. Leng*

PROBABLY the most misleading cliché in the sciences that make up ruminant nutrition is the one 'all flesh is grass'. This has led to the general belief that green grass is a high quality feed (i.e. balanced) for ruminants, and that it is essential to include some grass in a diet, particularly those based on crop residues. There is no doubt that some pastures (i.e. pastures in early growth without restriction of nutrients or water) will support high levels of productivity in ruminants. However, in the majority of the world's grasslands both large and small ruminants grow only slowly, and productivity from pasture, even where it is of high digestibility, is below expectation.

For grazing ruminants, or even for those tethered and fed cut grass, evaluation of feed by chemical analysis of cut samples and prediction of productivity levels are illogical, because the selection of a diet from the pasture by a grazing animal is largely unknown. In addition the pasture composition and components continuously change with season and particularly with grazing pressure. Further, as will be discussed, the chemical analyses currently used to assess quality do not indicate whether the feed provides for an efficient microbial ecosystem in the rumen. In addition, the analyses bear little relationship to the availability of nutrients that are critical for efficient utilisation of feed by the animal.

Production per Hectare vs Production per Head

Improving productivity by increasing stocking rate rather than by promoting animal production per head is only logical where high rates of animal productivity cannot be achieved even at low stocking rates (i.e. the animal is nutritionally constrained). This is illustrated as follows: if pasture available represents 10 000 kg of dry matter (DM) per hectare that could be potentially grazed and animals grow at 1 kg/day, the feed conversion ratio could be 8:1 (1 kg liveweight gain per 8 kg DM consumed), and 1250 kg of liveweight would

be produced per hectare. However, if growth rates were only 500 g/d, the feed conversion ratio may be 20:1, realising only 500 kg of liveweight/hectare. The factors involved are much more complex than stated here. Nevertheless, the faster an animal grows at pasture, the more efficiently it uses the available resources.

Productivity of ruminants is primarily a function of feed intake which, in turn, is determined by the capacity of the diet:
- to support an efficient microbial milieu in the rumen;
- to supply the quantities and balances of nutrients required by the animal in different productive states.

The primary consideration for optimising intake of a forage is that the rate of fermentative digestion and the efficiency of microbial growth in the rumen is maximised; a deficiency of an essential nutrient for microorganisms will be reflected in a lowered rate of digestion of feed and also a lower than optimum microbial growth efficiency in the rumen expressed as Y-ATP (g dry cells produced/mole ATP available).

The capacity of a feed to supply the quantities of nutrients required in proportions that are balanced to meet a particular productive function depends on:
- its potential digestibility and potential rate of digestion;
- its ability to support a high rate of fermentative digestion, a high protein (microbial) synthesis rate relative to volatile fatty acids (VFA) produced (protein to energy (P/E) ratio), and a high rate of propionate production relative to acetate plus butyrate (i.e. glucogenic energy/energy (G/E) ratio);
- its ability to provide critical dietary materials which bypass the rumen.

Nutrient Availability

The nutrients available for metabolism are:
- the products of fermentative digestion, especially VFA (which include acetate, propionate, butyrate and higher fatty acids), and the digestible components of microbes synthesised in the rumen (which are about 60% protein);

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• the dietary nutrients escaping the rumen and available for digestion in the small intestine, including bypass protein and starch providing amino acids and glucose respectively, and long chain fatty acids from dietary lipids.

Essential Nutrients

It is perhaps not surprising that nutrients that appear to be critical for efficient production in ruminants (essential amino acids, glucose and long chain fatty acids) are the same as the principal nutrients present in milk. In evolutionary terms, the long-term suckling of young animals through the growth period and the receipt of critical bypass nutrients in milk has removed the need for a highly efficient microbial growth in the rumen.

Ørskov (1970) summarised the situation in terms of availability of amino acids and energy and the ability of the microbial ecosystem in the rumen to provide these. This is shown in Fig. 1. The microbial ecosystem can supply a suitably balanced protein: energy ratio in the products of fermentative digestion to support maintenance and the first two thirds of pregnancy, but not moderate to high growth nor growth of the pregnant uterus close to term, or moderate to high levels of milk production.
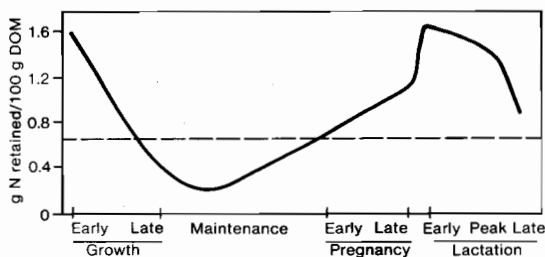
Fig. 1. Effect of physiological state on potential retention of nitrogen in relation to digestible organic matter intake.

A deficiency of absorbed dietary amino acids for production will often limit feed intake and the efficiency of feed utilisation, particularly in highly productive animals such as cattle in the last 60 days of pregnancy (Lindsay et al. 1982). This has been discussed for forages by Leng et al. (1977) and Leng (1984). Roy et al. (1977) have attempted to describe ruminant amino acid requirements in terms of the amounts of microbial and dietary protein available. This was based on a standardised and calculated microbial growth efficiency and a constant value for protein escape from the rumen for various feeds. This appears to be a major oversimplification, if the predictions of protein availability from a supplement

are to apply in a variety of diets based on crop residues through to grain-based concentrates and highly digestible forages such as lucerne. This is discussed further below.

Microbial Growth Efficiency and Dietary Bypass Protein

Undoubtedly microbial growth efficiencies are variable depending on numerous factors. The major factors that have been identified are:
• deficiencies of microbial nutrients such as ammonia, sulfur, amino acids and peptides.
• microbial species present in the rumen. In particular, a large population of protozoa decreases the protein yield to the intestines (Bird and Leng 1985; Veira et al. 1984).
• physiological state, which as well as affecting rumen microbial growth yields through the effects on digesta flow from the rumen, may also affect the overall digestibility of microbial and dietary bypass protein through increases in the capacity of the small intestine and increased enzyme secretions (Oldham 1984).

The above factors indicate the uncertainty about the efficiency of microbial growth and therefore the availability, from fermentative digestion, of protein relative to energy (P/E). The theoretical variability of P/E with microbial efficiency is shown in Fig. 2. The point stressed here is that the theoretical values for the P/E ratio from fermentative digestion can change from about 10:1 to over 40:1 (g protein/MJ available energy) (Preston and Leng 1985).

Calculation of the ratio of protein/energy available for utilisation by ruminants, taking into account all the
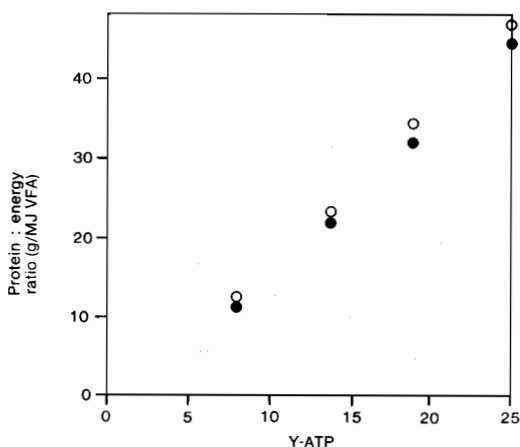

Fig. 2. The relationships between Y-ATP and the protein to energy ratio in the products of fermentation (o, data for a fermentation pattern 70 acetate, 20 propionate, 10 butyrate; •, for a pattern 60, 30, 10).

variables, clearly is not simply modelled. It does seem, however, that for some people the use of a computer gives the system a respectability and acceptability, even though, as with the more simple 'adding machine' approach, the results are only as good as the understanding of the interaction involved and the accuracy of the experimental data used to build the models.

It must be strongly stressed that the precision of the measurements of availability of nutrients to ruminants on particular diets is not very high. The present practice of collecting and averaging the data on availability of microbial protein production and the percentage of a dietary protein perhaps escaping rumen fermentation, must be regarded with scepticism. The estimate of these values relies on experimentation with cannulated animals and experimental diets and in feeding systems that mostly cannot be related to those used in practice. The estimation by these methods (MacRae 1975; Faichney 1975) of microbial or dietary protein delivered to the small intestine is inherently inaccurate. This is because it relies on (1) a number of chemical analyses with inbuilt errors; (2) liquid and particulate flow rate values, which are estimated indirectly using markers that label uncertain components, giving rise to at least 100% variations in measured microbial outflow (Siddons et al. 1982); (3) fairly arbitrary separation of digesta contents into those that flow as solids and those that flow with liquid.

In these calculations, errors are large because they depend on the sums of products of flow rate and the marked digesta components (Bergman and Azen 1974). Thus, the reported values of microbial protein availability should only be guides to the amounts produced, and the main use of the technology is to compare results within experiments.

Possible Requirements for Glucose

Glucose is required for a number of essential functions, and requirements change with physiological state. At the present time there are no analyses of feed that indicate the likely availability of glucose precursors. It is the difficulty of predicting glucose availability that jeopardises systems of feed evaluation based on net or metabolisable energy.

This is an area in which there is considerable controversy and therefore the evidence for glucose being essential is discussed in more detail.

Background: Most dietary carbohydrates are fermented to VFA and microbial cell components in the rumen, with the result that glucose absorption is minimal in ruminants. Glucose is largely synthesised from propionate (Leng et al. 1967), but amino acids

may also contribute to gluconeogenesis (Lindsay 1980). In cattle on certain high grain diets, appreciable but variable quantities of starch escape fermentative digestion (Waldo 1973). Maize, sorghum and rice have a variable capacity to escape microbial activity in the rumen, and are therefore digested in the small intestines and absorbed as glucose.

Under certain conditions, however, where glucose requirements are markedly increased (as in fattening animals on diets low in fat) and/or where propionate production in the rumen is low, amino acids can be used extensively for glucose synthesis. Propionate is the major precursor of glucose and probably accounts for 80–90% of the glucose synthesised in maintenance-fed animals (Cridland 1984).

The essentiality of glucose for efficient use of absorbed nutrients is inferred from a large number of different research approaches. The major ones are summarised below.

Growth Studies

FORAGE DIETS

Thomson (1978) found that the efficiency of utilisation of ME for bodyweight gain in sheep was higher for a concentrate/forage diet based on maize and forage (clover or grass) than for barley and forage even though the metabolisability of the DM (ME/DM) was the same on all diets (Table 1). One explanation is the proportionately greater post-ruminal digestion of maize compared with barley. Clover, as compared to grass-based diets, was also more efficiently used by the animal. There is higher protein (more bypass) and generally there appears to be a higher fat content in legumes that in grasses, indicating the likely relative nutrient availabilities on the two diets. In addition, maize contains up to twice the content of oil found in barley.

Table 1. Efficiency of utilisation of metabolisable energy for fattening cattle (kf) according to the nature of the ingredients in the diet (from Thomson 1978).

Forage/grain	Energetic efficiency (kf%)
Ryegrass + barley	36
Ryegrass + maize	42
Clover + barley	44
Clover + maize	50

Infusion Experiments or Feeding Trials

The superior nutritive value of propionic acid compared with acetic acid, observed in the original work of Armstrong and Blaxter (1957) and Armstrong

et al. (1957) with starved mature sheep, and Armstrong et al. (1958) with feeding sheep, and the absence of differences in efficiency of use of these two VFA acids in the experiments of Ørskov and Allen (1966) can be explained in terms of the glucogenic potential of the basal diet. The diet used by Armstrong et al. (1958) was dried grass (low glucogenic potential) whereas Ørskov and Allen (1966) gave the different VFAs to animals fed mainly on barley grain (high glucogenic potential).

Glucose in Low-fat Diets

The need for glucose for high efficiency of feed utilisation appears to be more obvious where the diet is low in lipid, and/or when the animal is in a late growth phase (i.e. fattening). The evidence for this is discussed below.

DIETS BASED ON SUGAR CANE

Rice polishings with a large proportion of broken rice grains and oil (12–18%) were a better supplement than cassava root meal (low in fat) for growth of cattle on sugar cane-based diets (Preston et al. 1976). The starch in rice polishings escaped rumen fermentation almost totally (Elliott et al. 1978), whereas the starch of cassava root meal was fermented rapidly in the rumen (Santana and Hovell 1979). Glucose entry rates were higher in cattle fed sugar cane-based diets when these diets were supplemented with rice polishings rather than cassava root meal (Ravelo et al. 1978). On these diets the rice polishings provided considerable fat in addition to bypass protein and starch.

Supplementary maize grain (with good rumen escape characteristics and with a relatively high content of oil) improved feed conversion efficiency in cattle fed sugar cane pith, whereas the same amount of molasses energy (completely fermented in the rumen containing no fat) depressed feed conversion efficiency (Donefer, cited by Pigden 1972).

INFUSION STUDIES

Strong evidence for the thesis comes from the studies reported by Ørskov et al. (1979), where growing lambs nourished by infusion of VFA into the rumen and infusion of casein into the abomasum (no lipids were given) increased their nitrogen retention as the proportion of propionic acid in the infused VFA was increased (see Fig. 3). The effects were the same in sheep fed at maintenance or twice maintenance.

In the studies of Blaxter and his colleagues (Blaxter 1962), there was apparently a positive linear relationship between the molar proportions of propionate in rumen VFA and the efficiency of utilisation of
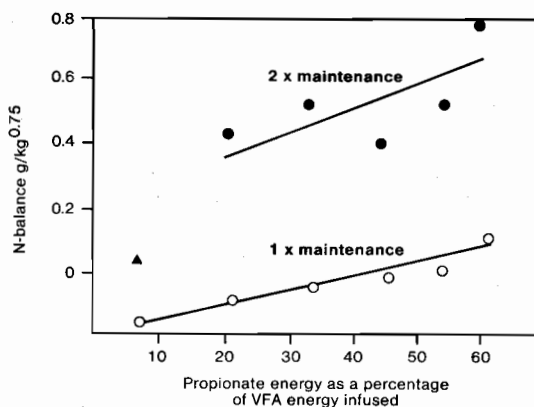

Fig. 3. Relationship between proportion of glucogenic energy in the mixture of VFA infused into the rumen of sheep and the N retention (the sheep were nourished by VFA infused into the rumen and casein infused into the abomasum at calculated rates for maintenance and twice maintenance (Preston and Leng 1985 — adapted from Ørskov et al. 1979)).

metabolisable energy above maintenance for fattening of sheep (see Fig. 4). As these animals were of mature body size they were presumably fattening, as compared to the lambs in Ørskov et al. (1979) experiments which would have been depositing mainly proteinaceous tissues (and water).

A comparison of the data summarised by Blaxter (1962) with the results obtained by Ørskov et al. (1979) with young lambs nourished by infusion of VFA into the rumen and casein into the abomasum, is given in Fig. 4.
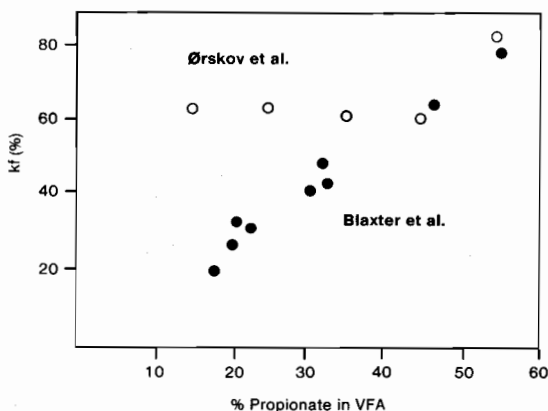

Fig. 4. Relationship between the molar proportion of propionic acid in the rumen VFA and the efficiency with which metabolisable energy consumed above maintenance is used for tissue synthesis (Preston and Leng 1985; the data are from Ørskov et al. (1979) and also adapted from Blaxter 1962, assuming that the molar proportion of butyric acid was only 10% of the total VFA).

There is obviously less need for glucogenic energy in the growing animal when the body tissue gain is high in protein rather than lipid. The highly efficient use of both dietary energy and protein at the highest glucogenic energy to energy ratio in the absorbed nutrients (i.e. where the two sets of data coincide) is clearly the optimum balance of nutrients for maximum efficiency of growth (i.e. a G/E ratio of 53% and a G/P ratio of 54 kJ/g). The optimum balance of these nutrients, however, would be dependent on the P/E ratio which is 10 for the infusions into young lambs (Ørskov et al. 1979). A P/E ratio of 10 represents an efficiency of microbial growth in the rumen equivalent to a Y-ATP of 7, which is relatively low (Leng 1982).

Glucose and Milk Production

Kronfeld (1982) discussed the critical need for glucose as a metabolic determinant of milk production in the relatively high-yielding dairy cow, based on biochemical and physiological concepts.

LCFA and Glucose

Part of a ruminant's glucose requirements are undoubtedly needed for oxidation to allow fat synthesis to occur. Therefore the need for glucose is a function of the level of fat in a diet. This is important, since it highlights the role of dietary fat and its analysis in feed evaluation systems, and therefore considerable background information is given.

LCFA Synthesis and Catabolism

Long chain fatty acids (LCFA) are rapidly released from the feed glycerides in the rumen by bacterial lipase. In the rumen, LCFA may be hydrogenated to give saturated acids but are otherwise unchanged, and are efficiently absorbed from the small intestine following their movement down the tract in digesta. Lipid may contribute approximately 1-10% of the dry matter of a forage consumed, depending on the species, its maturity and the components consumed. Long chain fatty acids of the diet are incorporated into body tissues and milk with high efficiency, and at times become critical, since a low dietary intake may increase the requirements for glucose and, indirectly, for amino acids.

Evidence to support the concept that lipids of adipose tissue arise mainly from the uptake of circulating long chain fatty acids which are of dietary origin was provided by Lindsay (1983), and the concept was supported by Thornton and Tume (1984).

Whilst fat synthesis in growth from acetate almost certainly requires glucose to be oxidised, most of adipose tissue long chain fatty acids probably arise

from dietary fat. On the other hand, only half the fat in milk fat (about half the C_{16} and all the C_{18} fatty acids) arises from dietary fat. The rest is synthesised from acetate and butyrate (i.e. half the C_{16} and all the C_4-C_{18} fatty acids) (Linzell 1968).

Glucose Oxidation and Fat Synthesis from Acetate

The interrelationships between glucose oxidation and fat synthesis from acetate are illustrated in Fig. 5. The process of synthesis of palmitate from acetyl CoA is shown below.

8 Acetyl-S-CoA + 14 NADPH + 14H$^+$ + 7 ATP + H_2O $\longrightarrow$ Palmitic acid + 8 CoA + 14 NADP + 7 ADP.
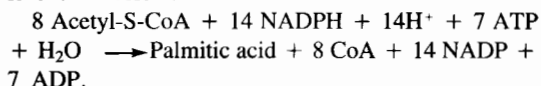
The NADPH is formed, at least in part, via the phosphogluconate pathway from glucose in which 1 mole of glucose-6-phosphate is oxidised to Co_2.

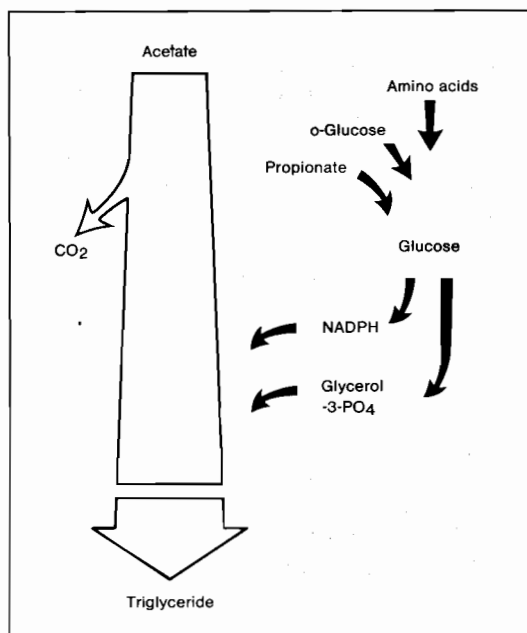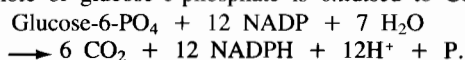Glucose-6-PO$_4$ + 12 NADP + 7 H_2O $\longrightarrow$ 6 CO_2 + 12 NADPH + 12H$^+$ + P.

Fig. 5. Diagram of the relationships between availability of glucogenic precursors and pattern of acetate utilisation (from Oldham 1983).

Thus, for every 8 moles of acetate converted to palmitate, 14 moles of NADPH must be provided. If this arises from glucose oxidation, then 1.17 moles of glucose are oxidised via the phosphogluconate pathway. In addition, 1 mole of glycerol-phosphate is needed to esterify three moles of palmitic acid and this arises from glucose. The overall reaction for the synthesis of tri-palmitin is as follows:

24 acetyl-S-CoA + 42 NADPH $\longrightarrow$ 3 palmitic acid + 42 NADP

3.5 glucose $\longrightarrow$ 21 CO_2 + 42 NADPH

0.5 glucose $\longrightarrow$ 1 glycerol.

Thus, where glucose provides the NADPH, 4 moles of glucose are oxidised in the synthesis of 1 mole of tri-palmitin or 89 g of glucose are used in the formation of 100 g of fat.

It appears that in adipose tissue, glucose oxidation provides most of the NADPH for fat synthesis. There is, however, evidence (Baumann and Davis 1975; Moore and Christie 1981) that a proportion of the NADPH (up to 50%) for long chain fatty acid synthesis in mammary tissue may arise through other reactions than the phosphogluconate pathway (eg: dehydrogenation of isocitrate to 2-oxoglutarate) but relative contribution of this pathway has not been truly quantified (Vernon 1981).

As discussed earlier, there is strong evidence that body fat arises largely from dietary fat on diets in which fat is present in average amounts. Milk fat is synthesised from approximately equal quantities of VFA and dietary long chain fatty acids (Linzell 1968).

The need for glucose appears to depend to a large extent on the amounts of long chain fatty acids absorbed, since fat synthesis in body weight gain (which is quite a small proportion of gain in early growth but increases in fattening animals) and milk fat synthesis (which can be a very high demand for fat) will require glucose to be oxidised, and this increases with the amount of fat that has to be synthesised. Moreover, if glucose requirements are increased by the need to synthesise fat (e.g., because of the low availability of dietary LCFA) this could lead to excessive demand for glucose and an increased deamination of amino acids to maintain glucose availability. Thus, the requirements for dietary bypass protein may be increased where propionate production in the rumen is low, and particularly where dietary fat is low. This is typical of crop residues. If long chain fatty acid synthesis were limited by glucose availability, the animal would have to increase heat production by 'burning off' acetate in futile cycles (essentially uncoupled oxidative phosphorylation) and/or it would decrease its feed intake. Thus the availability of long chain fatty acids could be a determinant of the level of 'requirements' for glucose (and indirectly essential amino acids) and could modify voluntary feed intake. These effects may be different in the growing, as compared to the fattening, ruminant.

Interactions among Nutrients

The major conclusion that arises from the above discussion is that it is the balance among the three major groups of nutrients (amino acids, glucose and long chain fatty acids) which determines the rate of production and the efficiency with which the metabolisable energy is utilised for a particular productive purpose (e.g. work, growth, reproduction and lactation).

The requirements for amino acids are well recognised. The roles of glucose and long chain fatty acids have become more apparent as a result of the increasing understanding of the constraints to animal production on so-called 'low quality' diets (Leng and Preston 1976, 1985; Preston and Leng 1980, 1985).

LCFA, AMINO ACIDS AND GLUCOSE FOR CONVENTIONAL FEEDING STANDARDS

The relationship of nutritional characteristics of a feed resource or forage with predicted animal productivity is the basis of all feeding standards. Information from chemical analysis combined with assumptions on the efficiency of utilisation of 'energy' and amino acids for production have been used in tables of 'feeding standards' which interpret chemical analyses of feed resources in terms of their capacity to supply energy, amino acids, vitamins and minerals required for a particular productive purpose. However, these assumptions are too generalised for the wide range of feeds and feeding systems used, and the relevance of present methods of feed analysis and of 'feeding standards' must be challenged in the light of the above discussion.

A new approach to feeding standards and feed evaluation is necessary, since:
- the microbial growth efficiency in the rumen cannot be predicted with any precision by any form of feed analysis;
- feed intake on a diet that is deficient in the critical nutrients bears no relationship to digestibility, but is influenced by supplementation, and these effects will be different for different physiological states i.e. early growth, fattening, pregnancy and lactation;
- availability of ammonia or amino acids to the rumen microbes, or amino acids to the animal, cannot be inferred from the crude protein content of the diet;
- the efficiency of utilisation of metabolisable energy is largely determined by the quantities and balance of glucogenic energy, long chain fatty acids and essential amino acids absorbed by the animal which in turn vary for different physiological states.

In the early 1960s, Professor Max Kleiber expressed a similar concern for these issues and stated (as quoted by Kronfeld 1982) '. . . metabolisable energy is not a homogeneous entity; instead it represents an assembly of nutrients or metabolites each of which is used with a specific efficiency for a particular purpose'. To this could be added that the relative amounts of these

nutrients, and their interactions, affect the efficiency of energy utilisation.

The above discussion centres on the inability of feed analysis to indicate the efficiency of rumen function and the balance of critical nutrients available. However, there are a number of other major criticisms of feed evaluation methods and analysis to compound the difficulties and uncertainties of applying these when developing feeding systems. It is recognised that no system will be perfect and although there is a major need to find an economic system for feed evaluation to replace the standard methods, this is not yet available. The presently suggested approach provides only guidelines for ration formulation or the need for supplementation, and emphasises maximising production for the available resources rather than providing nutrients to attain the genetic potential of the animal (Preston and Leng 1985).

Digestible Energy to Metabolisable Energy

In general, the relationship of digestible energy to metabolisable energy assumes that a constant proportion of the digestible energy (i.e. about 80%) is unavailable, largely as gaseous energy losses (methane) and the heat of fermentation. Here again, both these values are variables since methane loss is dependent on fermentative patterns (i.e. a high propionate fermentation lowers methane production relative to a high acetate fermentation, and the heat of fermentation is dependent on the proportion of the microbes that are lysed in the rumen). Both parameters are manipulable; for example, propionate production in the rumen may be altered by chemical additives (e.g. monensin or rumensin) (Chalupa 1980). Bacterial lysis is variable, depending on diet (Nolan and Leng 1972; Nolan and Stachiw 1979), and is often a function of intermittent feeding, since bacteria die and are lysed when without substrate for as little as two hours (Hespell 1979); the presence of a large protozoal population may increase lysis rate of bacteria considerably and thus reduce protein availability to the animal (Bird and Leng 1985) since they engulf and digest bacteria (Coleman 1975).

METABOLISABLE ENERGY TO NET ENERGY

The conversion of metabolisable energy to net energy depends on assumptions of the efficiencies of use of metabolisable energy for maintenance and for synthesis of milk, meat, wool, etc. The foregoing discussion indicates that this is a particularly misleading concept, and the established conversion factors (ARC 1980) at times bear no relationship to the attained efficiencies. The evidence for this has been reviewed and these variable efficiencies appear to be dependent on the proportion of the metabolisable energy absorbed as glucogenic energy, long chain fatty acids and essential amino acids.

CRUDE PROTEIN TO AMINO ACIDS ABSORBED

It is generally accepted that a measure of crude protein in a feed does not indicate the likely contribution of dietary N to (i) ammonia, (ii) the amino acid pool in the rumen or (iii) the protein escaping ruminal fermentation to be digested in the small intestine. It is also recognised that the supply of fermentable N and the absorption of amino acids are subject to a large number of factors within the animal and the feed, which include:
- dietary components which effect microbial populations and liquid outflow from the rumen;
- the pH of rumen fluid;
- presence of secondary plant components (e.g. tannins);
- the effects of intermittent feeding. Feeding six times a day, rather than once, increased microbial growth efficiency twofold (Tamminga 1981, cited by Twigge and Van Gils 1984).

Forage evaluation must take these factors into account.

Forage Evaluation Objectives

The specific objectives of a forage evaluation program must be carefully defined. The evaluation will be different where the intention is to produce:
- pasture that will be grazed without other inputs;
- fermentable biomass which is to be supplemented to balance the available nutrients;
- a forage to use as a supplement to provide critical nutrients to diets based on other (locally available) fermentable carbohydrate resources, such as crop residues or agroindustrial by-products.

Forages as the Feed Source

At a minimum, these must provide the rumen with all essential nutrients for efficient fermentative digestion, and provide bypass nutrients to correct any imbalances in the nutrients required by the animal for any demanding physiological states, such as lactation. As a basis for discussion, the following are indicative of a good quality forage:
- high feed digestibility (i.e. in excess of 65%);
- soluble protein in the diet providing about 30g N/kg digestible dry matter (DDM);
- bypass protein providing about the same amount of protein as arises from microbes, i.e. 200g protein/kg DDM intake.
- level of fat in the diet approaching that of temperate pastures, i.e. 4–8% dry matter.

- glucogenic energy comprising a high proportion of the VFA energy absorbed from the rumen, i.e. >25%

A Source of Biomass for Ruminant Production

Forages used as a source of biomass need high yield per hectare, a high digestibility and freedom from toxic components. The production of biomass (e.g. sugar cane or napier grass) in this way is outside the scope of the paper. The likely requirement for supplements to maximise the utilisation of such a diet has been reviewed by Preston and Leng (1984).

Forage as a Supplement

The criteria of quality here will be governed by the likely deficient nutrients in the available feed resources that are fed as the basal diet (which in the context of this symposium is likely to be a straw-based diet or dry pasture). The deficient nutrients in straw are now fairly well defined, and the forage, if it is to be an efficient supplement, must supply in order of priority some of the following (Preston and Leng 1984):
- fermentable N, i.e. ammonia in the rumen to meet a minimum level;
- bypass protein;
- long chain fatty acids;
- minerals — including S, Ca, P, and other macro minerals and trace elements according to locality;
- bypass starch where the animal's requirements for glucose are high.

As the supplement must be generally kept below 15–20% of the total feed intake, the order of requirements for the above nutrients is five times that indicated for a complete feed. This is almost impossible, and the forage can necessarily only provide one or two components. For instance, it may be important to provide a source of fermentable N (because of the unavailability of urea) to allow the efficient fermentation of a diet containing 80% straw. To accomplish this, almost all the N in the forage supplement (which may be 15–25% crude protein) must be fermentable in the rumen. Conversely, if the objective is to provide bypass protein (the ammonia being provided as urea in, for example, a molasses nutrient block (Leng 1984)), to be effective all the protein in the legume must be protected from rumen fermentation. Legumes appear to be higher in fat (5–10%) than grass (4–8%) and much higher than straws (about 1% fat) or mature dry pasture, which contains only 1–2% fat. Therefore, such supplements are likely to double the fat in a diet based on straw, when added at 20% of the total diet.

Forages as Complete Feed

Earlier discussions emphasised that for maximum efficiency of use of forages, animal productivity per head should be maximised. Moreover, the primary overriding factors involved in high productivity are intake, digestibility and the balance of critical nutrients. These are not independent but interactive, since intake and digestibility are interdependent and both are influenced by the balance of nutrients absorbed. The amount of feed consumed is a major indication (and determinant) of feed quality, the other is the efficiency with which this digestible energy is used for production.

Feed Intake Control

Appetite control is a highly complex and interactive phenomenon (Weston 1983) but a few simple effects can be outlined which can dominate feed intake. These include the ability of the feed to support an efficient rumen system i.e. provide N, S, P, Ca, trace minerals, a balance of soluble sugars to fibrous materials, a balance of microbes supported, and the presence of unpalatable components (such as tannins). The criteria of an efficient rumen include:
- a high rate of fermentation;
- a high microbial cell yield (microbial protein digested per unit of VFA produced or feed intake), which is less important if dietary bypass protein is high;
- a high propionate fermentation rate;
- a high rate of comminution for low digestibility feeds to particle sizes that can be removed rapidly from the rumen (i.e. >2 mm).

Efficient Utilisation of ME

Efficient utilisation of a feed by the animal is wholly dependent on the availability of critical nutrients for the particular productive purpose. These include the balance of available critical nutrients – amino acids, LCFA, glucose or glucogenic intermediates, and energy substrates, which can be any of the first three in combination with acetate and butyrate.

As production (milk secretion, growth, etc.) is a continuous process, the timing of availability of nutrients is also very important but is not easily determined.

Forage Evaluation

In order to evaluate forages for their potential to support high levels of ruminant production, several considerations are necessary involving interactive and interdependent factors. The ones that are of major concern include, in order of priority, voluntary intake, digestibility, extent of ruminal digestion of the fibrous

components and efficiency of microbial growth, and the capacity of constituent proteins and starches to avoid rumen fermentation and be digested in the intestines.

Toxic components are important, but mostly their presence results in clinical symptoms of toxicity or the animal reduces its feed intake.

The previous discussion suggests that the forage evaluation must essentially consists of three distinct phases, including rapid screening (where availability of forages are at the plot trial stage), measurement of voluntary intake of the forage and finally growth or production trials.

Screening Forages

For logistic and economic reasons simple laboratory approaches are needed to ascertain: 1) digestibility (both rate and potential or total); 2) chemical analysis for N content, and for potential fermentable N and bypass protein and its intestinal digestibility; and 3) chemical analysis for long chain fatty acids.

MEASUREMENT OF DIGESTIBILITY

Essentially three methods are available: 1) prediction of digestibility of the forage from measurements of crude fibre or neutral and acid detergent fibre; 2) prediction of in vivo digestibility from in vitro digestibility measurements (Tilley and Terry 1963); 3) measurements of digestibility and rate of digestibility by using the nylon bag approach.

The selection of a method is dependent on many factors. Methods based on fibre analysis have been established, and are routine in many laboratories, but there appears to be very little confidence amongst researchers in taking the step to prediction of in vivo digestibility from these analyses. The predictive approach does not require the use of animals and often leads to laboratory specialisation, which never develops to the stage where animals are used for the final assay of quality.

These analyses are useful where the feeds being analysed are high in digestible nutrients and are already used extensively in compounded feeds, and where relationships between intake and digestibility have been established. However, the need to establish (or check) these relationships for a 'new' forage, and the uncertainty of prediction in all circumstances suggests that these have only limited use. Also, these approaches do not provide information on the adequacy of the feed to support an efficient microbial digestion.

The use of in vitro digestibility is also based on a highly significant relationship between in vitro and in vivo digestibilities. There are still the uncertainties
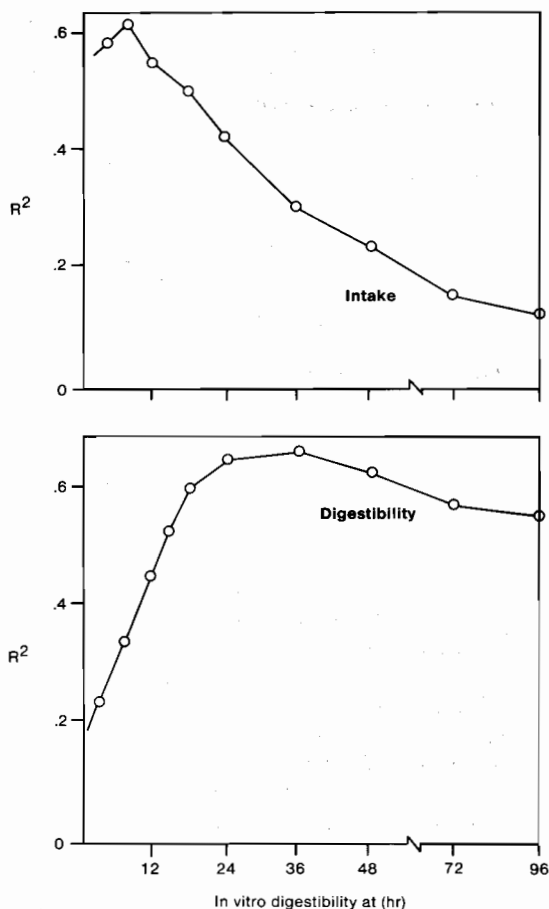

Fig. 6. The variations in the correlation (R^2) between in vitro digestibility at specific incubation times and the voluntary intake of a range (181) of temperate forages; and the correlation for in vitro/in vivo relationships of digestibility for various incubation periods for the same forages (Van Soest 1982).

associated with prediction, but the major difficulty is that for most forages the rate of digestibility and also the rate of comminution of the fibre are most important aspects determining feed intake. Again the method does not predict whether an efficient rumen would result.

The relationship between digestibility and voluntary intake even for temperate forages is not very highly correlated. At the best this relationship has a correlation coefficient of 0.8. This correlation of intake and in vitro digestibility is highest when the incubation period is only 6 or 12 hours, and may be very low when the digestibility is determined over 48 hr (r = 0.4) (Fig. 6) indicating that intake is largely a function of the more readily fermentable cell wall constituents. These components are lower in tropical species relative to the temperate species used to establish the relationships

shown in Fig. 6. On the other hand the correlation of in vitro and in vivo digestibility is more or less constant after about a 24 hr incubation ($r = 0.8$). The low predictability of feed intake and the uncertainties of the relationships between feed intake and digestibility for tropical forages (see Minson 1982) indicated that the only recourse eventually is to ascertain voluntary intake for a forage directly. The plant and soil factors that influence the relationships between voluntary intake of a forage and digestibility have been discussed by Minson (1982).

The use of nylon bags to obtain digestibility values is fraught with practical difficulties, and also requires a large number of safeguards as well as standardisation. But it has major advantages, which include the relatively simple facilities required and the direct measurement of digestion rate and potential digestibility. (Ffoulkes, these proceedings).

CHEMICAL ANALYSIS FOR N CONTENT

Crude protein content estimated as Kjeldahl-N is absolutely essential for forage evaluation. This analysis does not, however, indicate the extent of the crude protein breakdown in the rumen, nor does it evaluate the potential to supply bypass protein. As a first screening, soluble and insoluble-N will give useful guides, but in a second screening the capacity of the feed to sustain rumen ammonia levels above a critical level (say 150mgN/l) (Krebs and Leng 1984) must be ascertained.

CHEMICAL ANALYSIS FOR LCFA

Simple ether extracts will give some indication of the availability of these components. This includes a wide variety of compounds, including waxes, and it would be more reliable to depend on analysis of the long chain fatty acid components.

Maturity of Pastures

Many researchers have demonstrated that stage of maturity affects the feeding value of forages. However, because of seasonal variations, growth of forages is intermittent (except for shrub or tree forages) and even heavy stocking rates are necessary to maintain tropical and subtropical pastures in a young vegetative growth (this often results in weed infestation). Low feed availability in these conditions usually limits animal production. Even in well managed pastures where grazing is controlled, animals usually have access to relatively mature plant materials. In countries with pronounced seasons (i.e. those with wet/dry or warm/cold seasons) animals depend for long periods on mature or mature-but-dead plant materials. Forage evaluation must take this into account, and therefore forages must be evaluated over full growth periods.

Under some circumstances, however, the ability of the plant when it matures and senesces to retain nutrient levels, particularly N, is highly significant in its evaluation. Leucaena leaf, even when it falls off the shrub, appears to retain a relatively high N content.

Forage Assessment

VOLUNTARY FEED INTAKE

This is the most important criterion of quality of a forage in terms of its potential to support animal productivity. If forage meets criteria of quality, then voluntary feed intake will be high (i.e. 2.5–3.0% of body weight). Where analysis indicates deficiencies of critical nutrients, say fermentable N (as indicated by rumen ammonia) and long chain fatty acids (as indicated by ether extract), then a second intake measurement is needed where these critical nutrients are given in a supplement.

Voluntary feed intake encompasses most of the aspects of feed quality, and should be measured under highly standardised conditions with animals which have a high potential intake, i.e. young animals or animals that have been caused to lose considerable weight previously.

EFFICIENCY OF RUMEN FERMENTATION

A particularly high-yielding forage may have a low intake by ruminants for a variety of reasons, including the presence of toxic elements or deficiencies in essential rumen microbial nutrients (e.g. NPN or trace minerals such as cobalt), and an assessment of rumen function should accompany the measurement of voluntary feed intake. There are a number of critical analyses that may indicate the relative efficiency, including rumen measurements of the following:
- level of rumen ammonia;
- level of sulfide-S;
- digestibility (in sacco) and rate of digestibility of a standard material (cotton wool or a high digestibility forage);
- microbial pool size, as indicated by microbial protein/ml;
- proportion of volatile fatty acids as propionate.

Ammonia levels indicate the sufficiency of fermentable N and should remain above 150 mg/l at all times (Krebs and Leng 1984). Sulfide in rumen fluid is another microbial nutrient likely to be in short supply, and should be above 10 mg/l (Bray and Till 1975).

The activity of fibrolytic organisms can be ascertained by the disappearance rate of a relative pure fibre source from nylon bags in the rumen. The microbial protein that can be precipitated or centrifuged from rumen fluid may also indicate the activity of the fibrolytic organisms, and will indicate whether specific

groups of organisms (protozoa vs bacteria) are enhanced.

It seems unlikely that starches of forages escape rumen fermentation. However, where seed heads are present it is almost certain that there will be a variable escape and variable digestion of seeds in the intestine. There is no information on the potential for seed of pasture plants or legumes to bypass the rumen.

Where there are no seeds in a forage then the glucose requirements of the animal will depend mainly on propionate production in the rumen, which is indicated by level (Leng 1970).

PRODUCTION MEASURES

Following preliminary screening, and measures of voluntary feed intake and the efficiency of rumen fermentation, forage assessment must finally depend on the attained productivity of ruminants given that feed as the total diet, or supplemented with the likely deficient critical nutrients. In general, final assessment of a feed must compare production of groups of sheep each fed the following diets:
• a standard balanced feed to establish potential productivity of the test animals under the prevailing environmental condition;
• the test forage fed ad libitum;
• the test forage given ad libitum and supplemented with any likely critical nutrients, including a complete mineral mix, nutrients for microbial metabolism and bypass nutrients for productive purposes.

FORAGES AS SUPPLEMENTS

This is mainly dependent on their capacity to provide the nutrients that are deficient in the basal feed. This includes their ability to provide essential microbial nutrients, and also critical nutrients to meet the animals' requirements and increase the efficiency of feed utilisation.

Thus the criteria for evaluating forages in this capacity depends on the basal diet. However, where the basal diets are mature fibrous feeds, these are almost always deficient in total N, and low in fat, protein and sometimes minerals.

Although forage supplements to these mature fibrous feeds are often used to increase digestible energy intake, their mode of action in stimulating productivity is in general diffuse, and may be due to the role of providing critical nutrients. Often it has little or nothing to do with the digestible energy supplied per se. Where supplemental forages are consumed readily and increase total intake, they are almost certainly supplying nutrients which overcome an appetite suppression, thus increasing efficiency of digestion and efficiency of utilisation of metabolisable energy.

From the above discussion, a supplement to a basal low-N, low-digestibility forage should provide fermentable N (for rumen ammonia), minerals, bypass protein and long chain fatty acids. The major criteria of quality of a forage supplement are: 1. crude protein; 2. long chain fatty acids. The content of bypass protein may then be assessed in a growth, milk yield or wool growth assay (Leng et al. 1984).

Conclusions

The accepted feed evaluation systems for energy and protein nutrition of ruminants have been generally developed in temperate countries, and can be used where management is intensive and diets are compounded from a limited number of ingredients rich in energy and protein. There are serious doubts about the use of these systems for forage evaluation.

There is a need to develop feed evaluation systems that will allow the prediction of the quantities and balances of nutrients that become available to the animal from a feed. Considerable research is needed to delineate the interactions among the different absorbed nutrients. These interactions almost certainly affect the requirements of the animal for glucose, which appears to have a major effect on the amount of a forage consumed and the efficiency of its use for productive purposes.

Feed analysis, based on proximate analysis and/or detergent fibre analysis, appears to be unnecessary because of the uncertainties of relating these measures to specific nutrient availability. The fibre analyses do not provide information on the adequacy of a forage to provide for an efficient rumen, nor to provide those dietary nutrients required to balance the absorbed nutrients arising from fermentative digestion, for maximum efficiency of conversion of the feed to products.

The approach that is recommended relies on rapid screening of rate, potential digestibility and total protein. Plants selected for high digestibility and crude protein content are then assessed for their capacity to support both an efficient rumen ecosystem and a high voluntary intake. The final assessment must be that of the production trial.

References

ARC 1980. The Nutrient Requirements of Ruminant Livestock. Commonwealth Agricultural Bureaux, Farnham Royal, U.K.

Armstrong, D.G., and Blaxter, K.L. 1957. The heat increment of steam-volatile fatty acids in fasting sheep. Br. J. Nutr., 11, 247–272.

Armstrong, D.G., Blaxter, K.L., and Graham, N.McC. 1957. The heat increment of mixtures of steam-volatile fatty acids in fasting sheep. Br. J. Nutr., 11, 392–408.

Armstrong, D.G., Blaxter, K.L., Graham, N.McC., and Wainman, T.W. 1958. The utilization of the energy of two mixtures of steam-volatile fatty acids by fattening sheep. Br. J. Nutr., 40, 163–167.

Baumann, D.E. and Davis, C.L. 1975. Regulation of lipid metabolism. In: McDonald, I.W., and Warner, A.C.I. ed., Digestion and Metabolism in the Ruminant. University of New England Publishing Unit, Armidale, 496–509.

Bergman, R.N. and Azen, S.P. 1974. Measurement error inherent in the determination of hepatic glucose balance. J. App. Physiol., 6, 269–272.

Bird, S.H. and Leng, R.A. 1985. Productivity responses to eliminating protozoa from the rumen of sheep. In: Leng, R.A., Barker, J.S.F., Adams, D.B., and Hutchinson, K.J. ed., Biotechnology and Recombinant DNA Technology in the Animal Production Industries, Reviews in Rural Science. No. 6, University of New England Publishing Unit, Armidale, 109–117.

Blaxter, K.L. 1962. The Energy Metabolism of Ruminants. Hutchinson, London.

Bray, A.C. and Till, A.R. 1975. Metabolism of sulphur in the gastro-intestinal tract. In: McDonald I.W., and Warner, A.C.I., ed., Digestion and Metabolism in the Ruminant. University of New England Publishing Unit, Armidale, NSW, 243–260.

Chalupa, W. 1980. Chemical control of rumen microbial metabolism. In: Ruckebush, Y., and Thivend, P., ed., Digestive Physiology and Metabolism in the Ruminant. MTP Press, Lancaster.

Coleman, G.S. 1975. Interrelationship between rumen ciliate protozoa and bacteria. In: McDonald, I.W., and Warner, A.C.I., ed., Digestion and Metabolism in the Ruminant, University of New England Publishing Unit, Armidale, 149–164.

Cridland, S.W. 1984. Studies on the flows of propionate carbon to glucose in sheep. PhD Thesis, University of New England, Armidale.

Elliott, R., Ferreiro, H.M., Priego, A., and Preston, T.R. 1978. Rice polishings as a supplement in sugar cane diets: the quantities of starch (glucose polymers) entering the proximal duodenum. Trop. Anim. Prod., 3, 30–35.

Faichney, G.J. 1975. The use of markers to partition digestion within the gastro-intestinal tract of ruminants. In: McDonald, I.W., and Warner A.C.I., ed., Digestion and Metabolism in the Ruminant, University of New England Publishing Unit, Armidale, 277–291.

Hespell, R.B. 1979. Efficiency of growth by ruminal bacteria. Fed. Proc., 38, 2707.

Krebs, G., and Leng, R.A. 1984. The effect of supplementation with molasses/urea blocks on ruminal digestion. Proc., Soc. Anim. Prod., 15, 704.

Kronfeld, D.S. 1982. Major metabolic determinants of milk volume, mammary efficiency and spontaneous ketosis in diary cows. J. Dairy Sci., 65, 2204–2212.

Leng, R.A. 1970. Formation and production of volatile fatty acids in the rumen. In: Phillipson, A.T., ed., Physiology of Digestion and Metabolism in the Ruminant. Oriel Press, Newcastle-Upon-Tyne, 406–421.

1982. Modification of rumen fermentation. In: Hacker, J.B., ed., Nutritional Limits to Animal Production from Pastures. CAB, Farnham Royal, U.K., 427–453.

1984. The potential of solidified molasses-based blocks for the correction of multinutritional deficiencies in buffaloes and other ruminants fed low-quality agro-industrial byproducts. IAEA Occasional Publications.

Leng, R.A., Davis, J., and Hill, M.K. 1984. Estimation of

bypass protein based on wool growth. Anim. Prod. in Aust., 15, 431–433.

Leng, R.A., Kempton, T.J., and Nolan, J.V. 1977. Non-protein nitrogen and bypass proteins in ruminant diets. AMRC Review, 33, 1–21.

Leng, R.A., and Preston, T.R. 1976. Sugar cane for cattle production: Present constraints, perspectives and research priorities. Trop. Anim. Prod., 1, 1–22.

1985. Constraints to the efficient utilisation of sugar cane and its byproducts as diets for production of large ruminants. In: Australian Fibrous Residues Research Network — Symposium 1985, Bogor, Indonesia.

Leng, R.A., Steel, J.W., and Luick, J.R. 1967. Contribution of propionate to glucose synthesis in sheep. Biochem. J., 103, 785–790.

Lindsay, D.B. 1970. Carbohydrate metabolism in ruminants. In: Phillipson, A.T., ed., Physiology of Digestion and Metabolism in the Ruminant. Oriel Press, Newcastle-Upon-Tyne, 438–451.

1983. Growth and fattening. In: Rook, J., and Thomas, P.C., ed., The Nutritional Physiology of Farm Animals, Longman, N.Y., 261–313.

Lindsay, J.A., Mason, G.W.J., and Thomas, M.A. 1982. Supplementation of pregnant cows with protected proteins when fed tropical forage diets. Proc. Aust. Soc. Anim. Prod., 14, 67–78.

Linzell, J.L. 1968. The magnitude and mechanisms of the uptake of milk precursors by the mammary gland. Proc. Nutr. Soc., 27, 44–52.

MacRae, J.C. 1975. The use of re-entrant cannulae to partition digestive function within the gastro-intestinal tract of ruminants. In: McDonald, I.W., and Warner, A.C.I., ed., Digestion and Metabolism in the Ruminant, University of New England Publishing Unit, Armidale, 261–276.

Minson, D.J. 1982. Effects of chemical and physical composition of herbage eaten upon intake. In: Hacker, J.B., ed., Nutritional Limits to Animal Production from Pasture. ÇAB, Farnham Royal, U.K., 165–182.

Moore, J.H., and Christie, W.W. 1981. Lipid metabolism in the mammary gland of ruminant animals. In: Christie, W.W., ed., Lipid Metabolism in Ruminant Animals, Pergamon Press, Oxford, 227–277.

Nolan, J.V., and Leng, R.A. 1972. Dynamic aspects of ammonia and urea metabolism in sheep. Br. J. Nutr., 27, 177–194.

Nolan, J.V., and Stachiw, S. 1979. Fermentation and nitrogen dynamics in Merino sheep given a low-quality roughage diet. Br. J. Nutr., 42, 63–80.

Oldham, J.D. 1980. Amino acid requirements for lactation in high yielding dairy cows. In: Haresign, A.W., ed., Recent Advances in Animal Nutrition. Butterworth, London, 33–43.

1984. Protein – energy interrelationships in dairy cows. J. Dairy Sci., 67; 1090–1114.

Ørskov, E.R. 1970. Nitrogen utilization by the young ruminant. In: Swan, H., and Lewis, D., ed., Proceedings of the Fourth Nutrition Conference for Feed Manufacturers. J. and A. Churchill, London, 20–35.

Ørskov, E.R., and Allen, D.M. 1966. Utilization of salts of volatile fatty acids by growing sheep. I. Acetic and propionate and butyrate as sources of energy for young growing lambs. Br. J. Nutr. 20, 295–305.

Ørskov, E.R., Grubb, D.A., and Smith, J.S. 1979. Efficiency of utilization of volatile fatty acids for maintenace and energy retention by sheep. Br. J. Nutr. 41, 541–552.

Pigden, W.J. 1972. Sugar cane as livestock feed. Report to Caribbean Development Bank, Barbados.

Preston, T.R., Carcano, C., Alvarez, F.J., and Guttierez, D.G. 1976. Rice polishings as a supplement in a sugar cane diet: effect of level of rice polishings and processing the sugar cane by derinding or chopping. Trop. Anim. Prod., 1, 15–16.

Preston, T.R., and Leng, R.A. 1980. Utilization of tropical feeds by ruminants. In: Ruckebush, Y., and Thivend, P., ed., Digestive Physiology and Metabolism in Ruminants. MTP Press, Lancaster, 621–640.

1984. Supplementation of diets based on fibrous residues and byproducts. In: Sundstol, F., and Owen, E., ed., Straw and Other Fibrous Byproducts as Feed, Elsevier Press, Amsterdam, 373–413.

1985. Matching Livestock Systems to Available Feed Resources, ILCA, Addis Ababa.

Ravelo, G., Fernandez, A., Bobadilla, M., Macleod, N.A., Preston, T.R., and Leng, R.A. (1978). Glucose metabolism in cattle on sugar cane based diets: a comparison of supplements of rice polishings and cassava root meal. Trop. Anim. Prod., 3, 12–18.

Roy, J.H.B., Balch, C.C., Miller, E.L., Ørskov, E.R., and Smith, R.H. 1977. Calculation of the N-requirement for ruminants from nitrogen metabolism studies. In: Protein Metabolism and Nutrition. EAAP, Wageningen, 126–129.

Santana, A., and Hovell, F.O.D. 1979. Degradation of various sources of starch in the rumen of Zebu bulls fed sugar cane. Trop. Anim. Prod., 4, 107–108 (abstract).

Siddons, R.C., Beever, D.E. and Nolan, J.V. 1982. A comparison of methods for the estimation of microbial nitrogen in duodenal digesta of sheep. Br. J. Nutr. 48, 377–389.

Thomson, D.J. 1978. Utilization of the end products of digestion for growth. In: Osbourne, D.F., Beever, D.E., and Thomson, D.J., ed., Ruminant Digestion and Feed Evaluation. Agricultural Research Council, London, 12.1–12.5.

Thornton, R.F., and Tume, R.K. 1984. Fat deposition in ruminants. In: Barker, S.K., Gawthorn, J.M., Mackintosh, J.B., and Purser, D.B., ed., Ruminant Physiology: Concepts and Consequences, University of Western Australia, Perth, 289–298.

Tilley, J.M.A., and Terry, R.A. 1963. A two stage technique for in vitro digestion of forage crops. J. Br. Grssld Soc., 18, 104–111.

Twigge, J.R., and Van Gils, L.G.M. 1984. Practical aspects of feeding protein to dairy cows. In: Haresign, W., and Cole, D.J.A., ed., Recent Advances in Animal Nutrition. Butterworths, London, 201–217.

Van Soest, P.J. 1982. Nutritional Ecology of the Ruminant. O. and A. Books Inc., Oregon, USA.

Veira, D.M., Ivan, M., and Jui, P.Y. 1984. The effect of ciliate protozoa on the flow of amino acids from the stomach of sheep. Can. J. Anim. Sci., 64(Suppl.), 22–23.

Vernon, R.G. 1981. Lipids in the adipose tissue of ruminant animals. In: Christie, W.W., ed., Lipids in the Adipose Tissue of Ruminant Animals. Pergamon Press, London, 280–362.

Waldo, D.R. 1973. Extent and partition of cereal grain starch digestion in ruminants. J. Anim. Sci., 37, 1062–1074.

Weston, R.H. 1983. Principles of feed intake control in ruminants given roughages. In: Doyle, P.T., ed., The Utilization of Fibrous Agricultural Residues as Animal Feeds. Proceedings of the 3rd annual workshop of the Australian–Asian Fibrous Agricultural Residues Research Network, held at The University of Peradeniya, Sri Lanka, 14–27.

Maximising the Effective Measurement of Digestibility *in sacco*

D. Ffoulkes*

THE main purpose of this paper is to encourage the standardisation of the rumen bag technique and its use in the simplest form to evaluate locally available feeds for their potential use in ruminant diets. Study objectives include the prediction of apparent digestibility in vivo, the measurement of degradability of potential sources of fermentable carbohydrate and bypass protein. Studies on rumen processes will be discussed, together with material methods and some limitations to the technique.

The nutritive value of feeds for ruminant diets cannot be predicted from proximal analyses alone as they do not give a measure of fermentative and intestinal digestion. The relative importance of ruminal and post-ruminal digestion has been reviewed by a number of authors including Ørskov (1978) Kempton et al. (1977) and Leng (these proceedings).

A number of laboratory techniques have been developed to predict the digestion of feeds in the rumen. The assumption that the relationship between in vitro and in vivo digestibility is the same is not always valid because of the inherent differences between the two methods of measurement. It is preferable to measure digestibility in vivo.

The evaluation of large numbers of feeds in the intact animal from feed intake and faecal output is often not practical. The rumen bag technique, designed for an animal fitted with a rumen cannula, allows fermentative digestion of many feed samples to be estimated simultaneously. Furthermore, the relative rates of digestion (degradability) of feeds and their components, and the interactions between feeds and rumen processes, can also be studied.

Objectives

There are several objectives to this work:
- Prediction of apparent digestibility in vivo; Aerts et al. (1977) advocated the use of rumen bags for predicting in vivo organic matter (OM) digestibility. Samples in bags were placed in the rumen for 48 h and

after removal and washing, were incubated in pepsin-HC1 solution at 39°C for 48 h. The washed residue was then analysed for ash content.

- Measurement of rate of ruminal digestion of OM; the importance of rate of digestion in relation to voluntary intake by ruminants was discussed by Balch and Campling (1962). The potential rate of breakdown of carbohydrates in feeds can be measured simply as dry matter (DM) loss after 24 h with reference to a known standard. There are three components to this measurement (soluble, insoluble but readily fermentable, and refractory carbohydrate) and the relative digestibilities of these components may be studied over time.

- Evaluation of supplements; some nutrients (e.g. amino acids and glucose precursors) that are required by the animal in addition to those supplied from the end products of fermentation, are most efficiently utilised when they escape rumen digestion (Kempton et al. 1977; Ørskov 1970). The rates of disappearance from rumen bags of DM, protein or starch are used in conjunction with known standards to assess the potential of feedstuffs to provide supplementary nutrients in the small intestine.

- Rumen studies; manipulation of the rumen ecosystem to give optimal conditions of fermentation can also be studied with rumen bags. Ffoulkes et al. (1983) studied the sugar-fibre interactions in molasses-based diets using the DM loss of cotton wool in bags as an indicator of fibre digestibility. Similarly, the effect of different levels of rumen ammonia on fibre digestion were examined by Krebs and Leng (1984) using cotton wool and a standard fibre source of ground oaten chaff.

- Basal diets; measurements of rate of digestion of feeds in rumen bags will vary with different basal diets (Ffoulkes 1985). Normally, rations that furnish optimal rumen conditions are used for evaluating the nutritive value of the feedstuff. On poor quality basal diets, comparative standards become important when interpreting the results. If the objective is to study rumen processes by imposing treatments on the basal diets, then standard materials are used in the bags.

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Materials and Methods

Experimental Design

Mehrez and Ørskov (1977) suggested that the sources of variation in DM loss from bags could be minimised by replicating samples in at least three animals using one bag/animal and two experimental periods (total of 6 bags/feed sample). Perdok (pers. comm.) recommended 2–3 replicate bags/animal for greater precision.

For simple measurements of digestibility, bags are placed in the rumen for 24 h (Leng, pers. comm.) or 48 h (Aerts et al. 1977). Degradation studies involve incubating a series of samples in the rumen for different periods. Total incubation time (potential degradation) will vary according to the type of feedstuff. For most roughages, the loss of material from bags is measured after 12, 24, 36 and 48 h. Concentrates may need shorter intervals of time (e.g. 4, 8 and 12 h) while slowly digested materials such as untreated straws will probably require up to 72 h. In addition, one bag per treatment should be washed without incubation to provide an estimate of the soluble pool in the sample. Standards of known digestibilities at 24 or 48 h are also included as a reference standard.

Rumen Bag Material

The standard material used is polyester (dacron) (obtained from Swiss Screens, 15 Anvil Rd, Seven Hills, NSW 2147, Australia) with a single fibre weave and pore size of $44/\mu m$. It is recommended that a bag size of 9×17 cm is used for 5 g of sample (Mehrez and Ørskov 1977). Bags of 7×15 cm were used for straws (3 g) by Perdok (pers. comm.). The corners at the bottom of the bag are rounded to prevent trapping of residues.

Preparation of Sample

Dry feeds are prepared by hammer-milling through a 2.5 mm screen. The preparation of fresh forage, described by Minor and Hovell (1979), involves chopping the leaf (25 mm² pieces) and shredding these in a domestic homogeniser for 20–30 sec to break up the leaf structure. Concentrates (cereals and protein meals) are not processed further, unless the comparative digestibilities of specific nutrients in different samples are to be examined, in which case the supplement should be ground to the same particle size before incubation.

Preparation of Bags

Bags containing a weight (e.g. marble or bijou bottle) of about 40 g are tared (weighed) before loading with 5 g of sample; the total weight is then recorded and the bags tied with either a draw-string or nylon fishing line. There should be at least 25 cm of cord between the bag and the cannula in sheep (Mehrez and Ørskov 1977) and 50 cm in cattle (Rodriguez 1968) to allow free movement of the bag in the rumen. Alternatively, bags may be tied to a flexible plastic pipe which is inserted into the rumen. Bags should be wetted before insertion to ensure rapid immersion of samples in the rumen fluid.

Post-incubation Procedures and Measurements

When bags are withdrawn from the rumen, they are washed and continuously squeezed under a running tap (3 min) until the rinse water is clear, then dried in an oven to constant weight. The DM loss of material (or specific nutrient loss, e.g. nitrogen (N), starch) is calculated as the difference between weights before and after incubation.

Repeated Use of Bags

It has been observed from electron microscopy that the pores of the bags become clogged with residues if they are not cleaned properly after use. Following soaking in a soap solution for 2 h, bags are placed in a 4% chromic acid solution (60 g $K_2Cr_2O_7$; 100 ml water, 1 l conc. H_2SO_4) for 24 h in an oven at 60–70°C. They are then rinsed thoroughly in water.

Interpretation of Results

Apart from its use to predict in vivo apparent digestibility of DM, the rumen-bag technique provides a comparative rather than an absolute method of evaluating the nutritive value of feeds. Many studies have been reported in the literature. For example, the 24 h losses of DM and N from bags for some high protein forages reported by Minor and Hovell (1979) are given in Table 1. The nutritive value of leucaena as a high-protein forage supplement is well documented (see Pound and Martinez 1983). It can be seen from the data presented that cassava forage ranks closest to leucaena as a potential source of bypass protein, whereas the plant proteins of sweet potato appear to be rapidly fermented in the rumen. Banana leaves are only slowly digested in the rumen and may provide a

Table 1. Degradation of high protein forages in cattle fed sugarcane based diets (Minor and Hovell 1979).

Forage	N content (%)	Digestibility in 24 h(%) DM	N
Leucaena	3.5	51	54
Cassava	3.0	72	56
Sweet potato	3.4	93	95
Banana	2.6	28	44

steady source of N to the microorganism. Further studies are warranted to test these hypotheses.

In another example, Aii and Stobbs (1980) measured the disappearance of DM and crude protein (CP) at various intervals over 72 h (see Fig. 1). The potential degradation of leucaena DM in the rumen was 65% compared with only 40% for *Desmodium intortum*. The disappearance of CP from leucaena was also quite rapid (30% in 24 h) compared with *D. intortum* (5% in 24 h). The authors suggested that while leucaena may be partially degraded in the rumen, a large proportion of the plant proteins may also be available in the small intestine while the proteins from *D. intortum* which are not degraded in the rumen, are likely to pass through the small intestine undigested.
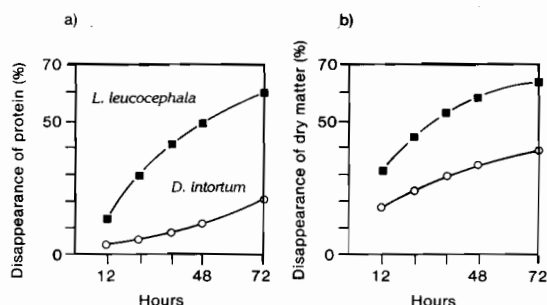
Source: Aii and Stobbs 1980.

Fig. 1. Rates of disappearance of two tropical legumes from nylon bags suspended in the rumen of cattle: a). crude protein, b). dry matter.

The nutritive value of feeds for ruminants, as measured in rumen bags, may be broadly summarised as follows:
1. Carbohydrate source in the basal diet:
   - a DM loss/24 h of 55–65% indicates a feed with potential for productivity and high DM intake.
   - a DM loss/24 h of 40–55% indicates a feed of less potential and is likely to require supplementation or other treatments.
   - a DM loss/24 h of less than 40% will require considerable inputs to increase digestibility.
2. Supplements:
   - generally, feeds with a DM loss/24 h of below 50% will contribute to the nutrient flow into the small intestine.
   - feedstuffs containing high levels of nutrients but having very low digestibilities in the rumen may also pass through the small intestine without being digested and absorbed.

More detailed comparisons of the rates of disappearance of feeds are most simply made by plotting the percentage loss of material over time and fitting the curve (see Fig. 1).

A sophisticated analysis of curves in terms of the relative rates of digestion of soluble, rapidly and slowly degraded pools in the feed sample is described in the literature (Ørskov et al. 1980; Kempton 1980; and Preston and Leng 1985).

Discussions and Conclusions

The rumen bag technique gives a simple and rapid assessment of the nutritive value of feedstuffs in the rumen. However, there are certain limitations to the method that must be taken into account when interpreting results.

Firstly, the preparation of samples by grinding or cutting may not be representative of the feed after ingestion by the animal. One would expect a faster degradation of material with smaller particles as the surface area exposed to microbial attack is increased. To avoid this effect, some laboratories reduce the particle size of samples as little as possible (Rowe, pers. comm.).

Secondly, the DM loss of material in bags is likely to be an overestimation of feed digestion in the rumen as particles could normally leave the rumen at a size many times larger than the pores of the bag. On the other hand, as pointed out by Ørskov et al. (1980), the measurement of DM loss from the bag does not necessarily represent the complete degradation of complex substances to simple chemical compounds.

Thirdly, the ecosystem within the bag may not be representative of that in the rumen. Meyer and Mackie (1983) found that the numbers and proportions of microbial species within the incubating bags were different to those in the surrounding rumen fluid. Bags with pore sizes between 30–53/μm were found to be optimal.

With these constraints in mind, the use of the rumen bag technique can greatly assist in our understanding of the rate of breakdown of fibrous feeds, which is the major factor limiting intake and digestion in ruminants, and allows assessment of supplements in terms of their contribution to nutrients flowing into the small intestine. Furthermore, the effect of manipulating rumen processes on digestion can be also studied. The rumen bag technique thus provides a simple means of ranking locally available feeds in terms of their usefulness for ruminants.

References

Aerts, J.V., de Brabander, D.L., Cottyn, B.G., and Buysse, F.X. 1977. Comparison of the laboratory methods for predicting the organic matter digestibility of forages. Animal Feed Science and Technology, 2, 337–349.

Aii, and Stobbs, T.A. 1980. Solubility of the protein of tropical pasture species and the rate of its digestion in the rumen. Animal Feed Science and Technology, 5, 183–192.

Balch, C.C., and Campling, R.C. 1962. Regulation of voluntary food intake in ruminants. Nutrition Abstracts and Reviews, 32, 669–686.

Ffoulkes, D. 1985. Practical feeding systems for ruminants based on sugarcane and its byproducts. In: The Utilization of Fibrous Agricultural Residues as Animal Feeds. Melbourne University Press (in press).

Ffoulkes, D., Krebs, G., and Sutherland, T.M. 1983. Cellulolysis and urea in molasses based diets. In: Farrell, D.J., and Pran Vohra, ed., Recent Advances in Animal Nutrition in Australia 1983. Armidale, University of New England Publishing Unit, 167–174.

Kempton, T.J. 1980. The use of nylon bags to characterise the potential degradibility of feeds for ruminants. Tropical Animal Production, 5, 107–116.

Kempton, T.J., Nolan, J.V., and Leng, R.A. 1977. Principles for the use of non-protein nitrogen and by-pass proteins in diets of ruminants. World Animal Review, 22, 2–10.

Krebs, G., and Leng, R.A. 1984. The effect of supplementation with molasses/urea blocks on ruminal digestion. Proceedings of the Australian Society of Animal Production, 15, 704.

Mehrez, A.Z., and Ørskov, E.R. 1977. A study of the artificial fibre bag technique for determining the digestibility of feeds in the rumen. Journal of Agricultural Science, Cambridge, 88, 645–650.

Meyer, J.H.F., and Mackie, R.I. 1983. Microbiology of feed samples incubated in nylon bags in the rumen of sheep. South African Journal of Animal Science, 13, 220–222.

Minor, S., and Hovell, F.D.De B. 1979. Rate of rumen digestion of different protein sources using the in vivo nylon bag technique with cattle fed sugarcane. Tropical Animal Production, 4, 105.

Ørskov, E.R. 1970. Nitrogen utilization by the young ruminant. In: Swan, H., and Lewis, D. ed., Proceedings of the 4th Nutrition Conference for Feed Manufacturers. London, Churchill Press, 20–35.

1978. Relative importance of ruminal and post-ruminal digestion with respect to protein and energy nutrition in ruminants. Tropical Animal Production, 3, 91–103.

Ørskov, E.R., Hovell, F.D. De B., and Mould, F. 1980. The use of the nylon bag technique for the evaluation of feedstuffs. Tropical Animal Production, 5, 195–213.

Pound, B., and Martinez Cairo, L. 1983. Leucaena: its cultivation and uses. London, Overseas Development Administration.

Preston, T.R., and Leng, R.A. 1985. Matching livestock systems to available feed resources in developing countries. Addis Ababa, ILCA (in press).

Rodriguez, H. 1968. In vivo bag digestibility: the relative position within the rumen. Cuban Journal of Agriculture, 2, 285–287.

Toxins in Forages

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THE principal effects of toxins or deleterious substances in forages are to reduce production, e.g. in weight gains or reduced production of milk or meat. Animal deaths are rarely an important effect and the animals may or may not show clinical signs of ill health. Culvenor (1985) has estimated that in Australia the overall losses due to the poisoning of grazing animals by naturally occurring toxins are about A\$70–80 million/annum. Four diseases associated with temperate forages—lupinosis, subterranean clover infertility, annual rye grass toxicity and poisoning by *Heliotropium* species — accounted for well over half of the total. These estimates were based mainly on information supplied by the State Departments of Agriculture or Primary Industry.

The situation in Australia, where animals graze forages over large areas of grassland, is markedly different from that in Asia where there is considerable pressure on land resources, and the areas available for grassland or commercial production are limited. So in Asia a large proportion of ruminants does not obtain feed from grazed pasture sources. Forages are frequently cut and brought to the animals. Information on losses of production caused by any toxins in the forage is therefore scanty. However, many of the forage species now being introduced are common to other tropical countries where some have been shown to contain deleterious substances. This paper considers the toxic effects caused by some grasses and legumes, and examines ways in which these effects may be overcome. The species were chosen principally because they have been shown to be useful or potentially useful as forage in Southeast Asia (Skerman 1977; Food and Fertilizer Technology Centre for the Asian and Pacific Region 1984), or have been implicated in plant poisonings.

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Toxicities of some Tropical Grasses and Crops

Cynodon plectostachyus (African Star Grass).

This is one of the pasture grasses recommended for use in the Philippines (Guzman 1984). It contains cyanide (HCN), but under most conditions ruminants seem to eat the plant without any ill effects. It is regarded as a good fodder plant in Africa, India and the United States. Deaths from acute HCN poisoning are rare, but there have been reports from Rhodesia (Rodel 1971) that ewes grazing the plant during pregnancy produced goitrous lambs. In the rumen the HCN is converted to thiocyanate which interferes with the trapping of iodine by the thyroid gland, and goitre results.

Another plant that contains cyanide is cassava, and in villages near Bogor cassava leaves are the major single species fed to goats and sheep. Experiments by Juarini et al. (1983) indicated that cassava leaves fed under these conditions did not adversely affect thyroid function. A significant proportion of the sulfur ingested by the animals may be used to detoxify the HCN, and further work is needed to determine whether this may result in an induced deficiency of sulfur, as has been suggested by Wheeler et al. (1975) in animals grazing *Sorghum* species. Supplemental sulfur will correct the deficiency.

Cenchrus ciliaris and *Setaria sphacelata*

These grasses have been among promising pasture species introduced into various countries in Southeast Asia, and on which research is continuing. *C. ciliaris* may contain up to 1–2% soluble oxalate and considerably higher concentrations (3–5%) have been reported in grasses of the *Setaria* complex (Hacker 1974). Similar values have been obtained for these species (as well as, unexpectedly, some shrub legumes) collected and analysed in Bogor, Indonesia (I. Sutikno, unpubl.). In Australia, horses eating these plants develop a calcium deficiency syndrome, nutritional secondary hyperparathyroidism, characterised by lameness and bone lesions (Walthall and McKenzie 1976). However, ruminants are usually able to metabolise the

oxalate. Recent evidence (McKenzie and Schultz 1983) shows that these grasses contain substantial amounts of calcium oxalate in crystalline form and that, in spite of the action of ruminal oxalate-degrading bacteria, a reduced availability to cattle of calcium from these grasses can occur. The significance of these findings to the principal ways in which these grasses are used as forage in Asia has yet to be determined.

Brachiaria decumbens and *B. brizantha*

The signal grasses (*B. decumbens* and *B. brizantha*) are vigorous creeping perennial grasses from Africa. They have shown high production of digestible dry matter in higher rainfall areas, and have been widely introduced or tested as pasture grasses in many places in the tropics. In Thailand, Malaysia and Indonesia there have been a number of experimental plantings but few for actual production. However one should note an area of successful plantings in the Citanduey River headwaters of Java. There have been reservations about use of brachiarias because they have been associated with outbreaks of a photosensitising disorder in sheep or cattle, with occasional high mortality. The much more robust para grass (*B. mutica*) and the small annual brachiarias do not seem to be implicated. Photosensitisation is usually followed by death of the animal and is caused by phylloerythrin from incomplete metabolic breakdown of chlorophyll, due to loss of liver function; the primary toxic effect is on the liver itself. Although these outbreaks have sometimes disruputed experimental trials, and personal research contacts have indicated additional sporadic cases, there has until recently been little published in Southeast Asia on the nature, causes or indeed existence of the syndrome. However, recently, deaths of sheep on fresh and ensiled brachiaria were observed near Bogor (Tri Budhi Murdiati et al. 1984), and in Malaysia (Abas et al. 1983).

A number of publications from South America (CIAT 1978; 1981) attribute the disorder to the mycotoxin sporidesmin produced by the saprophytic fungus *Pithomyces chartarum*, and this fungus was positively identified in pastures that gave rise to intoxication. The syndrome would then be essentially identical to 'facial eczema' (f.e.), caused by the same fungus growing on perennial ryegrass in New Zealand, in which country the condition is well known and extensively studied.

Liver pathology of the sheep that died at Cicadas near Bogor showed generalised liver damage, agreeing broadly with the descriptions of f.e. pathology (Tri Budhi Murdiati et al. 1984). From the existing South American literature, together with the sporadic nature of the outbreaks observed in Southeast Asia, the pathology, and the growth habit of brachiaria (with much senescent leaf material below the actively growing sward), it would be reasonable to suppose that one is indeed dealing with the f.e. syndrome.

We wish to record indications to the contrary arising from discussions at the Ruakura Animal Research Centre where much f.e. research has been carried out. The histopathology of liver sections from a recent similar outbreak in Malaysia, when compared directly with those for f.e. at Ruakura Animal Research Centre in New Zealand, was unequivocally not that of f.e. (P.H. Mortimer, pers. comm.). Furthermore, although *P. chartarum* was positively identified in the Colombian studies, it can in fact be isolated almost anywhere, and the observed spore levels were much lower than those associated with f.e. outbreaks (M. de Mena, pers.comm.). The chemical lability of sporidesmin is such that it is unlikely to persist under tropical conditions or to withstand ensilation (E. Payne, pers.comm.).

The cause of brachiaria toxicity is not yet established. Neither is the actual scale of the problem in the region, but clearly it must be better understood if the plant is to make a useful contribution.

Toxicities of some Tropical Legumes

Leucaena leucocephala

L. leucocephala (leucaena) is a vigorous, highly palatable, digestible and nutritious shrub legume that has become increasingly popular for fodder production on well drained, non-acidic soils in the tropics (Jones 1979). However its use as forage for ruminants and non-ruminants has been limited by the presence in all parts of the plant of a toxic non-protein amino acid, mimosine. Jones (1985) has comprehensively reviewed present knowledge of the toxicity of leucaena, and only the main conclusions are presented here. Emphasis is placed on the recent development of a novel solution to the problem of leucaena toxicity to ruminants, which will allow the potential of this important legume to be realised.

Mimosine is toxic to both ruminants and non-ruminants. However, in the ruminant, mastication with saliva and reaction with rumen microorganisms produce both autolytic and microbial degradation of mimosine to 3-hydroxy-4-(1H)-pyridone, (DHP), a potent goitrogen with thiouracil-type activity, which is excreted in the urine. The chronic effects on cattle grazing leucaena in Australia and in Papua New Guinea are caused by the antithyroid and other pharmacological actions of DHP. No such toxic effects were observed in ruminants grazing leucaena in some tropical countries, including Hawaii and Indonesia,

and this has been shown (Jones 1981; Jones and Lowry 1984) to be due to the presence in the rumen of animals in these countries of bacteria that degrade DHP. These bacteria are absent from the rumen of Australian animals. It has been possible to transfer the ability to degrade DHP from an Indonesian goat to Australian goats fed on Australian-grown leucaena by infusion with rumen fluid (Jones and Lowry 1984; Tangendjaja and Lowry 1983). Transferring Hawaiian rumen fluid or mixed cultures of bacteria from the rumen fluid to Australian cattle has allowed complete ruminal metabolism of DHP, thus preventing hypothyroidism and other symptoms associated with leucaena toxicity (Jones and Megarrity 1983; Jones 1985).

No solution to the problem of the toxicity of leucaena as a feed for monogastric animals has yet been found. The possible benefits from converting mimosine to DHP in poultry diets has been investigated, but DHP has been shown to be more active in depressing feed intake than was mimosine (Tangendjaja and Lowry 1983).

Indigofera Species

The genus *Indigofera* contains more than 700 species in tropical and subtropical regions of the world. They range from delicate herbaceous annuals to robust woody perennials. The genus is found on all soil types in rainfalls from 200 to 2000 mm/annum, and in all habitats from dry, rocky hills to seasonally flooded plains. Many species are grazed by native herbivores, but are generally regarded as toxic to domestic livestock.

As is the case with other toxic plants, there is conflicting evidence of toxicity, and more than one toxin may be involved. *I. hirsuta* has been introduced into southern USA where it is used commercially as a forage without any apparent ill-effects. On the other hand, *I. spicata* (formerly *I. endecaphylla*) (creeping indigo) was introduced into Hawaii as a high-rainfall zone legume. It grew well with a variety of grasses and was persistent and highly palatable, but when it formed more than 50% of the diet of cattle, toxicity symptoms appeared. The main adverse effects were on the liver and on the reproductive system; pregnant cows aborted (Norfeldt et al. 1952). The outstanding characteristics of the plant as a forage encouraged various workers to search for the toxin(s). As a result of these investigations the toxic substances have been isolated and identified, and its has been possible to screen many other species for their presence.

The leaves of *I. spicata* contain 3-nitropropionic acid in several glycosidic forms (see Stermitz and Yost 1978 for a brief review). In monogastric animals high doses of 3-NPA can cause a rapid rise in methaemoglo-

bin concentrations in the blood and alveolar emphysema or locomotor disturbances (James et al. 1980). However, the range of concentrations of 3-NPA in many *Indigofera* species tested (Williams 1981) suggests that the compound may not present serious toxicity problems. Ruminants are able to metabolise substantial amounts of 3-NPA (Majak and Clark 1980) and it seems unlikely that the concentrations in *Indigofera* species could pi ve toxic.

The leaves and seeds of *I. spicata* contain a non-protein amino acid, indospicine, (2-amino-6-amidinohexanoic acid) (Hegarty and Pound 1970) which accounts for the hepatotoxic and abortifacient effects produced by the plant. The substance is also a teratogen in rats, producing cleft palates (Pearn and Hegarty 1970). Indospicine behaves as a specific antagonist of the naturally occurring amino acid arginine and an inhibitor of protein synthesis (Christie et al. 1975).

It is now possible to screen many species of *Indigofera* for both 3-NPA and indospicine. Williams (1981) found 3-NPA in 64 out of 249 of the *Indigofera* species tested. The screening for indospicine has not so far been as comprehensive but indicates that indospicine occurs in only a small proportion of *Indigofera* species tested. For example, Miller and Smith (1973) detected it in only one (*I. spicata*) of 17 species tested. Similar results were obtained by Charlwood and Bell (1977). Neither toxin has been detected in *I. arrecta, I. hirsuta* or *I. schimperi*, but all 22 accessions of *I. spicata* tested have contained indospicine (R.D. Court, pers.comm.).

A sufficient number of suitable non-toxic forage species would probably be found within such a large genus, so that those known to contain toxins would not have to be used. However, there may be other toxins present in some species and feeding trials with rats should be used to complement the chemical screening (Aylward et al. 1983).

There is circumstantial evidence that ruminants in some countries may be able to metabolise indospicine since they are reported to eat different indospicine-containing species without any apparent detrimental effects. The species are: *I. linnaei* in Central Australia (Bell and Everist 1951), and in India (Nath et al. 1971); *I. subulata* in East Africa (Rogerson 1955); *I. spicata* in Trinidad (Stehle 1956). Further work is needed to determine if this hypothesis is correct.

Crotalaria Species

Many species of *Crotalaria* contain hepatotoxic pyrrolizidine alkaloids and are toxic to ruminants and non-ruminants. The genus is generally regarded as potentially toxic and is little used as forage. However,

in Thailand, sunnhemp (*Crotalaria juncea*) grows well in a paddy environment after the rice crop has been harvested. When fed to cattle the young plants are readily eaten without any apparent detrimental effects (Wailapon and Pongskul 1984).

Toxicity of Phenolic Compounds

These are the most abundant and diverse of the plant secondary metabolites. They are considered to have broadly defensive functions for the plant, but in terms of plant-herbivore interactions it is generally considered that they deter herbivory, not by toxicity, but (particularly the tannins) by reducing intake and digestibility through a variety of protein-tannin effects (Swain 1979). Because of the ubiquity of plant phenolics and the well established mechanisms for conjugation and excretion, acute toxicity to herbivores seems unlikely. Reviewers have concluded 'there is no evidence that forage tannins have any detrimental effect on the grazing ruminant . . .' (McLeod 1974), or 'not only is there no clear evidence that tannins are harmful in ruminant diets, but . . .' (Price and Butler 1980).

It is thus worth pointing out that there are in fact cases where hydrolysable tannins can cause mortality in ruminants, under conditions where gallic acid (or pyrogallol) is apparently liberated and absorbed in such quantity that it swamps the detoxification system. Acute effects occur through kidney necrosis. This has been shown for cattle on *Quercus havardi* in the USA (Pigeon et al. 1962), and more recently in tropical Australia for sheep and cattle on *Terminalia oblongata* (McCosker and Hunt 1966; McSweeney, unpubl.).

Although there are no direct phytochemical comparisons of different floras, it is evident that many species of tropical plants, including some used for feed, contain higher levels of phenolic compounds than occur in temperate forages. One must therefore be conscious of the possibility of toxicity arising from the absorption of phenols, whether from hydrolysable tannins or possibly from large levels of simple phenolic compounds. There is also, of course, the possibility of specialised ruminal microbial metabolism detoxifying these compounds if they constitute sufficient substrate.

Relevance to Village Feeding Systems

This discussion has centred largely on plants of known forage applications. However, cut-and-carry feed loads are typically drawn from a much wider range of species, many unfamiliar in grazing systems, some known or likely to contain toxic constituents, and others about which nothing is known. The occurrence of some degree of subclinical toxicity and reproductive loss is almost certain. The extent of this, and the effect on production, must be known to enable full utilisation of village feed resources.

Conclusions

Grazing animals and animals being fed large amounts of forage can ingest a wide variety of chemical compounds that may adversely affect production. Some compounds are detoxified in the rumen, and toxic symptoms may only develop when the ruminal flora is unable to catabolise all the substance ingested. When the detoxification causes a nutritional imbalance, supplementation may overcome this.

Leucaena toxicity has been overcome by transfer of rumen microorganisms, and it is possible that this approach may be successful for other forage toxins. Recombinant DNA techniques may be of use in transferring appropriate metabolic plasmids to ruminal bacteria.

Management practices which control the intake of deleterious compounds are still useful in limiting the toxic effects of some compounds. Chemical and biological screening methods are now available for finding non-toxic accessions of some promising forages. The range of compounds for which such methods are available is likely to increase, allowing the screening of potentially useful new forage species for toxins to be carried out at an early stage.

References

Abas Manzi, O., Mohamed Khusahry, Y., and Sheikh Omar, A.R. 1983. Jaundice and photosensitisation in indigenous sheep of Malaysia grazing on *Brachiaria decumbens*. Malaysian Veterinary Journal, 7, 254–263.

Aylward, J.H., Court, R.D., and Haydock, K.P. 1983. Screening legumes for toxicity. CSIRO Division of Tropical Crops and Pastures, Annual Report 1982–83. Brisbane, Australia, 81–182.

Bell, A.T., and Everist, S.L. 1951. *Indigofera enneaphylla*: a plant toxic to horses (Birdsville Disease). Australian Veterinary Journal, 28, 185–188.

Charlwood, B.V., and Bell, E.A. 1977. Qualitative and quantitative analysis of common and uncommon amino-acids in plant extracts. Journal of Chromatography, 135, 377–384.

Christie, G.S., Wilson, M., and Hegarty, M.P. 1975. Effects on the liver in the rat of *Indigofera spicata*, a legume containing an inhibitor of arginine metabolism. Journal of Pathology, 117, 195–205.

CIAT 1978. Beef Program 1978. Annual Report, Centro Internacional de Agricultura Tropical, Cali, Colombia.
    1981. Tropical Pasture Program, Annual Report 1981. Cali, Colombia.

Culvenor, C.C.J. 1985. Economic loss due to poisonous plants in Australia. In: Seawright, A.A., Hegarty, M.P., James, L.F., and Keeler, R.F., ed., Plant Toxicology,

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Proceedings of Symposium, Brisbane, May 1984. Queensland Poisonous Plants Committee, Brisbane, 3–13.

Food and Fertilizer Technology Centre for the Asian and Pacific Region 1984. Asian pastures: recent advances in pasture research and development in Southeast Asia. Taipei, p. 219.

Guzman, M.R. de 1984. Pasture research and development in the Philippines. In: Asian pastures: recent advances in pasture research in Southeast Asia. Food and Fertilizer Technology Centre for the Asian and Pacific Region, Taipei, 44–57.

Hacker, J.B. 1974. Variations in oxalate, major cations, and dry matter digestibility of 47 introductions of the tropical grass setaria. Tropical Grasslands, 8, 145–154.

Hegarty, M.P., and Pound, A.S. 1970. Indospicine, a hepatotoxic amino acid from *Indigofera spicata*: isolation, structure and biological studies. Australian Journal of Biological Sciences, 23, 831–842.

James, L.F., Hartley, W.J., Williams, M.C., and van Kampen, K.R. 1980. Field and experimental studies in cattle and sheep poisoned by nitro-bearing *Astragalus* or their toxins. American Journal of Veterinary Research, 41, 377–382.

Jones, R.J. 1979. The value of *Leucaena leucocephala* as a feed for ruminants in the tropics. World Animal Review, 31, 1–11.

1981. Does ruminal metabolism of mimosine and DHP explain the absence of leucaena toxicity in Hawaii? Australian Veterinary Journal, 57, 55.

1985. Leucaena toxicity and the ruminal degradation of mimosine. In: Seawright, A.A., Hegarty, M.P., James, L.F., and Keeler, R.F., ed., Plant Toxicology, Proceedings of Symposium, Brisbane, May 1984. Queensland Poisonous Plants Committee, 111–119.

Jones, R.J., and Lowry, J.B. 1984. Australian goats detoxify the goitrogen 3-hydroxy-4(1H)-pyridine (DHP) after infusion from an Indonesian goat. Experientia, 40, 1435–1436.

Jones, R.J., and Megarrity, R.G. 1983. Comparative response of goats fed on *Leucaena leucocephala* in Australia and Hawaii. Australian Journal of Agricultural Research, 34, 781–790

Juarini, E., Thahar, A., and Petheram, R.J. 1983. Blood thyroxine level in sheep and goats on a cassava-based diet in villages near Bogor. Research Report, Project for Animal Research and Development, Balai Penelitian Ternak, Ciawi, Bogor, Indonesia, 45–55.

Majak, W., and Clark, L.J. 1980. Metabolism of aliphatic nitro compounds in bovine rumen liquid. Canadian Journal of Animal Science, 60, 319–325.

McCosker, P.J., and Hunt, S.E. 1966. Toxicity of yellow wood (*Terminalia oblongata*.). Australian Veterinary Journal, 42, 355.

McKenzie, R.A., and Schultz, K. 1983. Confirmation of the presence of calcium oxalate crystals in some tropical grasses. Journal of Agricultural Science, Cambridge, 100, 249–250.

McLeod, M.N. 1974. Plant tannins — their role in forage quality. Nutrition Abstracts and Reviews, 44(11), 803–815.

Miller, R.W., and Smith, C.R. 1973. Seeds of *Indigofera* species; their content of amino acids that may be deleterious. Journal of Agricultural and Food Chemistry, 21, 909–912.

Nath, K., Malik, N.S., and Singh, O.N. 1971. Chemical composition of *Indigofera enneaphylla* and *I. cordifolia* as

sheep feeds. Australian Journal of Experimental Agriculture and Animal Husbandry, 11, 178–780

Norfeldt, S., Henke, L.A., Morita, K., Matsumoto, O.H., Takahashi, M., Younge, O.R., Willers, E.H., and Cross, R.F. 1952. Feeding tests with *Indigofera endecaphylla* Jacq. (creeping indigo), and some observations on the poisonous effects on domestic animals. University of Hawaii, Agricultural Experiment Station Technical Bulletin 15.

Pearn, J.H., and Hegarty, M.P. 1970. Indospicine — the hepatotoxic factor from *Indigofera spicata*. British Journal of Experimental Pathology, 51, 34–37.

Pigeon, R.F., Camp, B.J., and Dollahite, J.W. 1962. Oral toxicity and polyphenol moiety of tannin isolated from *Quercus havardi* (Shin oak). American Journal of Veterinary Research, 23, 1268–1269.

Price, M.L., and Butler, L.G. 1980. Tannins and Nutrition. Agricultural Experiment Station, Purdue University, Indiana, Bulletin No. 272.

Rodel, M.G.W. 1971. Neonatal goitre and skeletal deformities in autumn-born lambs on Star grass pasture. Rhodesian Agricultural Journal, 68, 109–110.

Rogerson, A. 1955. Nutritive value of green *Indigofera subulata* herbage. East African Agricultural Journal, 20, 240–241.

Skerman, P.J. 1977. Tropical Forage Legumes. Food and Agricultural Organization of the United Nations, Rome, p.609.

Stehle, H. 1956. Survey of forage crops in the Caribbean. Caribbean Commission Central Secretariate, Port of Spain, Trinidad, p. 397.

Stermitz, F.R., and Yost, G.S. 1978. Analysis and characterization of nitro compounds from *Astragalus* species. In: Keeler, R.F., van Kampen, K.R., and James L.F., ed., Effects of Poisonous Plants on Livestock. New York, Academic Press, 371–378.

Swain, T. 1979. Tannins and lignins. In: Rosenthal, G.A., and Janzen, D.H., ed., Herbivores – their Interaction with Plant Secondary Metabolites. London, Academic Press.

Tangendjaja, B., and Lowry, J.B. 1984. Identification of antinutritive factors in leucaena leaf meal: effects of treated leaf meal on chicks. ILMU Dan Peternakan, 1, 363–367.

Tri Budhi Murdiati, Helmy Hamid, van Eys, J., Wilson, A.J., Paderi Zahari, and Stolz, D.R. 1984. Preliminary examination of *Brachiaria* spp. toxicity. Scientific Meeting on Small Ruminant Research, Research Institute for Animal Production, Bogor, Indonesia, 237–240.

Wailaipon, B., and Pongskul, V. 1984. Pasture establishment in the farming systems of northeast Thailand. In: Asian Pastures: recent advances in pasture research in Southeast Asia. Food and Fertilizer Technology Center for the Asian and Pacific Region, Taipei, 44–57.

Walthall, J.C., and McKenzie, R.A. 1976. Osteodystrophia fibrosa in horses at pasture in Queensland: field and laboratory observations. Australian Veterinary Journal, 52, 11–16.

Wheeler, J.H., Hedges, D.A., and Till, A.R. 1975. A possible effect of cyanogenic glucoside in sorghum on animal requirements for sulphur. Journal of Agricultural Science, Cambridge, 84, 377–379.

Williams, M.C. 1981. Nitro compounds in *Indigofera* species. Agronomy Journal, 73, 434–436.

Rhizobium Collections and their Assessment

H.V.A. Bushby*, R.A. Date* and J. Sundram**

THE provision of legume inoculants to farmers is an exercise in applied microbiology that aims to increase biological nitrogen fixation and reduce the dependence upon nitrogenous fertilisers. In order to realise these aims rhizobia need to be collected, then isolated, authenticated and tested for effective nitrogen fixation before being supplied to the farmer in a suitable form e.g. as a peat-based inoculum. It is important to realise at the outset that the establishment of the infrastructure necessary for the manufacture and distribution of legume inoculants is expensive, but it may not be necessary for all countries to become involved in this aspect of agriculture. This can only be determined by the patient collection of good scientific data from 'need for inoculation trials' carried out by competent personnel. Strains for these initial experiments can be imported from countries such as Australia at minimal cost until it has been established that there is a problem that can only be solved by either the application of nitrogenous fertilisers or inoculation with highly effective strains of *Rhizobium*. The 'need for inoculation trials' will be discussed towards the end of this chapter.

The sources of new strains of rhizobia are existing collections or isolations from nodules collected from designated legumes in their native habitat. In this paper, information is provided on existing collections and methods for the collection, isolation and authentication of rhizobia. Finally some techniques for assessing the effectiveness of strains in the laboratory and field are presented.

Existing Collections of *Rhizobium*

There are a number of collections of strains of *Rhizobium* throughout the world, and some are listed in Table 1. A comprehensive list can be obtained from the 'World Catalogue of *Rhizobium* Collections' (Skerman 1983) which is a specialised catalogue taken from a more general index (McGowan and Skerman 1982). The latter publication contains information on a wide range of microorganisms including rhizobia and a statement as to whether the collectors have published a catalogue of their strains. The catalogues usually consist of at least a list of strains, the legumes from which they were isolated and effectiveness ratings on a number of legumes. Other information may be provided on the country of origin, the laboratory of isolation, growth rates, and acid or alkali production when growing on yeast mannitol media containing bromothymol blue (Norris and Date 1976). Cultures and catalogues for most collections can be obtained upon written request and usually without charge to bona fide research organisations or with only nominal charges to cover postage costs. Cultures will usually arrive as either lyophilised cells in vacuum sealed ampoules or on agar slopes. When requesting strains it is advisable to indicate the proposed use as a guide to the curator who may well be able to suggest more appropriate strains than those that are only the most effective on a particular legume e.g. low soil pH may be a significant factor in a proposed experiment.

Collection, Isolation and Authentication of Rhizobia

Collection

Ideally, nodule collections should be made at the same time as plant collections, but this is not always possible due to constraints of time and the fact that plant collections are usually made when plants have produced mature seed. At this mature growth stage it may not be possible to recover nodules suitable for isolation. Plant collectors should therefore adequately document the collection site to allow revisits if necessary for nodule sampling. In the absence of prior plant collections, investigations of the possible distribution of the legumes of interest should be made by the collector, together with a review of available literature on soils, vegetation and climate to identify areas for collection. This is important, as edaphic factors have been found to affect the suitability of

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Table 1. Some *Rhizobium* culture collections.

Country	Address[a]	Catalogue[c]
Argentina	Dept. Microbiology, Instit. Nat. Tec. Agropecuaria, c.c. 25–1712 Castelar Villa Udaondo	—
Australia	AIRCS, Department of Agriculture, P.O. Box 720, Gosford, NSW 2250, Australia	+
Australia	Division of Tropical Crops and Pastures, CSIRO, 306 Carmody Road, St. Lucia, Brisbane 4067	+
Australia	Division of Plant Industry, CSIRO, P.O. Box 1600, Canberra City, A.C.T. 2601, Australia	—
Australia	Plant Pathology Branch, Queensland Department of Primary Industries, Meiers Road, Indooroopilly, Brisbane, Queensland	—
Brazil	IPEACS Km 47, via Campo Grande ZC-26, GB	—
Brazil	MIRCEN, IPAGRO, Microbiologia do Solo, Rua Goncalves Dias, 570, 90.000, Porto Alegre, RS, Brazil	+
Canada	Department of Microbiology, University of Guelph, Guelph, Ontario	—
China[b]	Soils and Fertilizer Institute, Chinese Academy of Agricultural Sciences, Beijing, China	—
Colombia	CIAT, Apartado Aereo 67-13, Cali	+
Czechoslovakia	Dept. Soil Microbiology, Research Institute of Crop Production, 16106 Prahaab, Ruzyne 507	—
India	ICRISAT 1-11-256 Begumpet, Hyderabad, 500016	—
New Zealand	Plant Disease Division, DSIR, Private Bag, Auckland	—
New Zealand	Plant Disease Division, DSIR, Private Bag, Palmerston North	—
Nigeria	IITA, Oyo Road, PMB 5320, Ibadan	—
Singapore	Dept. Botany, National University of Singapore, Kent Ridge Road, Singapore 1025	—
South Africa	Plant Protection Research Institute, Private Bag 134, Pretoria	—
Thailand	Thailand Institute of Scientific and Technological Research, 196 Phahonyothin Road, Bangkhen, Bangkok 9	—
Thailand	BNF Resource Centre, Rhizobium Building, Dept. Agriculture, Phaholyothin Road, Bangkhen, Bangkok 10900	—
United Kingdom	Dept. Soil Microbiology, Rothamsted Experimental Station, Harpenden, Hertfordshire	+
Untied Kingdom	Welsh Plant Breeding Station, University College of Wales, Plas Gogarddan, Aberystwyth SY23 3EB, Dyfed, Wales	—
USA	Crop Research Division, Agricultural Research Service, USDA, Beltsville, Md 20705	+
USA	Dept. of Bacteriology, University of Wisconsin, Madison, WISC. 53706	—
USA	NifTAL Project, University of Hawaii, P.O. Box 0, Paia, Maui, Hawaii 96779	+
Zimbabwe	Grassland Rhizobium Collection, Soil Productivity Research Laboratory, Private Bag 3757, Marandellas	—

a: Correspondence should be addressed to the 'Curator of Rhizobium Collections'.

b: Dr Tao Tian-Shen is a contact for further cultures within China.

c: + = catalogue produced.

strains, in terms of effectiveness on some legumes and their adaptation to particular soil types (Date et al. 1979; Chowdhury 1965; Chatel and Greenwood 1973; Chatel and Parker 1973). Thus, strains collected from acid soils, for example, seem to be most suited to inoculation into similar soils. This is an obvious but frequently forgotten aspect in the collection of new strains of *Rhizobium*. It is necessary, therefore, that the collector clearly identify any objectives apart from simply the collection of effective strains.

When collecting, descriptions of the site should include the country, the nearest town, the distance and direction to that town, and the latitude and longitude. The altitude, rainfall and soil type, texture, depth, drainage and pH should also be noted. Particular attention should be paid to whether the legume is growing in a cultivated or virgin site, and if in a cultivated region whether the legume has been innoculated previously. It would be easy to reisolate inoculum strains in such areas.

Plants may need to be excavated in order to find nodules. However, this is not alway necessary, nor is it

always possible e.g. tree legumes. Care should be taken when removing soil from around the root system to confirm that the nodule collected is attached to the root system of the legume of interest. This can be difficult, but is important if a number of legumes are growing in the vicinity. An idea of the nodule morphology can be useful, as it may be characteristic of a legume or group of legumes (Fred et al. 1932; Corby 1981). About 15–20 fresh, firm nodules per plant should be collected, preferably when plants are actively growing. This number will ensure that sufficient are available if initial attempts at isolation fail. Further, each nodule potentially yields one strain that is distinct from the next isolation, even if taken from the same legume. Since a wide range of strains can infect a native legume, isolations may vary in serology, effectiveness in nitrogen fixation, competitiveness etc. Notable exceptions to the above do exist e.g. in Australia *Lotononis bainesii* is always nodulated by CB360 or CB376 (Diatloff 1977) and *Trifolium semipilosum* seems only to be effectively nodulated by CB782 (Jones and Date 1975). Similarly, most isolations from soybean nodules collected in Australia yield CB1809 (Diatloff, pers. comm.). These however are the exceptions as serologically distinct strains are usually obtained from each nodule (Date, pers. comm.). All nodules from one plant may be stored in a single container but should not be mixed with nodules from another plant even if it is the same species. On short (2–3 day) collection trips nodules may be placed in plastic bags, but on longer trips they should be desiccated over silica gel or anhydrous calcium chloride to prevent nodule breakdown and proliferation of fungi and non-rhizobial bacteria. Each sample should be labelled with a specimen number and a note made of the name of the legume. Better still, a sample of the plant should be taken which includes leaves, flowers and seed pods if available, to facilitate identification back at the laboratory. Although not essential, one of the authors (HVB) also collects 0.5–1.0 kg soil from the vicinity of the nodules. Thus, detailed soil analyses can be carried out and correlations made between these characters and those of rhizobia taken from those soils.

Isolation

Successful isolations depend very much upon the quality of the nodule sample. Damaged or partially decomposed nodules are unsatisfactory and should be used after mild surface sterilisation (15–30 sec in 7–8% sodium hypochlorite solution) to inoculate a legume trap host grown under aseptic conditions (Norris and Date 1976). If the trap host is different from the original legume this should be noted as there is the possibility of variations due to selection by different hosts. Desiccated nodule samples should be imbibed with water prior to surface sterilisation. The general protocol for isolation from nodules has been described by Vincent (1970) but modifications can be made by each laboratory. Briefly, adhering soil is removed, nodules placed in sterilant (7–8% sodium hypochlorite) for 3–4 minutes and then rinsed with at least five changes of sterile water. Nodules are then individually crushed in a drop of water and a YMA plate streaked in the normal way. After growth, an individual colony is selected and stored on an agar slope until shown to be a *Rhizobium*. Isolates should not be included in 'mother collections' (see below) or distributed as inoculants until they have been properly authenticated.

The inclusion of antifungal agents such as cycloheximide (100–200 μg/ml, Vincent 1970), benomyl (benzimidazole, 50–100 μg/ml, Bushby unpublished data) or pimaricin (250–500 μg/ml, Bushby 1984) in the media can aid isolations but should only be used when necessary as pimaricin and benomyl can be toxic to some rhizobia.

Date (1982) describes a method for making initial isolations while actually on the field trip. The 'Hotel Technique', as it has been aptly named, is useful when particularly small nodules have been collected (e.g. from *Stylosanthes* species) in which the rhizobia die rapidly upon desiccation.

Authentication

Following the isolation of a bacterium from a nodule and storage on an agar slope in an air-tight, screw-capped tube (Vincent 1970) it is essential that the isolate be authenticated as a *Rhizobium* species. This is dependent on one criterion only, viz. the formation of nodules on a legume under bacteriologically controlled conditions. The legume used for authentication should be the same as that from which the original nodule was taken. However, if this is not possible, freely nodulating alternate hosts can be used, such as *Macroptilium atropurpureum*, *M. lathyroides* and *Teramnus uncinatus* for 'cowpea-type' legumes, *Stylosanthes guianensis* cv. Endeavour or Cook and *S. hamata* cv. Verano for many species of *Stylosanthes*. *Glycine ussuriensis* is a small-seeded convenient species for testing strains from soybean in tubes (Brockwell et al. 1975). The homologous hosts should be used for isolates from *Leucaena*, *Lotononis*, *Cicer*, and such *Stylosanthes* species as *S. capitata*. At this stage, selections can be screened as either effective or ineffective relative to an uninoculated, no nitrogen control plant, and unless ineffective cultures are required for particular reasons, it is possible to discard them and so reduce the number

retained for permanent storage. It should be remembered, however, that host specificity can determine the effectiveness of a strain, and what is ineffective on one legume may be effective on another. In spite of this, discretion is needed, as large numbers of ineffective strains are easy to collect, and it can be very time consuming maintaining large collections of generally unused strains.

Although nodule formation is the absolute test for assignment to the genus *Rhizobium*, rhizobia do conform to a number of other criteria. They are medium sized gram negative rods, grow poorly on glucose-peptone media, do not produce acid in broths of litmus milk, and usually do not take up congo red and so produce pinkish to white or translucent colonies (Vincent 1970). Although these features are not proof of identity, they can be used when nodulation is obtained but contamination is suspected.

Preservation

Preservation of cultures in stable form is necessary, due to the possibility of contamination, loss of viability or genetic variation in symbiotic efficiency, colony characteristics and antigenic constitution. One set of preserved cultures designated the 'mother collection' should be stored for the conservation of germplasm, while a duplicate, separate set can be maintained for routine use and further study. It is important that the mother collection be considered a stable resource and not be available for routine use, as important cultures can be lost if this is not adhered to. We do not allow the number of preserved cultures in our mother collection to fall below three.

The simplest method for preservation is the screw-capped tube with a layer of sterile paraffin at least 2 cm deep covering the top of the agar to prevent drying. Cultures at CSIRO, Brisbane have maintained viability over 20 years by this method, although the more reliable method of freeze drying is now used. Cultures can also be stored by desiccation onto porcelain beads (Norris 1963), by freeze drying (lyophilisation) and by storage in liquid nitrogen at −196°C. Details of the various techniques are described by Vincent (1970), Norris and Date (1976) and Dye (1980). The essential features of lyophilisation, the most commonly used method of permanent storage, are: suspension of growth from an agar slope in a protective medium containing 10% sucrose and 5% peptone; samples are then frozen, desiccated by sublimation and stored dry under vacuum, as oxygen is toxic to desiccated bacteria.

Assessment

To measure the effectiveness of nitrogen fixation,

reference to Vincent (1970), Norris and Date (1976), Brockwell (1980) or Dye (1980) will provide essential details of methods of evaluation in the controlled environment, glasshouse and field. The first task is to screen a large number of cultures by inoculation of the appropriate legume, growing either in a controlled environment room (usually small seeded legumes in 1500 mm × 25 mm tubes) (Brockwell 1982) or in the glasshouse (usually larger legumes growing in Leonard jars). Strains are ranked according to yields relative to uninoculated controls, with and without nitrogen, and can be scored as highly effective, effective, partially effective, ineffective or parasitic. The Leonard jar (Vincent 1970) consists of a beer bottle with its bottom cut off and inverted into a snugly fitting glass container which acts as a nutrient reservoir. The inverted neck of the bottle is plugged with cotton wool and the bottle filled to within 10–15 mm of the rim with washed river sand. Nutrient solution (Norris and Date 1976) is placed in the reservoir and the whole unit covered with a paper bag and secured with rubber bands. The unit is then autoclaved for 2 hrs at 120°C. Each jar is sown with germinated or ungerminated seed, and inoculated with a single rhizobial strain.

Use of the acetylene reduction technique to measure nitrogen fixation is not recommended, due to inaccuracies in the assumptions underlying the technique (Minchin et al. 1983).

From Leonard jar trials, strains are selected for inclusion in pot or field experiments, using ratings that are not less than 70% of the plus nitrogen, uninoculated control. Experience has shown that field trials usually cannot differentiate between strains with nitrogen fixation capacities in Leonard jars greater than or equal to 70% of the plus nitrogen control. Pot trials are used to further reduce the number of strains for field testing and to identify possible interactions between soil type, strain and legume. Preliminary estimates of competitive ability can also be obtained from pot trials by determining the percentage of nodules formed by the inoculum strain, but because of the artifical conditions of pot experiments these should be regarded as guidelines only, and the time invested adjusted accordingly. One disadvantage of pot trials is that the soil is usually sieved, and this releases nitrogen which can mask any variation between strains for nitrogen fixation. Undisturbed cores transferred to pots have been used successfully to screen rhizobia against a number of pasture legumes (Vincent 1970; Sylvester-Bradley et al. 1983). The advantages of such cores are that mineralisation of nitrogen is reduced, and as reorganisation of the soil fabric is kept to a minimum, the effectiveness and competitive performance of

inoculum strains are more likely to approximate field conditions.

Field trials can be costly in terms of resources and manpower, so careful consideration needs to be given to the treatments, the site and the design. The site should be uniform for soil type and vegetation, and should be nearly level so that surface wash is minimal. The importance of levels of soil nitrogen and native rhizobia will depend upon the experimental aims. The ideal site for strain testing is low in available soil nitrogen and naturally occuring rhizobia, but for competitiveness and persistence trials an established rhizobial population is necessary. Sites should not previously have been sown with seed inoculated with rhizobia, since these strains are likely to nodulate the legume under investigation.

The simplest experimental design consists of three main treatments set out as a randomised block with several (usually not less than four) replications. The three treatments are (a) uninoculated, no nitrogen control (b) uninoculated, plus nitrogen control and (c) inoculation treatments, of which there can be any number of inoculum strains tested, depending on the method of sowing and the aims of the experiment. A basal application of fertiliser minus nitrogen is usually applied to the whole of the experimental area to remove possible restrictions to legume growth due to nutrient deficiencies. Treatment (a) is necessary as a check of the effectiveness of the established rhizobial population and/or the level of nitrogen in the soil. Thus, poor growth of the uninoculated, minus nitrogen control means that the native strains able to fix nitrogen on the test legume are at a low level. Good growth of this treatment, however, means that the native strains are effective and/or that there is a high level of mineralised nitrogen available to the legume. Careful examination of the nodules on several root systems should indicate their effectiveness, as effective nodules are pink when sliced in half but ineffective nodules are usually small and white internally.

Treatment (b), the plus nitrogen, uninoculated control serves as a check on the suitability of the legume for a particular environment, and ensures that fertiliser rates are sufficient for the crop/pasture requirements. This treatment, together with the other control, provides the reference points against which the inoculum treatments are compared. Responses to inoculation are usually estimated by measuring one or more of the following factors: vegetative yield, grain yield, % nitrogen content or nitrogen accumulation (%N × vegetative yield).

More complex trials can be carried out (e.g. Date 1977) but should not be attempted by inexperienced personnel. The following precautions should be taken in all cases:

1. sites should be carefully selected, especially regarding slope;
2. uninoculated controls should be sown before inoculated treatments;
3. hands and implements should be rinsed in alcohol between treatment sowings;
4. drainage ditches should be constructed to prevent flow of water across treatments.

When partially effective or effective strains are present in the soil (i.e. when the no nitrogen, uninoculated control is similar to the inoculation treatments) the plant measurements outlined above provide little information on the performance of inoculum strains. Nodule number and mass can be used to assess the response of nodule formation to inoculation, but measurement of each of these attributes is very time consuming and laborious. Brockwell (1980) has obtained good correlations between nodule score and vegetative dry matter from a system of nodule scoring which takes into account nodule number, distribution and effectiveness.

For information on the ability of inoculum strains to compete for nodule formation with native rhizobia, the strains used as inoculum must be identifiable. The most commonly used methods of strain identification are serological techniques and drug resistance, e.g. Date (1974) and Bushby (1984). Both techniques allow the percentage of nodules due to the inoculum strain to be identified and monitored at any time after sowing. In general, these studies show that while during the initial year of sowing the majority of nodules are formed by the inoculum, in subsequent growing seasons this decreases at rates that depend on the legume, the strain and the soil (Date 1982; Bushby 1982). Usually this is accompanied by effective nodulation by native rhizobia, which presumably out-perform the inoculum strains. Explanations as to why this occurs are unsatisfactory, and highlight our imperfect understanding of the ecology of both introduced and native strains of *Rhizobium*.

Is Inoculation Necessary?

As stated in the introduction, the provision of inoculants has the practical aim of reducing dependence upon chemically produced nitrogenous fertilisers. In many circumstances, however, and especially in tropical regions, neither inoculation of legumes nor the application of such fertilisers are necessary, as the native rhizobia are highly effective, are present in the soil in large numbers and nodulate a wide range of legumes. The need for inoculation can be determined from the results of field trials outlined above. If

inoculation does not increase yields above the uninoculated, minus nitrogen control, if roots bear apparently effective nodules and soil nitrogen levels are not excessive, then it is unlikely that inoculation will increase farm yields. The importance of inoculation trials early in a research program cannot be overemphasised.

As a guide to the possible need for inoculation, legumes have been arranged in groups according to their ability to nodulate effectively with a wide range of strains under Australian conditions (from Date 1977):

Group FE

FREELY NODULATING AND EFFECTIVE

Plants in this group are nodulated effectively with rhizobia taken from a wide range of genera and species. Thus there is much cross nodulation between genera in this group. Nodulated plant performance is usually greater than 80% of the nitrogen control and plants are not likely to need inoculation. This group corresponds most closely to that usually referred to as the 'cowpea group' and includes the genera *Arachis, Calopogonium, Cajanus, Canavalia, Clitoria, Crotalaria, Cyamopsis, Desmanthus, Dolichos, Galactia, Glycine, Indigofera, Lablab, Macroptilium, Macrotyloma, Pueraria, Rhynchosia, Mucuna (Stizolobium), Teramnus, Tephrosia, Vigna* and some species of *Stylosanthes* and *Zornia*.

Most of these legumes are nodulated by slow-growing rhizobia, however *Desmanthus* and *Crotalaria* are nodulated by fast growers. Nothing is known of the cross infection between these two groups.

Group FI

FREELY NODULATING BUT OFTEN INEFFECTIVE

Plants in this group will nodulate with a wide range of strains, but not always effectively. Cross inoculation that is effective does not always occur between legumes from different genera or species of this group. Typical genera within this group are *Adesmia, Aeschynomene, Desmodium, Psoralea, Sesbania* and *Stylosanthes*. The genera *Adesmia, Psoralea* and *Sesbania* are nodulated by fast growing rhizobia, but the remaining three are nodulated by slow growers. As for group FE, nothing is known of cross nodulation between these groups, but any nodules are unlikely to be effective. Inoculation is recommended for legumes in this group.

Group S

SPECIFIC

Legumes within this group only nodulate effectively with rhizobia from the same species. Rhizobia from

other legumes either nodulate ineffectively or not at all with this group. Examples of such legumes are *Lotononis* and *Trifolium*. Inoculation is essential.

The purpose of inoculation is to strategically introduce a desired strain such that it has the maximum opportunity for infection and nodule formation. This can be accomplished in a variety of ways (Brockwell 1980; Norris and Date 1976), only one of which will be described here. Peat-based inoculum is applied to seed using adhesives such as methofas (4% w/v solution), gum arabic (40% w/v) or sucrose (10% w/v). The best way is to add the adhesive to the seed, thoroughly mix then add the peat containing inoculum all at once and mix thoroughly. A protective pellet may be required when some legumes are sown into acid soils (lime pellet) or if the inoculated seed has to be mixed with fertiliser or solid pesticide. It is important to sow the inoculated seed within 48 hours of inoculation, as rhizobia die rapidly on drying (Date 1970; Bushby and Marshall 1977).

The pelleting material, microfine lime, powdered rock phosphate or bauxite (100% to pass through a 300 mesh sieve i.e. 0.078 mm openings), is usually added before the adhesive plus inoculum mixture dries onto the seed. Whether a lime or bauxite (or rock phosphate) pellet is most suitable has been fully discussed by Norris (1967) and Norris and Date (1976) and depends upon both the pH of the soil and whether the strain produces acid or alkali on yeast mannitol agar. The slow growing alkali producing strains seem to be reasonably adapted to acid soils and are often not benefited by a lime pellet which increases the pH of the soil surrounding the seed. This is in marked contrast to acid producing (fast growers) strains from say *Astragalus, Leucaena,* and *Phaseolus*. When pelleting is necessary it is recommended that bauxite or rock phosphate be used for the alkali producing strains and lime for the acid producers. The recommended quantities of inoculum, adhesive and pellet for various seed sizes are in Table 2 (Norris, D.O. and Date, R.A. pers. comm.).

Areas for Research and Development

Although there is scope for research to improve some aspects of the procedure from nodule collection to the provision of high quality cultures for the farmer, much can be done by the consistent and thorough application of existing knowledge. It is important, for example, that as much information as possible be obtained on the site of collection of each strain, particularly of host and soil type. There is mounting evidence that soil type (not just pH) is a major factor determining the competitive ability of strains, hence information on the soil of origin of a strain can be used

Table 2. Quantities of peat, adhesive and pelleting material for inoculation of legume seed.

	Small	Seed size[a] Small-Medium	Medium	Large
Seed weight (g)	25	38	50	100
Peat, 1 g doses	15–35 g	100 g	200 g	400 g
Adhesive (ml)	1.	1	1	1
Coating (g)	12.5	12.5	12.5	12.5

d: Four basic seed sizes are recognised:
Small seeded e.g. White clover, *Lotus, Lotononis*
Small-medium seed e.g. *Desmodium intortum,* Lucerne, *Stylosanthes*
Medium seeded e.g. Subterranean clover, *Glycine,* Siratro, *Medicago*
Large seeded e.g. Vetch, Cowpea, *Lablab, Leucaena*

in the selection of strains with particular characteristics for evaluation in experimental programs. In such programs, the use of soil cores could be a better alternative than pots containing sieved soil (Sylvester-Bradley et al. 1983), although this would have to be weighed against the increased work load and the core to core variation.

Research into possible alternatives to sterile peat as inoculant carrier may be useful in countries where peat is not readily available, although to date, alternatives such as soil or coir dust are not as good as peat. Investigations of the most appropriate methods of inoculation for particular countries and particular crops within countries are necessary for the successful extension of inoculation technology to farmers. This will take into account the level of expertise of the farmers, their ability to assimilate and put such technology into practise, and such factors as the distance and conditions under which inocula will have to travel to points of distribution. With present technology it would not be advisable, for example, to inoculate seed and transport it long distances under adverse conditions prior to planting. It is normally recommended that inoculated seed be sown within 48 hours of inoculation because desiccated rhizobia die rapidly. Useful research could therefore be carried out to develop techniques that enhance the long term viability of desiccated rhizobia by the use of protective substances, e.g. the use of oil-based carriers (Kremer and Petersen 1983).

All of the above suggestions for further research are only sensible if results from the most important experiments, the 'need-to-inoculate' trials carried out on many soil types, indicate that significant responses to inoculation are likely to be obtained by farmers and not just researchers. If this is not indicated, then associated research, although interesting, may not have much practical significance.

References

Brockwell, J. 1980. Experiments with crop and pasture legumes — principles and practice. In: Bergersen, F.J., ed., Methods for Evaluating Biological Nitrogen Fixation. John Wiley and Sons, 417–488.

— 1982. Host plants for symbiotic experiments. In: Vincent, J.M., ed., Nitrogen Fixation in Legumes. Academic Press, Sydney, 69–83.

Brockwell, J., Diatloff, A., Grassia, A., and Robinson, A.C. 1975. Use of wild soybean (*Glycine ussuriensis*, Regal and Maack) as a test plant in dilution — nodulation frequency tests for counting *Rhizobium japonicum*. Soil Biology and Biochemistry, 7, 305–311.

Bushby, H.V.A., and Marshall, K.C. 1977. Some factors affecting the survival of root-nodule bacteria on desiccation. Soil Biology and Biochemistry, 9, 143–147.

Bushby, H.V.A. 1982. Rhizosphere populations of *Rhizobium* strains and nodulation of *Leucaena leucocephala*. Australian Journal of Experimental Agriculture and Animal Husbandry, 22, 293–298.

— 1984. Colonisation of rhizospheres and nodulation of two *Vigna* species by rhizobia inoculated onto seed: influence of soil. Soil Biology and Biochemistry, 16, 635–641.

Chatel, D.L., and Greenwood, R.M. 1973. The colonisation of host-root and soil by rhizobia. II. Strain differences in the species *Rhizobium trifolii*. Soil Biology and Biochemistry, 5, 433–440.

Chatel, D.L., and Parker, C.A. 1973. Survival of field-grown rhizobia over the dry summer period in Western Australia. Soil Biology and Biochemistry, 5, 415–423.

Chowdhury, M.S. 1965. The growth and persistence of *Rhizobium trifolii* Dangeard and *Rhizobium lupini* Schroeter in sandy soil. PhD Thesis, University of Western Australia.

Corby, H.D.L. 1981. The systematic value of leguminous root nodules. In: Polhill, R.M., and Raven, P.H., ed., Advances in Legume Systematics. Part 2. Royal Botanic Gardens, Kew, England.

Date, R.A. 1970. Microbiological problems in the inoculation and nodulation of legumes. Plant and Soil, 32, 703–725.

— 1974. Serology of rhizobia for tropical legumes. Proceedings of the Indian National Science Academy. B: Biological Science, 40, 700–712.

— 1977. Inoculation of tropical pasture legumes. In: Vincent, J.M., Whitney, A.S., and Bose, J., ed., Exploiting the Legume–Rhizobium Symbiosis in Tropical Agriculture. College of Tropical Agriculture Miscellaneous Publication 145, Department of Agronomy and Soil Science, University of Hawaii.

— 1982. Collection, isolation, characterisation and conservation of *Rhizobium*. In: Vincent, J.M. ed., Nitrogen Fixation in Legumes. Academic Press, Sydney, 95–109.

Date, R.A., Burt, R.L., and Williams, W.T. 1979. Affinities between various *Stylosanthes* species as shown by rhizobial, soil pH and geographic relationships. Agro-Ecosystems, 5, 57–67.

Diatloff, A. 1977. Ecological studies of root-nodule bacteria

introduced into field environments — 6. Antigenic and symbiotic stability in *Lotononis* rhizobia over a 12-year period. Soil Biology and Biochemistry, 9, 85–88.

Dye, M. 1980. Functions and maintenance of a *Rhizobium* collection. In: Subba Rao, N.S., ed., Recent Advances in Biological Nitrogen Fixation. Edward Arnold, London, 435–471.

Fred, E.B., Baldwin, I.L., and McCoy, E. 1982. Root Nodule Bacteria and Leguminous Plants. University of Wisconsin Studies Number 52, Science Number 5, Madison.

Jones, R.M., and Date, R.A. 1975. Studies in the nodulation of Kenya white clover (*Trifolium semipilosum*) under field conditions in south-east Queensland. Australian Journal of Experimental Agriculture and Animal Husbandry, 15, 519–526.

Kremer, R.J., and Peterson, H.L. 1983. Effects of carrier and temperature on survival of *Rhizobium* spp. in legume inocula: development of an improved type of inoculant. Applied and Environmental Microbiology, 45, 1790–1794.

McGowan, V.F., and Skerman, V.B.D. 1982. World Directory of Collections of Cultures and Microorganisms. World Data Centre, University of Queensland, Australia.

Minchin, F.R., Witty, J.F., Sheehy, J.E. and Muller, M. 1983. A major error in the acetylene reduction assay: decreases in nodular nitrogenase activity under assay condition. Journal of Experimental Botany, 34, 641–649.

Norris, D.O. 1963. A porcelain bead method for storing *Rhizobium*. Imperial Journal of Experimental Agriculture, 31, 255–258.

1967. The intelligent use of inoculants and lime pelleting for tropical legumes. Tropical Grasslands, 1. 107–121.

Norris, D.O., and Date, R.A. 1976. Legume bacteriology. In: Shaw, N.H., and Bryan, W.W., ed., Tropical Pasture Research: Principles and Methods. CAB Bulletin Number 51. Commonwealth Agriculture Bureaux, Farnham Royal, U.K., 134–174.

Skerman, V.B.D. 1983. World Catalogue of *Rhizobium* collections. World Data Centre, University of Queensland, Australia.

Sylvester-Bradley, R., Ayarza, M.A., Mendez, J.E., and Moriones, R. 1983. Use of undisturbed soil cores for evaluation of *Rhizobium* strains and methods for inoculation of tropical forage legumes in a Colombian oxisol. Plant and Soil, 74, 237–247.

Vincent, J.M. 1970. A Manual for the Practical Study of Root-Nodule Bacteria. Blackwell Scientific Publications, Oxford.

Performance of Rhizobia under Adverse Conditions

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FORAGE legumes are already widely used in the tropics, and are an extremely important source of protein for animal consumption and of nitrogen to maintain soil fertility. *Desmodium, Pueraria, Calopogonium, Centrosema,* and *Mucuna* stand out as some commonly used tropical pasture plants. In protein-poor localities, legumes are especially important because the crude protein content often ranges as high as 18%, compared to 5% in grasses (Alexander 1971).

Because of their symbiotic relationship with *Rhizobium*, the root nodule bacterium which fixes atmospheric nitrogen, legumes are often able to fulfill not only their own nitrogen requirement, but in some cases fix enough so that soil fertility is greatly enhanced. Where nitrogen fertilisers are too costly for the farmer, especially the small farmer, legumes are of substantial benefit both in producing food and also in adding usable nitrogen to the soil, thus benefiting other crops. Despite the actual and potential advantages of legumes to tropical agriculture, there are many serious problems in growing them. Often excellent nitrogen fixation and crop yields are found in areas adjacent to farms getting poor yields. Low yields are common, and often farmers apply nitrogen fertilisers to legumes rather than depend on symbiotic nitrogen fixation.

The nutritional requirements of the forage legumes resemble those of other plants, except that their potential for symbiotic assimilation of atmospheric nitrogen creates special demands, notably for molybdenum and cobalt, but also for boron, copper, phosphorus and zinc. Any nutritional problem may limit nitrogen fixation and influence foliar protein concentration and quality, whether by effects on the symbiotic system as a whole, or on the growth of the plant (Munns and Mosse 1980).

Among the legume production problems directly related to the *Rhizobium* bacteria are the following: 1) there are few or no rhizobia in the soil, those in the soil do not nodulate the crop that is planted, or the indigenous bacterial strains are not effective nitrogen fixers with the particular legume under cultivation; 2) the commercial *Rhizobium* inoculum provided does not contain the proper symbiont or, if the correct bacteria is being used, there are insufficient live bacteria to bring about satisfactory rates of infection; 3) any of a number of difficulties with the handling of the inoculum by the farmer; 4) the inoculated rhizobia do not survive on the seeds or in the soil long enough to infect the first crop; 5) the rhizobia infect the first crop but do not survive to infect subsequent plantings.

Training of personnel in use of *Rhizobium* inoculants will solve many of the above problems. A more difficult task will be to deal with those field problems arising because the required rhizobia do not persist in the soil. In such instances the many soil types, climates and legume (and therefore rhizobial) species are each variables, and potential causes of poor survival. Poor survival may be a problem even where the proper inoculum is available, because the farmer may forego using inoculum after variable results, presumed lack of time, or the bother of an additional step in the planting process. Thus, the ability to ensure survival of rhizobia in the soil, along with other required characteristics of the symbiosis, is critical for producing high yields of legumes, guaranteeing a satisfactory supply of edible protein and raising the fertility of many problem soils.

There is no comprehensive review of work specifically relating to rhizobial survival in soil. Nutman (1975) and Alexander (1975) have dealt briefly with selected topics regarding rhizobial ecology, and there are related reviews touching on the subject (Vincent 1965, 1974). The objective of this paper is to describe some of the recommendations for possibly appropriate farm practice.

Rhizobial Survival
Persistence in the Field

It is obvious that rhizobia bacteria have survived in the soil for long periods of time, and direct evidence supports the fact. In several studies, *R. leguminosarum, R. lupini, R. japonicum, R. meliloti,* and *R. trifolii*

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have been found to survive from 10 to 125 years since the cultivation of their respective hosts (Escuder 1972; Norman 1942; Jensen 1969; Nutman 1975). In particular, Nutman (1969) and Nutman and Ross (1970) tested samples of soil taken in 1968 that had grown wheat and root crops continuously since 1843. High numbers of species of *Rhizobium* were found to be present, and nearly all were effective nitrogen fixers. Reports exist of survival of inoculated strains with and without the presence of the host plant, but in general no correlation exists between rhizobial numbers and when the crop had been grown, or with the number of times the crop was grown (Elkins et al. 1976; Tuzimura and Watanabe 1959). It is possible that rhizobia sometimes persist in cropped land for periods long enough to get good infection of a crop without reinoculation, but it is not yet possible to predict survival in a specific field. There appear to be great differences in survival between fields and between strains but no systematic experiments have been reported.

Soil Factors

Because many agricultural soils are naturally somewhat acid, and because tropical soils are often highly leached and acidic, the effect of low pH on the survival of *Rhizobium* is of considerable importance.

The definition of 'critical' pH is not clear. One can imagine that the rhizobia grow or at least persist in fairly constant numbers above some pH value. Below this value, the bacteria probably decrease in numbers, very likely with greater rapidity as the pH decreases. It is important to establish this critical pH and to know the extent of survival in soils of lower pH values. If the soil pH is below the critical level but is high enough to allow sufficient rhizobia to persist into the next growing season, the bacteria may still cause nodulation the following years. Although there is considerable variation with strains, approximate 'critical' pH values for survival appear to be: *Bradyrhizobium* (Cowpea misc.), below pH 4.5; *R. trifolii, R. leguminosarum, R. japonicum* pH 4.5–4.9; *R. phaseoli*, about pH 5.0; and *R. meliloti*, pH 5.5 (Jensen 1969; Hartel and Alexander 1983; Ayanaba and Munns 1981; Keyser and Munns 1981).

Liming of acid soils often enhances rhizobial survival. For example, Vincent (1958) failed to find *R. meliloti* in soil of pH 5.3–5.7, whereas counts of 100 000/gram were found where the soil pH had been raised to 6.8. He also found that *R. trifolii* failed to spread beyond rows of lime-pelleted clover seeds, possibly because the interrow environment was too acid. Similar results have been found in more recent

investigations (Robson and Loneragan 1970) in both soils and artificial media.

Frequent reference is made to the possibility of Mn and Al toxicity to *Rhizobium*, especially in acidic soils in which Mn and Al are usually more available (Franco and Dobereiner 1971; Vincent 1974; Graham and Hubbel 1975; Alexander 1977; Hartel and Alexander 1983). Most studies done have been conducted in artificial media, and correlate poorly or not at all with performance in soils (Hartel and Alexander 1983). Direct effects of Al and Mn on survival of *Rhizobium* in soils have yet to be investigated, but it appears that in general, conditions of toxicity frequently limit the host plant to a greater extent than growth and function of *Rhizobium*.

Acid sulfate soils are common on marine floodplains of Southeast Asia, and are widely used for production of rice. Upon drainage, pH values lower than 2 have been reported. In a study by Vangnai and Chantadisai (1984), low numbers of ineffective *Rhizobium japonicum* were found in a Thailand acid sulfate soil where soybean had been previously grown. This was considered to be due to the low soil pH and presence of toxic substances in the soil.

Phosphorus is often limiting in tropical acidic soils, and work done with strains from six species of rhizobia showed that realistic soil levels of phosphate in solution severely restricted growth of some strains. In addition, the combination of soil acidity factors (high Al and Mn, low P and Ca) appear to inhibit rhizobial growth to a greater extent than any of the factors alone. However, comprehensive studies done in the soil environment are lacking, and are necessary before the importance of soil acidity factors on rhizobial growth can be established.

Growth of rhizobia is only one requirement for successful symbiosis. Establishment of nodulation is known to have greater requirements than independent growth of either symbiont for boron and calcium, and more exact requirements for pH (Lowther and Loneragan 1968; Munns 1977; Robson 1978). There is also some evidence that acidity and calcium deficiency, like molybdenum and cobalt deficiency, can impair the function of established nodules (Blevins et al. 1977; Mulder et al. 1966).

Saline and alkaline soils are found in arid regions which are poorly drained, or in places where salts wash down through the profile because of heavy rains and are returned with water to the surface during the dry period of the year (Pillai and Sen 1966). Such saline and alkaline soils often do not support good growth of legumes.

Rhizobia probably survive in saline-alkaline soils better than their legume hosts. Thus, Subba Rao et al.

(1972) noted that most test strains of *R. meliloti* grew in YEM medium containing 1% NaCl, whereas the host *M. sativa* was considerably inhibited when grown in a 0.5% or less NaCl solution. Mendez-Castro and Alexander (1976) were able to grow *R. japonicum* and *R. trifolii* on NaCl concentrations as high as 3–4%. Several recent investigators working with numerous isolates from several *Rhizobium* spp. have determined that many strains of *Rhizobium* can grow and survive at salt concentrations which are inhibitory to the host legumes (Singleton et al. 1982).

Thus, it is likely that rhizobial survival is not limiting the symbiosis in saline–alkaline soils, although the data are far from convincing because none of the studies have been done in non-sterile soil, and none dealt with growth or survival for time periods long enough to determine the rate of decline of bacteria in these soils.

Dry seasons are a part of the climatic variation in most of the tropics, and in the absence of irrigation, agricultural soils dry out. This desiccation has been recognised for a long time as a potential stress on rhizobial survival, especially in the absence of the host plant. An additional and often accompanying stress, particularly in the tropics, is high temperature. Because drying of soils and high temperatures often occur together, they are frequently studied together. For purposes of this discussion, high temperatures are taken to be those above 48°C, and normal temperatures to be 20–30°C.

It is clear that some rhizobia can survive in dry soils for periods of time long enough to be agronomically useful. Jensen (1961) reported on *R. meliloti* stored in air-dried soils for 30–45 years and *R. trifolii* and *R. leguminosarum* for 10–14 years, but found no correlation between length of storage and bacterial numbers. Pant and Iswaran (1970; 1972) observed that survival of *R. japonicum* and peanut rhizobia was shortest in the more alkaline soils of pH 8.1 and 8.5. Other studies have likewise reported no correlation with soil water content and rhizobial growth (Foulds 1971; Hedlin and Newton 1948). The present limited information on drying in soil suggests that rhizobia suffer a decline which is not closely related to water content. In addition, *Rhizobium* is quite persistent when certain soils are subjected to drying. It is therefore important to query soil type and its effect.

Rhizobial resistance to desiccation apparently differs between soils containing much clay and silt and those containing mostly sand (Danso et al. 1973; Mahler and Wollum 1981). Marshall has done the most extensive research on the protective influence of clay in connection with his studies of 'second year mortality' of annual clovers in Western Australia.

High mortality was primarily found on grey sands, was slightly less common on yellow sandy soils and was absent from red soils containing 6–8% silt and clay (Marshall et al. 1963). In a subsequent study, Marshall and Roberts (1963) amended the soils with montmorillonite and fly ash, and found that these materials provided protection for rhizobia at depths below 5 cm, where temperatures were below 40°C. They stated that is was possible that other microorganisms, antibiotics, soil texture or nutritional status might be altered by clay amendments.

Other factors important in resistance to drying have also been reported. Pant and Iswaran (1972) found a correlation between soil phosphorus and ability to survive drying. They also found that high soil pH made *R. japonicum* and peanut rhizobia more susceptible to drying. In addition, species differences to drying also have been established (Bushby and Marshall 1977; Foulds 1971; Delin 1971). There is evidence that the group of slow growers is more resistant than the fast growers.

Survival of rhizobia in soil at high temperatures is strongly conditioned by whether or not the soil is wet or dry. Survival at moderate temperatures is greater when soil is moist, while survival at temperatures above 40°C is greatest when soils are dry (Danso and Alexander 1974; Foulds 1971; Sen and Sen 1956). In moist soil, alfalfa rhizobia were found to survive 50°C but not 55°C for five hours. In dry soil, by contrast, these bacteria survived over 100°C for five hours. *Psoralea* rhizobia survived 60°C in moist soil for five hours, but some cells were still viable at 100°C in dry soils for the same period of time (Wilkins 1967). Despite unresolved questions on the mechanism of protection, it is clear that certain clays and iron oxides do protect some rhizobia from high temperatures in dry soils, that fast growers are more susceptible to heat in dry soils, and that heat in moist soil is much more detrimental to the rhizobia than in dry soil (Bushby and Marshall 1977; Bowen and Kennedy 1959).

Flooding of soil as stress to rhizobia has been studied to a very limited extent, but reports indicate that it is not always a problem (Tuzimura and Watanabe 1959; Boonkerd and Weaver 1982). In rice-based cropping systems, the number of rhizobia that may be available for nodulation depends on the extent to which the population decreased under flooding and its increase upon drainage. Very little is actually known of the chemistry of paddy soil when drained, or of changes in populations in rhizobia. Survival of rhizobia does, however, seem to be closely tied to soil type. In work done in Thailand, survival was much greater in heavy soils of higher clay content than in soils of a sandy texture (Panomthoranitkul and

Vangnai 1973; Rerkasem and Tongkumdee 1981). The data are too sparse to generalise, but it is likely that diversity exists between strains and species in their ability to withstand flooding. *R. japonicum* has been found to be much more sensitive to flooding than leucaena nodule bacteria (Rerkasem and Tongkumdee 1981).

Pesticides and Herbicides

Legume seeds are often treated with pesticides, many of which are not only toxic to rhizobia in culture but also reduce nodulation in the field (Ruhloff and Burton 1951; Vincent 1977). Unfortunately, it is often difficult to interpret experimental results because of the range of methods used and uncertainty over the concentration of the active ingredient. Formulations may themselves include toxic surfactants. Fungicides which are relatively safe include TMTD (tetramethylthiuram), spergon, and phygon, but those which contain heavy metals must be kept separate from rhizobia. Some insecticides are toxic, e.g. BHC and DDT (Braithwaite et al. 1958); dimethoate is extremely so when used as a seed dressing (Gross and Shipton 1965). Although chlorinated hydrocarbons such as dieldrin may not affect nodulation of *Medicago sativa* (Russell and Coaldrake 1966), they may delay nodulation of *Macroptilium lathyroides* (Jones 1965).

When it is essential to inoculate seed treated with toxic agrochemicals, the rhizobia must be spatially separated either by direct inoculation into the soil or onto seed previously coated with polyvinylacetate (Diatloff 1970). Free-living rhizobia are considerably resistant to most herbicides, but dinoseb and MCPA are particularly toxic (Grossbard 1970). The period between application of pre-emergence herbicides and sowing is important, e.g. a delay of 4 weeks after the application of treflan (trifluralin) is necessary if nodulation of cowpeas is not to be adversely affected (Hamdi and Tewfik 1969).

Rhizobium Strain Differences

The soil and the legume host, singly and together, effect a great selective pressure on the *Rhizobium* symbiont. It is possible to select *Rhizobium* strains in the laboratory that are resistant to drying (Delin 1971), antibiotics (Obaton 1971; Danso et al. 1973), high salt concentrations (Singleton et al. 1982), low pH values and moderately high temperatures (Mendez-Castro and Alexander 1976). Natural conditions, however, are much more complex than culture media, and in any field newly planted to a legume, it is not clear what characteristics must be selected for. The traditional criterion for choosing an inoculant strain, effective-

ness, must be supplemented by several more criteria: ability to invade the roots in competition with ineffective, indigenous strains; ability to grow outside the rhizosphere; capacity to withstand environmental extremes and persist in the soil in adequate numbers. In many cases, the proper matching of the bacterial strain and the legume cultivar will be crucial to attaining high yields. (Brockwell et al. 1968; Sherwood and Masterson 1974; Halliday 1981).

Conclusions

After over 75 years of study, scientists are still only beginning to probe *Rhizobium* ecology. Many reports make no distinction between legume nodulation and rhizobial survival, or confuse effects on the host plant or on the symbiosis with effects on the bacteria. Numerous stresses have been uncovered which potentially limit rhizobial survival, but there is little convincing evidence that these stresses are actually responsible for the microorganisms' failure to persist. In most cases in which poor establishment of a legume results from poor rhizobial survival, scientific inquiry ended once a persistent strain was discovered. Also, for agronomic reasons, most research on *Rhizobium* ecology has been carried out with *R. trifolii*, *R. meliloti* and *R. japonicum*, while virtually nothing is known about the survival of the other species, especially the tropical and cowpea-type rhizobia.

When in doubt about whether effective strains of *Rhizobium* are present, farmers should be encouraged to inoculate. In many countries of the temperate regions, inoculation is an inexpensive form of 'insurance' against nodulation failure. When choosing an inoculum, priority should be given to a strain proven to be effective with the plant variety and known to persist in the soil type under consideration. If the soil pH is low and difficulty in establishing is a good possibility, then the recommendation is to lime the soil or lime-pellet the seed. If soils are very alkaline, gypsum might be recommended. Dry sandy soils are a potential threat to survival of some strains of *Rhizobium*, and the suggested remedies, aside from irrigation, are using a resistant strain of *Rhizobium*, or if feasible, adding montmorillonite or illite or ash to the soil. High temperatures pose a substantial threat, especially if soil is likely to be moist, or in light textured soils that are dry. One method of alleviating high temperature stresses on rhizobia is to maintain a plant cover or to cover the exposed soil with plant remains (mulching). However, caution is in order if the field is newly cropped to a legume because leaving plant residues or maintaining a plant cover may be counterproductive. Changing soil microflora is not as easy as removing one crop and replacing it with another; in several

instances, enough microorganisms colonised a field to produce toxins antagonistic to newly inoculated *R. trifolii* (Chatel and Parker 1972; Parle 1964; Holland and Parker 1966). The old plant residues possibly stimulated the growth of these antagonistic organisms. Thus, in this case, removal of plant residues may be desirable.

Of primary importance is defining more precisely the reasons for poor survival of many rhizobia, or of rhizobia in certain circumstances. At the same time, but particularly with this information, strains should be developed that are capable of enduring natural stresses on the root-nodule bacteria, so that small farmers of the tropics can get greater benefits from the nitrogen-fixing activity of *Rhizobium* living in association with leguminous plants.

References

Alexander, M. 1971. Symbiotic and nonsymbiotic nitrogen fixation in tropical agriculture. In: Freitas, Y.M., and Fernandez, F., ed., Global Impacts of Applied Microbiology. Univ. of Bombay, India, 29–39.
    1975. Ecology of nitrogen-fixing organisms. Presented at a symposium on Biological Nitrogen Fixation in Farming Systems of the Humid Tropics. International Institute of Tropical Agriculture, Ibadan.
    1977. Introduction to Soil Microbiology, John Wiley and Sons, New York
Ayanaba, A., and Munns, D.N. 1981. Performance of acid-resistant cowpea rhizobia in soils. Plant and Soil, 48, 238–241.
Blevins, D.G., Barnett, N.M., and Bottino, P.J. 1977. Physiologia Plantarum, 41, 235.
Boonkerd, N. and Weaver, R.W. 1982. Survival of cowpea rhizobia in soil as affected by soil temperature and moisture. Applied and Environmental Microbiology, 43, 585–588.
Bowen, G.D., and Kennedy, M.M. 1959. Effect of high soil temperatures on *Rhizobium* spp. Queensland Journal of Agricultural Science, 16, 177–197.
Braithwaite, B.M., Jane, A.E., and Swain, F.G. 1958. Journal, Australian Institute of Agricultural Science, 24, 155.
Brockwell, J., Dudman, W.F., Gibson, A.H., Hely, F.W., and Robinson, A.C. 1968. An integrated programme for the improvement of legume inoculant strains. Trans. Ninth Intl. Cong. Soil Sci., Adelaide, 2, 103–114.
Bushby, H.V.A., and Marshall, K.C. 1977. Some factors affecting the survival of root-nodule bacteria on desiccation. Soil Biology and Biochemistry, 9, 143–147.
Chatel, D.L., and Parker, C.A. 1972. Inhibition of rhizobia by toxic soil-water extracts. Soil Biology and Biochemistry, 4, 289–294.
Danso, S.K.A., and Alexander, M. 1974. Survival of two strains of *Rhizobium* in soil. Soil Science Society of America Proceedings, 38, 86–89.
Danso, S.K.A., Habte, M., and Alexander, M. 1973. Estimating the density of individual bacterial populations introduced into natural ecosystems. Canadian Journal of Microbiology, 14, 1450–1451.

Delin, P.S. 1971. Production of *Rhizobium* strains resistant to drying. U.S. Patent No. 3,616,236.
Diatloff, A. 1970. Journal, Australian Institute of Agricultural Science, 36, 5621.
Elkins, D.M., Hamilton, G., Chan, C.K.Y., Briskovich, M.A., and Vandeventer, J.W. 1976. Effect of cropping history on soybean growth and nodulation and soil rhizobia. Agronomy Journal, 68, 513–517.
Escuder, A.M.Q. 1972. A survey of rhizobia in farm soils at Wye College, Kent. Journal of Applied Bacteriology, 35, 109–118.
Foulds, W. 1971. Effect of drought on three species of *Rhizobium*. Plant and Soil, 35, 665–667.
Franco, A.A., and Döbereiner, J. 1971. Toxidez de manganes de un solo acido na simbiose soja-*Rhizobium*. Pesq. Agropec. Bras. Ser. Agron., 6, 57–66.
Graham, P.H., and Hubbel, P.H. 1975. Soil-plant-*Rhizobium* interaction in tropical agriculture. In: Bornemisza, E., and Alvarado, A., ed., Soil Management in Tropical America. Soil Sci. Dept., North Carolina State Univ., Raleigh, N.C., 221–227.
Gross, O.M., and Shipton, W.A. 1965. Journal of Agriculture, Western Australia, 6, 659.
Grossbard, E. 1970. In: Lowe, J., ed., Occasional Symposium, British Grassland Society, No. 6, 47–59.
Halliday, J. 1981. Present constraints to, and a future strategy for, fuller utilization of legume-fixed nitrogen for crop production in the tropics. Paper submitted to International Workshop on Biological Nitrogen Fixation and Crop Production, National Chung Hsing University, Taichung, Taiwan.
Hamdi, Y.A., and Tewfik, M.S. 1969. Acta Microbiologica. Polon., 18, 53.
Hartel, P.G., and Alexander, M. 1983. Growth and survival of cowpea rhizobia in acid, aluminum-rich soils. Soil Science Society of America Journal, 47, 502–506.
Hedlin, R.A., and Newton, S.D. 1948. Some factors influencing the growth and survival of *Rhizobium* in humus and soil cultures. Canadian Journal of Research: Section C. Botanical Sciences, 26, 174–187.
Holland, A.A., and Parker, C.A. 1966. Studies on microbial antagonism in the establishment of clover pasture. II. The effect of saprophytic soil fungi upon *Rhizobium trifolii* and the growth of subterranean clover. Plant and Soil, 25, 329–340.
Jones, R.J. 1965. Australian Journal of Experimental Agriculture and Animal Husbandry, 5, 458.
Jensen, H.L. 1961. Survival of *Rhizobium meliloti* in soil culture. Nature, 192, 682–683.
    1969. The distribution of lucerne and clover rhizobia in agricultural soils in Denmark. Tidsskr. Planteavl., 73, 61–72.
Keyser, H.H. and Munns, D.N. 1981. Response of *Rhizobium* strains to acid and aluminum stress. Soil Biology and Biochemistry, 13, 115–118.
Lowther, W.L., and Loneragan, J.F. 1968. Plant Physiology, 43, 1362.
Mahler, R.L., and Wollum, A.G., II (1981). The influence of soil water potential and soil texture on the survival of *Rhizobium japonicum* and *Rhizobium leguminosarum* isolates in the soil. Soil Science Society of America Journal, 45, 761–765.
Marshall, K.C., Mulcahy, J.J., and Chowdhury, M.S. 1963. Second-year clover mortality in Western Australia — a microbiological problem. Journal, Australian Institute of Agricultural Science, 29, 160–164.

Marshall, K.C., and Roberts, F.J. 1963. Influence of fine particle materials on survival of *Rhizobium trifolii* in sandy soil. Nature, 198, 410–411.

Mendez-Castro, F.A., and Alexander, M. 1976. Acclimatisation of *Rhizobium* to salts, increasing temperature and acidity. Revista Latinoamericana de Microbiologia, 18, 155–158.

Mulder, E.G., Lie, T.A., Dilz, K., and Houwers, A. 1966. Effect of pH on symbiotic nitrogen fixation of some leguminous plants. Proc. Ninth Intl. Cong. Microbiol., 133–151.

Munns, D.N. 1977. In: Hardy, R.W.F., and Gibson, A.H., ed., A Treatise on Dinitrogen Fixation, IV, Wiley, New York, 354–382.

Munns, D.N., and Mosse, B. 1980. Mineral nutrition of legume crops. In: Summerfield and Bunting, ed., Advances in Legume Science. Royal Botanic Gardens, England, 1, 114–123.

Norman, A.G. 1942. Persistence of *Rhizobium japonicum* in soil. Journal, American Society of Agronomy, 34, 499.

Nutman, P.S. 1969. Symbiotic nitrogen fixation: legume nodule bacteria. Rothamsted Report for 1968, Part 2, 177–181.

1975. *Rhizobium* in the soil. In: Walker, N., ed., Soil Microbiology, A Critical Review. Butterworths, London, 111–131.

Nutman, P.S., and Ross, G.J.S. 1970. *Rhizobium* in the soils of the Rothamsted and Woburn farms. Rothamsted Report for 1969, Part 2, 148–167.

Obaton, M. 1971. Utilization de mutants spontances resistants aux antibiotiques pour l'étude ecologie des *Rhizobium*. C.R. Acad. Sci., Ser. D., Sci. Nat. (Paris), 272, 2630–2633.

Panomthoranitkul, M., and Vangnai, S. 1973. Survival of *Rhizobium japonicum* in flooded soils. Kasetsart Journal, 7, 19–28.

Pant, S.D., and Iswaran, V. 1970. Survival of groundnut *Rhizobium* in Indian soils. Mysore J. Agric. Sci., 4, 19–25.

1972. Survival of *Rhizobium japonicum* in Indian soils. Philippine Journal Science., 101, 81–91.

Parle, J.N. 1964. Some aspects of the nodulation problem occurring in the Wither Hills. Proc., N.Z. Grassland Assoc., 123–126.

Pillai, R.N., and Sen, A. 1966. Salt tolerance of *Rhizobium trifolii*. Indian Journal of Agricultural Science, 36, 80–84.

Rerkasem, B., and Tongkumdee, D. 1981. Legume–*Rhizobium* Symbiotic Development in Rice-based Multiple Cropping Systems. In: Gibson, A., and Newton, W., ed., Current Perspectives in Nitrogen Fixation. Australian Academy of Science.

Robson, A.D. 1978. In: Andrew, C.S., and Kamprath, E.J., ed., Mineral Nutrition of Legumes in Soil of the Tropics and Subtropics, 277–293.

Robson, A.D., and Loneragan, J.F. 1970. Nodulation and growth of *Medicago truncatula* on acid soils, I. Effect of calcium carbonate and inoculation level on the nodulation of *Medicago truncatula* on a moderately acid soil. Australian Journal of Agricultural Research, 21, 427–434.

Ruhloff, M., and Burton, J.C. 1951. Soil Science, 72, 283.

Russell, M.J., and Coaldrake, J.E. 1966. Soil Science. Journal, Australian Institute of Agricultural Science, 32, 214.

Sen, A., and Sen, A.N. 1956. Survival of *Rhizobium japonicum* in stored air-dry soil. J. Indian Soc. Soil Sci., 4, 215–220.

Sherwood, M.T., and Masterson, C.L. 1974. Importance of using the correct test host in assessing the effectiveness of indigenous populations of *Rhizobium trifolii*. Irish Journal of Agricultural Research, 13, 101–108.

Singleton, P.W., El Swaift, S.A., and Bohlool, B.B. 1982. Effect of salinity on *Rhizobium* growth and survival. Applied and Environmental Microbiology, 44, 884–890.

Subba Rao, N.S., Lakshmi-Kumari, M., Singh, C.S., and Magu, S.P. 1972. Nodulation of lucerne (*Medicago sativa* L.) under the influence of sodium chloride. Indian Journal of Agricultural Science, 42, 384–386.

Tuzimura, K., and Watanabe, I. 1959. Saprophytic life of *Rhizobium* in soils free of the host plant. Journal of the Science of Soil Manure, 30, 506–516, (in Japanese).

Vangnai, S., and Chantadisai, T. 1984. Microbial activities in acid sulfate soil in Thailand. Ecology and Management of Problem Soils in Asia. FFTC Book Series No. 27, 27–39.

Vincent, J.M. 1958. Survival of the root nodule bacteria. In: Hallsworth, E.G., ed., Nutrition of the Legumes. Butterworths, London, 108–123.

1965. Environmental factors in the fixation of nitrogen by the legume. In: Bartholomew, W.V., and Clark, F.E., ed., Soil Nitrogen. Amer. Soc. Agron., Madison, Wisc., 384–439.

1974. Root-nodule symbioses with *Rhizobium*. In: Quispel, A., ed., The Biology of Nitrogen Fixation. North Holland, Amsterdam, 265–341.

1977. Soil Science, 23, 355.

Wilkins, J. 1967. The effects of high temperatures on certain root-nodule bacteria. Australian Journal of Agricultural Research, 18, 299–304.

Management of Forages to Optimise Animal Production

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THE ruminant population in Indonesia, Malaysia, Thailand, the Philippines and the South Pacific countries is some 40 million head (FAO 1982). Of these, cattle and buffalo comprise 63.0% and of the small ruminants about 71.0% are goats. The majority of ruminants (about 90.0%) are owned by smallholders with farm areas ranging from less than 0.4 ha to 7.0 ha. Feed resources available are those from natural herbage on non-cultivatable land, roadside verges, banks and rice fields, crop residues and crop bypro-ducts (Ashari and Petheram 1983; Moog 1974). In some areas forage is cut from under plantation crops or stock are grazed on communal grazing lands.

Buffalo and cattle are primarily used as draught animals for land cultivation and transport, beef production being a byproduct of the farming system when animals have ceased their useful working life, or when sold to meet a family's economic needs. Use of large ruminants for commercial milk production is generally limited to areas of high population density where there is a market for fresh milk.

Goats and sheep are kept for meat and cash flow purposes where the ownership of larger numbers of animals offers greater flexibility in management of feed and financial resources. In highly populated areas, such as in Java and Madura, where farm sizes are of 0.5–1.8 ha and where there is a diminishing crop area per family, ownership of large ruminants is uneconomic and numbers have decreased while those of smaller ruminants have increased (Ivory and Siregar 1984).

This paper considers the potential for improving forage resources and their utilisation in the smallholder context. Management of forages under extensive grazing in the plantation crops are discussed by 't Mannetje, also Rika et al., elsewhere in these proceed-ings.

Forage Production

The search for more productive introduced grasses

and legumes for use in the tropics commenced in the 1930s. Senaratna (1937) reported on the use of *Pennisetum purpureum, Panicum maximum, Tripsa-cum laxum* and *Saccharum officinarum* as green feed grown on small areas (0.04 ha or less) for ruminants in Sri Lanka. In Hawaii *Desmanthus virgatus, Leucaena leucocephala* and *Cajanus cajan* were used in cut-and-carry systems of production (Takahashi 1952). Over the past 20 years research with improved forage species in Southeast Asia and the Pacific have shown the potential for high levels of dry matter production for grasses (40–60 t DM/ha) in the genera *Pennisetum, Panicum, Setaria* and *Brachiaria* and up to 24 t/ha from the shrub legume *Leucaena leucocephala* (Wong 1982; Mendoza and Javier 1980; Hassan and Izham 1984; Ivory and Siregar 1984; Chen 1985). These high yields have been obtained after fertiliser application to correct major known nutrient deficiencies. The rele-vance of these results in terms of adoption by smallholders is open to question, where there are limited financial resources for purchase of fertilisers for non-food crops. The alternative is a slower increase in soil fertility by use of animal manure (Manidool 1985; Suntraporn 1980) and legumes which improve soil N levels, as well as the protein supply for animals, i.e. initially the only option is for a low-cost system for improving forage production.

Within the region, climatic variation imposes con-straints on year-round feed supply, especially in the monsoon-tropical environments with distinct wet and dry seasons. The variation in quantity and quality of feed supply has severe implications for nutritional stress in large ruminants. Chantalakhana (1985) described a system of buffalo production in Thailand which presents a good example of nutritional con-straints to animal production. At the start of the wet season, buffalo are used for land preparation for crops, having experienced nutritional stress during the dry season. The land area available for feed is reduced through crop production, and hence quantity of feed supply is limited at a time when animals are required for work. Hence there is a reduction in work capacity, in reproductive efficiency and in ability to successfully

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raise calves. The average calf crop is only about 34% and mortality rates of calves less than one year old is from 30 to 40% (Bhannasiri 1980). Some of these losses may have been caused by disease but nutritional stress plays a major role. Improvement of forage production in these environments has the objectives of improving quantity of forage in the wet season and both quantity and quality of dry season feed.

Improving Feed Supplies

Forage Legumes on Paddy Banks

Rice stubble forms the basis of low quality roughage for dry season feed in many areas. Supplementing the diet with a legume could enhance the utilisation of such feeds. Gutteridge (1981) reported that verano stylo could produce 3.3 t/ha of dry matter when grown on paddy walls if not grazed during the wet season. Of a range of legumes evaluated, verano was the most promising in terms of ease of establishment and ability to regenerate and persist (Pasture Improvement Project, Khon Kaen University 1984).

Forage Crops in Paddy Fields

Residual soil moisture after the rice crop is harvested could be sufficient to grow a subsequent forage crop. *Crotalaria juncea* (sunnhemp), *Lablab purpureus* and *Macroptilium atropurpureum* have been successfully grown on the residual soil moisture from irrigated paddy fields when sown after harvest of the rice crop into a cultivated seedbed (Shelton 1980; Wilaipon and Pongskul 1984). Yields of sunnhemp and lablab were similar (2000 kg/ha) but the former more useful for smallholders because of the lack of requirement for *Rhizobium* inoculation. Research into sowing of *Stylosanthes guianensis* into upland rice has shown to be of potential value, if sowing is delayed after rice establishment (Shelton and Humphreys 1975).

Backyard Pastures

Sown pastures of grasses and legumes, or use of shrub legumes as hedgerows or as individual plants, offer opportunities for improving forage resources. Manidool (1985) reported the use in Thailand of hamil, guinea, ruzi grass, verano and siratro in mixed pastures and of *Leucaena, Gliricida, Sesbania* and *Erythrina* for hedgerow production. In the Philippines (Mendoza et al. 1976) showed that the optimum cutting height for hedgerows of *leucaena* was 15 cm with a cutting frequency of 45 days. The woody tree forms of leucaena could be utilised in this way if planted at high densities (100 000/ha) and cut every 45 days, yielding

10–20 t/ha/year. There may be an added advantage in using these genotypes for the dual role of forage and wood production.

Intercropping with Forage Legumes

Annual legumes have been shown to be suitable forage crops in rotations and for intercropping. Javier (1978) has described the dominant cropping patterns in the Philippines and suggested ways of integrating forage crops into these systems. *Cajanus cajan*, mungbean and soybean have been grown intercropped with maize, and produced up to 3.8 t of fresh legume forage without affecting yield of green maize or stover. In Northeast Thailand, verano stylo has been grown successfully as an intercrop with kenaf and cassava if sown after establishment of these crops (Wilaipon et al. 1981; Pongskul et al. 1982). Intercropping with legumes can have mutually beneficial effects on production of crop and forage through nitrogen input by the legume, and enhanced legume growth from fertiliser applied to the crop.

It is clear from much of the above research that emphasis is placed on the contribution of forage legumes to improving feed supplies. This is appropriate when one considers the nutritional differences between legumes and grasses in terms of animal requirements. The following parameters are important:
- legumes are the major source of protein.
- the rate of decline in digestibility with age is slower for legumes than tropical grasses, and legumes retain relatively high digestibility at maturity (Milford and Minson 1966).
- the voluntary intake of legumes is higher than grasses of similar digestibility (Thornton and Minson 1973).
- legumes have generally a higher mineral concentration than grasses except for sodium in some species.

Thus, in the inital stage of improving forage resources with no or small inputs of fertiliser, legume should have priority.

Use of Fertilisers

Earlier in this paper it was suggested that use of fertilizers was not an economic option available to smallholders in improving forage production. The role of different nutrients, and their level of concentration in plant material on nutritive value should, however, be recognised. Recommended dietary concentrations of minerals and nitrogen for large ruminants are presented in Table 1 (Minson et al. 1976). If minerals are deficient in the diet, intake is depressed. The major nutrients to be considered are nitrogen, sulfur, calcium, phosphorus, sodium and trace elements.

Table 1. Recommended dietary concentrations of mineral elements and nitrogen for finishing cattle weighing 300–500 kg (Minson et al. 1976).

Element	Concentration in DM of diet (%)	Element	Concentration in DM of diet (ppm)
N	1.8	Fe	30
P	0.22	Mn	40
K	0.31–0.44	Zn	20–40
Ca	0.22–0.35	Cu	4–10
Mg	0.12	Co	0.1
Na	0.05	I	0.12
		Se	0.05

Nitrogen

When the crude protein of grasses falls below 7.0% in the dry matter, voluntary intake is reduced (Milford and Minson 1965). If this diet is supplemented with a legume the voluntary intake of the grass and the dry matter digestibility is increased in direct proportion to the legume content of the feed (Minson and Milford 1967). Use of nitrogen fertiliser will produce new growth high in protein and low in cell wall and lignin content, and provide a higher overall digestibility. However, high rates of N fertiliser may also increase growth rate and maturity of grasses, produce earlier flowering and change the proportion of flowering to vegetative culms, thus reducing overall digestibility and intake (Hacker and Minson 1981).

Sulfur

Sulfur and nitrogen are required in the synthesis of protein. Rees et al. (1974) found that intake of pangola grass with 0.08% S was increased by 28% by supplying a sulfur supplement, but by 44% if the pasture was fertilised with a fertiliser containing sulfur. This implies that the response was due to an effect on the organic composition of the plant, and not to a S deficiency per se. The level of S in the diet influenced dry matter digestibility and intake, both increasing with S concentration; it also reduced retention time of feed in the rumen.

Calcium

Calcium levels in the diet influence digestibility, intake and feed retention time in the rumen in a similar way to sulfur (Rees and Minson 1976).

Phosphorus

The evidence on response to P concentration and effects on intake and digestibility is equivocal. However, when markedly deficient in the diet, <0.01%, increases in intake of 15% in sheep and 25% in cattle were obtained from supplementation with P (Playne 1969; Little 1968).

Sodium

Many legumes and some grass species are low in sodium (<0.04%) (Hacker et al. 1985), and supplementation can increase intake and animal production. Falvey and Mikled (1982) reported increased liveweight gains, calving percentages and lower calf mortalities by sodium supplementation to cattle grazing *Imperata cylindrica* pasture in the Thai highlands.

Trace Elements

Cobalt is the only trace element proved to be deficient for ruminant production in the region. Mannetje et al. (1976) and Ismael (1983) showed marked responses to Co (or vitamin B12) supplementation to cattle grazing improved pastures in Malaysia.

An obvious alternative to the use of inorganic fertilisers is a more widespread use of animal manure. Suntraporn (1980) calculated that buffalo excrete about 18 kg faeces/day or about 6.6 t/year, with an average content of 0.28% N, 0.23% P, 0.11% K and 0.21% Ca. On this basis 18.5 kg N, 15 kg P, 7.3 kg K and 13.9 kg Ca would be available per annum from animal manure as a source of fertiliser for forages or crops.

Feed Quality and Animal Production

Production is only achieved when feed eaten is in excess of that required for maintenance. Lactation requirements are greater than for body weight gain, and for cattle the nutritional requirements for 1 kg liveweight gain equates to that for about 10 kg milk. Levels of production are proportional to the daily intake of digestible dry matter and hence depend on the quantity eaten and its digestibility.

Although climate and soil environments primarily control the adaptation and potential growth of species, there are large differences in production and nutritive value between genera, species, cultivars and parts of the plant (Minson 1971; Laredo and Minson 1973; Hacker and Minson 1981; Norton 1982). Morphological and physiological differences between species such as growth habit, proportion and distribution of leaf and stem, and flowering behaviour, have marked effects on quantity and quality of forages available for either grazing or cutting. As plants grow there is a change both in the proportion of different plant parts and in their digestibility. In grasses at the early growth stage there is a high proportion of leaf which increases in yield with time, but declines in digestibility. The proportion of stem also increases, but digestibility

declines to a lower level than that of the leaf. Species with a high initial digestibility tend to decrease in digestibility at a greater rate than those of lower initial digestibility. Most of the tropical legumes and some of the grasses in the genera *Brachiaria, Digitaria* and *Setaria* have low rates of decline in digestibility relative to species in the *Panicum* genus. Although there is a close relationship between digestibility and intake, large differences in intake between species of grasses can occur. Minson (1971) reported that intake of *P. maximum* cv. Hamil was 27% greater than that of *P. coloratum* cv. Kabulabula when compared at the same digestibility, and the difference in intake was associated with differences in leafiness. Other studies have confirmed that the intake of leaf is higher than stem at a given digestibility. When pastures are grazed this may be of lesser importance than when fed as cut material, because of the greater opportunity for selection when forage is grazed. For cut-and-carry systems the opportunity for selection is less, and management of grasses through selection of leafier species and manipulation of defoliation frequency are important variables in influencing the quality of the diet.

Requirements of Different Animals

Most of the nutritional research has been undertaken for cattle, and little comprehensive research undertaken for buffalo, goats or sheep. However, goats have been shown to be more efficient at digesting fibre than sheep or cattle, and their metabolisable energy intake was higher in fibrous feeds, i.e. they have a higher digestive efficiency (Devendra 1980). These studies showed that the dry matter intake from guinea grass of 16–49 day regrowths only declined from 2.8 to 2.2% of bodyweight. In a comparison between goats and sheep fed varying proportions of leucaena and napier grass, Devendra (1982) found that voluntary intake was greater for goats; highest intakes were also from rations with the highest leucaena content (75% leucaena, 25% grass).

The nutritional requirements for milk production are greater than for growth, particularly in terms of digestible energy. Studies in which protein and energy supplements were fed to cows grazing tropical pastures showed that protein was less limiting than energy (Hamilton et al. 1970). There are also considerable differences between grass species in their ability to supply nutrients for milk production. Stobbs (1973) found, when comparing three week regrowths of Nandi, Kazungula, Narok and Splendida setarias with pangola and kikuyu grasses, that pangola and spendida produced more milk than the other species. Because of the differences in nutritive value between grasses and

legumes, mentioned earlier, the inclusion of legumes in the diets of lactating animals is essential for improving milk production without use of other supplements.

Conclusions

The topic for this paper was forage management to optimise animal production. In biological terms 'optimum' means the most favourable conditions for survival, growth or reproduction. Achievement of an optimum level of production requires an understanding of plant and animal requirements, and of plant/animal interactions. Research in species adaptation and utilisation in the smallholder context has shown a potential for improvement in forage resources for ruminants that could overcome nutritional limitations to livestock. Smallholders own few animals, and in some cases only one large ruminant on which the ability to farm and hence produce an income depends. Therefore, adoption of any new technology involves a risk factor, whether in economic outlay or management. Research has indicated possible solutions for improvement in production but the results need to be demonstrated at the farm level and clearly show how systems of forage production can be integrated into farming systems to produce sustained and long-term improvement in ruminant production.

References

Ashari, T., and Petheram, R.J. 1983. Ruminant feeding systems 'in West Java, Indonesia. Agricultural Systems, 10, 87–97.

Bhannasiri, T. 1980. Buffalo Production and Development in Thailand. In: Buffalo Production for Small Farms. FFTC Book Series No. 15, 21–28.

Chantalakhana, C. 1985. Water buffalo production and development in Thailand. Proc. 3rd AAAP, Animal Science Congress, 1, 54–61.

Chen, C.P. 1985. The research and development of pastures in Peninsula Malaysia. In: International Symposium on Pastures in the Tropics and Subtropics. Tropical Agricultural Research Series 18, Tsukuba, Japan, 33–51.

Devendra, C. 1980. Feeding and nutrition of goats. In: Church, D.C., ed., Digestive Physiology and Nutrition of Ruminants Vol. 3. O & B Books Inc., Corvalis, Oregon.
    1982. The Nutritive Value of *Leucaena leucocephala* cv. Peru. Balance and Growth studies with goats and sheep. MARDI Research Bulletin, 10, 138–150.

Falvey, J.L., and Mikled, C. 1982. Sodium and phosphorus studies of rangeland cattle in the Thai Highlands. In: Jainudeen, M.R., and Omar, A.R., ed., Animal Production and Health in the Tropics. Proc., First Asian Australasian Animal Science Congress 1980. Universiti Pertanian Malaysia, Serdang, 267–269.

Gutterridge, R.C. 1981. Productivity of forage legumes on rice paddy walls in northeast Thailand. Proc., 14th International Grassland Congress, 226–229.

Hacker, J.B., and Minson, D.J., 1981. The digestibility of

plant parts. Herbage Abstracts, 51, 459–482.

Hacker, J.B., Strickland, R.W., and Basford, K.E. 1985. Genetic variations in sodium and potassium concentrations in herbage of *Digitaria milanjiana*, and its relation to provenance. Australian Journal of Agricultural Research, 36, 201–212.

Hamilton, R.I., Lambourne, L.J., Roe, R., and Minson, D.J. 1970. Quality of tropical grasses for milk production. Proc., 10th International Grassland Congress, 860–864.

Hassan, Wahab, and Izham, Ahmad 1984. Status of pasture research and development in Peninsula Malaysia. In: Asian Pastures FFTC Book Series No. 25, 30–43.

Ismael, Dahlan 1983. The effects of cobalt, copper and a mineral lick (mixture) supplementation on Brahman × Kedah Kelantan cattle grazing pasture. MARDI Research Bulletin, 11, 21–29.

Ivory, D.A., and Siregar, M.E. 1984. Forage research in Indonesia: past and present. In: Asian Pastures, FFTC Book Series No. 25, 12–27.

Javier, E.Q. 1978. Integration of fodder production with intensive cropping systems in Southeast Asia. Proc., Symposium on Feedingstuffs for Livestock in Southeast Asia. Serdang, Malaysia, 19–36.

Laredo, M.A., and Minson, D.J. 1973. The voluntary intake, digestibility and retention time by sheep of leaf and stem fractions of five grasses. Australian Journal of Agricultural Research, 24, 875–888.

Little, D.A. 1968. Effect of dietary phosphorus on the voluntary consumption of Townsville lucerne (*Stylosanthes humilis*) by cattle. Proc., Australian Society of Animal Production, 7, 376–380.

Manidool, Chanchai 1985. Pastures in Thailand. In: International Symposium on Pastures in the Tropics and Subtropics. Tropical Agriculture Research Series 18. Tsukuba, Japan, 53–59.

't Mannetje, L., Sidu, A.S., and Murugaiah, M. 1976. Cobalt deficiency in cattle in Johore. MARDI Research Bulletin, 4, 90–98.

Mendoza, R.C., Altaman, T.P., and Javier, E.Q. 1976. Herbage crude protein and digestible dry matter yield of ipil-ipil (*Leucaena leucocephala* cv. Peru) in hedgerows. Philippine Journal of Crop Science, 1, 149–156.

Mendoza, R.C., and Javier, E.Q. 1980. Herbage yield determination from four recommended ipil-ipil (*L. leucocephala*) cultivars. Leucaena Newsletter 1.

Milford, R., and Minson, D.J. 1965. Intake of tropical pasture species. Proc., 9th International Grassland Congress, 815–822.

1966. Determinants of feeding value of pasture and supplementary feed. Proc., Australian Society of Animal Production, 6, 319–329.

Minson, D.J. 1971. The digestibility and voluntary intake of six varieties of *Panicum*. Australian Journal of Experimental Agriculture and Animal Husbandry, 11, 18–24.

Minson, D.J., and Milford, R. 1967. The voluntary intake and digestibility of diets containing different proportions of legume and mature pangola grass (*Digitaria decumbens*). Australian Journal of Experimental Agriculture and Animal Husbandry, 7, 545–551.

Minson, D.J., Stobbs, T.H., Hegarty, H.P., and Playne, M.J. 1976. Measuring the nutritive value of pasture plants. In: Shaw, N.H., and Bryan, W.W. ed., Tropical Pasture Research — Principles and Methods. Bulletin, Commonwealth Bureau of Pastures and Field Crops, No. 51, 308–337.

Moog, F.A. 1974. Backyard cattle raising in Batangas and its feeding systems. Quoted by Javier, 1978.

Norton, B.W. 1982. Differences between species in forage quality. In: Hacker, J.B., ed., Nutritional Limits to Animal Production from Pastures. Commonwealth Agriculture Bureaux, Farnham Royal, U.K., 89–131.

Pasture Improvement Project, 1984. Final Report. Faculty of Agriculture, Khon Kaen University, Thailand.

Playne, M.J. 1969. The effect of dicalcium phosphate supplements on the intake and digestibility of Townsville lucerne and spear grass by sheep. Australian Journal of Experimental Agriculture and Animal Husbandry, 9, 192–195.

Pongskul, V., Wilaipon, B., and Gutteridge, R.C. 1982. Undersowing upland crops with pasture legumes II. Kenaf (*Hibiscus sabdariffa* var. *altissima*) with *Stylosanthes hamata* cv. Verano. Thai Journal of Agricultural Science, 15, 7–10.

Rees, M.C., and Minson, D.J. 1976. Fertilizer calcium as a factor affecting the voluntary intake, digestibility and retention time of pangola grass (*Digitaria decumbens*) by sheep. British Journal of Nutrition, 36, 179–187.

1978. Fertilizer sulphur as a factor affecting voluntary intake, digestibility and retention time of pangola grass (*Digitaria decumbens*) by sheep. British Journal of Nutrition, 39, 5–11.

Rees, M.C., Minson, D.J., and Smith, F.W. 1974. The effect of supplementary and fertilizer sulphur on voluntary intake, digestibility, retention time in the rumen and site of digestion of panola grass in sheep. Journal of Agricultural Science, Canbridge, 82, 419–422.

Senaratna, J.E. 1937. Ceylon grassland. Proceedings of 4th International Grassland Congress, 166–172.

Shelton, H.M. 1980. Dry-season legume to follow paddy rice in Northeast Thailand. I. Species evaluation and effectiveness of native *Rhizobium* for nitrogen fixation. Experimental Agriculture, 16, 57.

Shelton, H.M., and Humphreys, L.R. 1975. Undersowing rice (*Oryza sativa*) with *Stylosanthes guyanensis*. Experimental Agriculture, 11, 89–111.

Stobbs, T.H. 1973. Milk production from tropical pastures. In: Commonwealth Scientific and Industrial Research Organization. Division of Tropical Agronomy Annual Report, 1972–73, p.72.

Suntraporn, Ratanadilok Na Phuket 1980. The role of swamp buffalo in small farm development in Thailand. In: Buffalo Production for Small Farms. FFTC Book Series No. 15, 74–83.

Takahashi, M. 1952. Tropical forage legume and browse plants research in Hawaii. Proceedings, 6th International Grassland Congress, 1411–1417.

Thornton, R.F. and Minson, D.J. 1973. The relationship between apparent retention time in the rumen, voluntary intake and apparent digestibility of legume and grass diets in sheep. Australian Journal of Agricultural Research, 24, 889–898.

Wilaipon, B., Gutteridge, R.C., and Chutikul, K. 1981. Undersowing upland crops with pasture legumes. 1. Cassava with *Stylosanthes hamata* cv. Verano. Thai Journal of Agricultural Science, 14, 333–337.

Wilaipon, B., and Pongskul, V. 1984. Pasture establishment in the farming systems of Northeast Thailand. In: Asian Pastures. FFTC Book Series No. 25, 65–84.

Wong, C.C. 1982. Evaluation of ten pasture legumes grown in mixtures with three grasses in the humid tropical environment. MARDI Research Bulletin, 10, 229–308.

Forages in Integrated Food Cropping Systems

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OVER 60% of food production in Asia is provided by small farmers who keep livestock in mixed crop/livestock farming systems (Camoens et al. 1985). In these farms the relationship between crops and livestock is complementary, whereby livestock provide farm power, transport, and manure, while by-products from crops and weeds from croplands are converted by livestock into meat and milk.

Feeding of animals in mixed crop/livestock farming systems revolves around forages which include crop residues, weeds, tree leaves and planted fodder crops (Moog 1974). The kind of crops grown, the intensity of cropping and the extent of land utilisation, coupled with the environmental and management factors, determine the availability of the above feedstuff for livestock production. Productivity or performance of livestock varies in different locations and differs among farms, depending upon the availability of forages and the farmers' ingenuity to manipulate feeding on a year-round basis (Moog 1980). Farmers feed their animals with minimum or no cost at all except labor, because their first order of business is to utilise the weeds and crop residues associated with their crops. Some farmers plant small areas to forage crops, either as monoculture or intercrops to provide feed quality and to assure availability of feed during periods of scarcity. Brans are fed when home-grown grains are milled, but they are seldom used.

This paper presents the value of cultivated food crops as a source of forage, and of especially grown forage species integrated with food crop production to support livestock.

Feeding Systems and Food Crop Production

The need to commit a major portion of land to the production of food crops greatly restricts the area on small farms that can be used for forage crops. This problem is partially solved by planting forage crops in association with staple food crops (Cornick and Kirby 1981). Because there is lack of sufficient land to satisfy the requirement for both food crops and forage crops, the small farmers must treat staple crops in a dual purpose manner. This is accomplished by investing large amounts of family labor in the collection of weeds and crop by-products that can serve as animal fodder.

The following discussions show the important role of weeds and the by-products from food crops as forages in upland and lowland rice cropping systems.

Upland Cropping systems

Upland cropping systems are widespread over the humid tropics of Asia. These are well developed farmsteads with permanent, cleared fields but with no bunding and no irrigation (McDowell and Hildebrand 1980). The major food crops grown under this system are rice, corn, sorghum, cassava and beans. Most households have small numbers of several species of animals — pigs, chickens, cattle and buffaloes, seldom with goats or sheep.

A traditional year-round feeding scheme in a rice/corn cropping village in Batangas, Philippines is presented in Fig. 1 (Moog 1980). Feeding of cattle is tied up with the existing cropping system in the village, with weeds from cultivated areas, orchard and idle lots serving as the principal forages. Weeds constitute 70–90% of the feed between July and
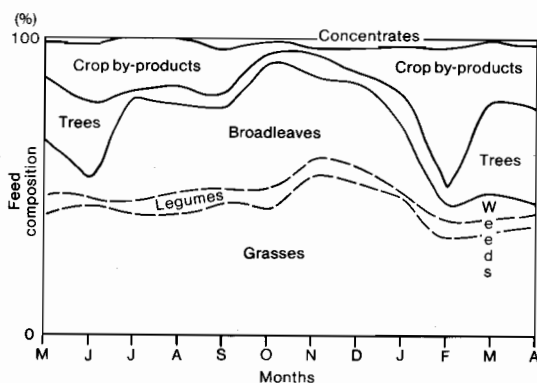

Fig. 1. Monthly composition of feeds given to cattle in rice/corn cropping systems (Golamay-amo, San Jose, Batangas, Philippines).

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January, and no less than 40% the rest of the year. The predominant grass is *Paspalum conjugatum*, which constitutes over 38% of the feed in June but declines in August to 1%, then gradually increases up to around 30% between November and May. Other grasses such as *Imperata cylindrica, Apluda mutica, Digitaria microbachne, Dactyloctinium aegyptium, Echinocloa colona* and *Rottboellia exaltata*, which are associated with rice, corn and cultivated crops, are abundant and preferentially fed from July to September. Broad-leaves, particularly *Synedrella nodiflora, Pseudoelephantopus* sp., *Triumfetta semitriloba*, though not fed in high amounts, are always a feed component throughout the year. From December to April weeds from croplands are scarce, and these are supplemented with fresh corn stalks and corn stover gathered during December and January, constituting over 45% of the feed. In July and August green corn constitutes up to 36% of the feed, with small parts coming from crop by-products such as coconut frond, jackfruit peelings and banana leaves and trunks. Rice straw is not gathered and fed. Farmers prefer the less fibrous and good quality fresh materials.

One of the most important upland crops grown in Asia is sugarcane. Though it is not a primary staple crop, it is interesting to present the distinct features of feeding livestock in a sugarcane farming village (Moog et al. 1981). Feeding of weeds is confined to the growing period of sugarcane (wet season). Crop by-products, principally canetops, which constitute up to 75% of total feed are the dominant feed during the milling season, coinciding with the dry season from November to April (Fig. 2). Small amounts of canetops and shoots from rattoon are harvested from May to October. *Imperata* is gathered throughout the year in small amounts, but higher feeding is evident during August and October, reaching up to 50% of the

Fig. 2. Monthly composition of feeds given to cattle in sugarcane cropping systems (Pacifico, Sta. Teresita, Batangas, Philippines).

feed. Other grass weed species like *Ageratum conyzoides, Paspalum conjugatum, Echinocloa colona, Eleusine indica* and some broadleaf species like *Elephantopus tomentosus, Synedrella nodiflora* were fed year-round with small amounts of legumes like *Centrosema pubescens* and *Desmodium* sp. Other crop by-products like banana leaves and corn fodder are fed in small amounts.

On Batangas upland farms, rice straw in not a desirable feed, but fields with standing rice stubble serve as temporary grazing areas for tethered cattle immediately after harvest (Moog 1974).

Corn is generally a dry season crop grown after the rice harvest. Although it is primarily a grain crop, its diversity has made corn a more valuable source of cattle feed than rice. In Batangas, corn comprises a major portion of cattle diet for a longer period than any other crop. It is fed at different stages of growth. Batangas farmers plant corn at high seeding rates and thinning of less vigorous plants is done twice, the first one month after planting and the second at the silking state. Plants obtained from the first thinning are not used as animal feed because they usually cause diarrhea. Green corn from the second thinning is preferred.

Corn is closely associated with fattening of cattle in the province. Its availability coincides with the months cattle are free from work in the field. Thus, more animals are being finished with a basal diet of chopped green corn and are sold in July/August or December/ January, .for the wet and dry season crops of corn respectively.

Lowland Rice

Rice is grown all over Asia, and is the staple food for the majority of its population.

In rice growing areas of Laguna and Central Luzon (Philippines), livestock are grazed along roadsides, irrigation lands and uncropped areas during the rainy season. Many are kept in the backyard with big stocks of rice straw. After the second crop is harvested, the animals are tethered with long leashes of rope, or let loose on the rice paddies (Javier 1975).

For buffalo, rice straw is the most utilised cereal by-product in five Philippine provinces surveyed (de Guzman 1981) and of 200 farms surveyed, 99% of buffalo owners fed rice straw (Kintana-Araral and Depositario 1983).

In Bali, Indonesia, rice straw was less preferred but comprised 30–60% of both cattle and buffalo diets during the dry season (Nitis 1980). During the wet season, cattle are fed 80% grasses, 14% tree leaves, 2% straws, 1% banana stem and 3% other compo-
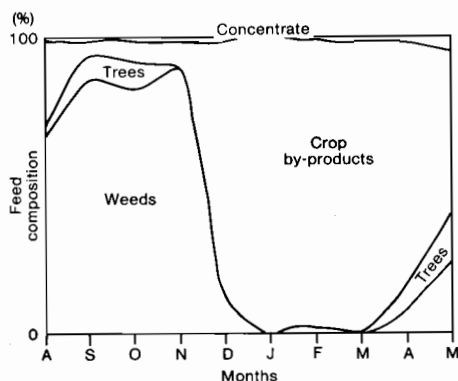
nents. Buffalo received a similar diet, but with only 1% tree leaves.

Forage Crops in Integrated Food Cropping Systems

Seasonal scarcity, especially during the dry season, tends to limit livestock production (Calub 1983). Even under the intensive systems of irrigated rice, feed shortages are experienced by farmers during the growing period of the crop before harvest. Forage crops, particularly the legumes, could be integrated with existing cropping systems as intercrops, relay crops, alley crops and even as companion crops in uncropped areas, without interfering with the regular cropping patterns.

Intercropping with Forage Legumes

Pigeon pea, mungbean and soybean, intersown at 200 000 plants/ha at 0, 1, 2 and 3 weeks after planting sweet corn, had no significant effects on harvested marketable green corn and stover yields, but delayed sowing of legumes reduced their fodder yield. Soybean sown simultaneously with corn produced the highest fodder yield (fresh) of 3.79 t/ha (Furoc 1978).

In another experiment, soybean intercropped with corn at 200 000–600 000 plants/ha and cut as fodder 40 and 60 days after sowing produced 4–9 t of fresh herbage/ha during the wet season, and 2.6–4.6 t in the dry season without affecting the yield of corn. In fact, corn yield was slightly higher with soybean intercrop, but corn with intercropped soybean cut at 60 days had lower yield compared to corn with soybean intercrop cut at 40 days. The same effects were observed in the case of corn harvested for grain. From the corn and the soybean intercrop, available dry matter of by-products and fodder was 5 t/ha which theoretically can support 5 steers in 120 days, giving an incremental liveweight gain of 240 kilograms.

Studies in central Laos and northeast Thailand also showed that it is possible to add fodder and nitrogen without decreasing rice yield (FOA 1985), and that competition between rice and fodder may be controlled by:

Choice of species Grass fodder will compete for nitrogen more than legumes. In slash-and-burn upland rice, incorporation of Molasses grass (*Melinis minutiflora*) and Guinea grass (*Panicum maximum*) significantly reduced rice grain yield in circumstances where inclusion of *Stylosanthes guianensis* cv. Endeavour did not (Shelton and Humphreys 1972). Non-scrambling or twining forage legumes are better companions for rice and grain crops.

Time of planting and crop duration Fodder crops

sown simultaneously with or before rice seeding or transplanting are expected to reduce grain yield. *S. guianensis* sown at high density coincidentally with rice sowing reduced grain yield by 36% (Shelton and Humphreys 1975a); this reduction may arise through the effect of stylo on the moisture or phosphorus available to the rice crop, or the shading of the upper rice leaves by tall stylo (Shelton and Humphreys 1975b). On the other hand, where *S. guianensis* was sown 10 or 30 days after rice sowing date (Shelton and Humphreys 1972, 1975b), rice yield was not reduced by the companion forage legume. The amount of forage grown is negatively related to the planting delay. However, this may be partially compensated by growing an early rice variety, which is harvested before all soil moisture is exhausted; a companion late rice variety will reduce stylo yield (Shelton and Humphreys 1975b).

Planting density Upland rice yield is sensitive to the density of a companion stylo crop, and was negatively related to stylo density over the range 0–81 plants/m^2 in central Laos (Shelton and Humphreys 1975a). However, stylo growth was relatively independent of rice density over the range 20–120 plants/m^2, and this was probably associated with the compensatory tillering.

Fertiliser practice The application of nitrogenous fertiliser depresses companion legume yield. At Khon Kaen, Thailand, the shoot yield of a rice/stylo association at the end of the wet season was about 100 kg N/ha over the whole range (0–80 kg fertiliser N applied/ha) (Shelton and Humphreys 1975c).

The practical implications of these studies were that the sowing of *S. guianensis* at about 2 kg/ha (giving around 25 plants/m^2) 10 days after sowing an early upland rice variety might be expected to provide an additional 3 t dry matter/ha of leguminous feed, with little or no reduction in rice yield. Self-regenerating legumes, such as *S. hamata*, are a viable alternative.

Alley Cropping with Tree Legumes

In the hilly areas in Mabini, Batangas (Philippines), leucaena is grown in hedgerows 3 to 4 m apart to avoid reducing the utility of land for the production of primary crops. In this area, the fruit tree 'atis' (*Anona squamosa*) is grown between rows of leucaena, and farmers observed that they harvest bigger fruits from the plants grown with leucaena. In another case, one farmer had raised 20 growing cattle on two hectares of leucaena planted in rows three metres apart, with anona plants between rows. With 20 animals and leucaena harvested every 40–60 days, the farmer had surplus fodder, and had to share the extra feed with his

neighbours to prevent the anona plants from being shaded.

Relay Cropping with Forages and Grain Legumes

Planting of forage crops after the harvest of wet season rice makes use of the residual moisture stored in the soil. Alternatively, an early maturing or short-duration crop like cowpea may also be grown before rice, in areas where the opening rains in moonsoon climates are uncertain.

In Thailand *Crotalaria juncea* had been found to be the most successful fodder legume after paddy rice. Initial planting of *Lablab purpureus* indicated the potential of this fast-growing legume in Sorsogon and Masbate, Philippines, as a short-duration fodder crop. In northern Philippines, dense plantings of corn and sorghum for fodder are normally sown after rice.

Several varieties of bush sitao, mungbean and cowpea were tested by IRRI before and after wetland rice. Mungbean provided 1.1–1.6 t dry fodder/ha; cowpea, 0.4–1.3 t; and bush sitao, 9.6–22.1 t fresh fodder.

Cattle Liveweight Gains on Leucaena-based Rations

Benefits from crop-livestock integration should be expressed in terms of animal performance or productivity. With the high nutritive value of forage legumes, particularly leucaena, feeding trials have been directed to the role of the plant as a primary source of protein, in combination with low quality roughages and farm by-products, particularly rice straw. Aside from being a good source of protein, leucaena has also high carotene content, which is absent in rice straw and in poor quality by-product roughages.

Feedlot trials demonstrated the value of leucaena in combination with rice straw as livestock feed (Marbella et al. 1979). Peformances of Santa Gertrudis heifers were compared on the following rations:
Ration 1 — 50% rice straw + 50% concentrate;
Ration 2 — 50% rice straw + 50% leucaena;
Ration 3 — 50% rice straw + 40% leucaena + 10% concentrate.

Results of the 120-day feeding trial showed that among treatments, Ration 3 gave the highest average daily gain (ADG) of 0.70 kg, followed by Ration 1 with 0.64 kg. Animals on Ration 2 had the lowest ADG of 0.52 kg. Feed conversion efficiencies showed the same trend as ADG on the three rations. Economic analysis, however, revealed the return above feed costs was highest on animals fed Ration 2, followed by

Ration 3. In the case of Ration 1, the value of liveweight gain obtained was not able to pay for the cost of concentrate.

The above findings indicate that though animal liveweight gain can be higher when part of the leucaena is substituted or replaced with concentrates in cattle rations, the incremental liveweight gain obtained from the substitution may not be enough to justify the cost of the concentrate substituted.

Observations in Batangas show that farmers who recognise the value of leucaena as cattle feed give their animals 5–20 kg fresh leucaena (28% DM)/day. Assuming an average of 10 kg (2.8 DM basis with CP content of 28%) 0.78 kg CP is available from leucaena alone. The amount is more than enough to meet the protein requirement (0.7 kg/day) of a growing steer weighing 350 kg and gaining 0.5 kg/day. Farmers may feed higher levels of leucaena with rice bran and limited concentrates to obtain an estimated average daily gain of 0.7–0.8 kg. Animals fed ordinary roughages are estimated to gain only 0.2–0.3 kg/day.

References

Calub, A.P. 1983. Smallholder crop–livestock integrated farming in the Philippines. Asian Cropping System Network Crop Livestock Research Workshop. IRRI. Los Baños, Philippines.

Camoens, J.K., McDowell, R.E., De Boer, A.J., Weinaladbarma, K.P., Bawden, R.J., Moog, F.A., and Workshop Participants 1985. Characteristics of Asian livestock production and management systems. In: Proc., Regional Workshop on Livestock Production Management. ADB, Manila, 147–238.

Cornick, T.R., and Kirby, R.A. 1981. Interaction of crops and livestock production in the generation of technology in sloped areas. Cornell Univ. Ithaca, N.Y.

de Guzman, M.R. 1981. Feeding and management practices, physical characteristics and utility of carabao (swamp buffalo) in five provinces of Luzon. Ph.D. Dissertation, University of the Philippines, Los Baños (UPLB).

FAO 1985. The improved integration of forage production with rice culture in Southeast Asia. Sixth Session, International Rice Commission. Los Baños, Philippines.

Furoc, R.E. 1978. Integration of fodder production with a corn-based cropping system. M.S. Thesis, UPLB, Philippines.

Javier, E.Q. 1975. Fodder crops in village livestock production systems in Southeast Asia. Innaugural Lecture, Professorial Chair, SEARCA, Los Baños, Philippines.

Kintana-Araral, P. and Depositario, P.T. 1983. Management practices of carabao raisers: an analysis. 20th Annual Scientific Convention. PSAS. PICC. Metro Manila, Philippines.

Marbella, J.L., Pineda, C.I., Bulay, R.N., Castillo, A.C., and Moog, F.A. 1979. Utilization of rice straw and Ipil-ipil for feedlot fattening. 16th Annual Scientific Convention, MIA, Parañaque, Metro Manila, Philippines.

McDowell, R.E. and Hildebrand, P.E. 1980. Integrated crop and animal production: making the most of resources available to small farms in developing countries. Working Paper, Rockefeller Foundation, USA.

Moog, F.A. 1974. Backyard cattle raising in Batangas and its feeding system. Term Paper, UPLB, Philippines.

1980. Backyard cattle raising and its feeding system in a Batangas barrio. M.S. Thesis. UPLB, Philippines.

Moog, F.A., Nagpala, R.G., Fulgencio, A.C. and Valenzuela, F.G., 1981. Cattle feeds and feeding practices under different cropping systems in Batangas and Quezon. PSAS Convention, PICC, Metro Manila, Philippines.

Nitis, I.M. 1980. Beef cattle and water buffalo production in Southeast Asia. Workshop on Feed Composition, Data Documentation and Feeding Sytems. APHCA. Manila.

Shelton, H.M., and Humphreys, L.R. 1972. Pasture establishment in upland rice crops at Na Pheng, Central Laos. Tropical Grasslands, 6, 223–228.

1975a. Undersowing rice (*Oryza sativa*) with *Stylosanthes guyanensis*. I. Plant density. Expl. Agric., 11, 89–95.

1975b. Undersowing rice (*Oryza sativa*) with *Stylosanthes guyanensis*. II. Delayed sowing time and crop variety. Expl. Agric., 11, 97–101.

1975c. Undersowing rice (*Oryza sativa*) with *Stylosanthes guyanensis*. III. Nitrogen supply. Expl. Agric. 11, 103–111.

Forages in Plantation Crops

I.K. Rika*

THE total plantation crop area in Indonesia is made up of 2.6 million hectares of coconut plantation, 2.4 million hectares of rubber plantation, 0.26 million hectares of oil palm, and 0.35 million hectares of clove plantation (Anon, 1979). The area under plantation crops has generally not been used effectively up to now for animal production because it is mostly covered by native grasses and shrubs or planted to cash crops (bananas, sweet potato, cassava, corn and other cash crops).

With the need for animal protein increasing linearly with increasing human population, the development of extensive systems of animal production is incapable of meeting increased demand for meat. One of the alternatives is to increase animal production in intensive systems.

In Malaysia, there are 2.8 million hectares of plantation crops (Wahib and Izham 1984) and in Thailand nearly 0.42 million hectares of coconut plantation (Manidool 1984) which can be used to keep animals in an integrated animal/crop system. Usually, the farmer already manages the area under plantation crops in the traditional system, which uses the native forages for animal feeding. Under coconut plantations that are covered by native grasses not more than one beast/ha can be carried. However, with improved pastures, such as *Brachiaria decumbens*, green panic, siratro and centrosema, the stocking rate can be increased to 3-4 beasts/ha (Rika et al. 1981). So if the utilisation of the area under coconuts or plantation crops is increased by the introduction of improved pastures and then grazed by animals, the economic value will be increased at the same time animal protein will be produced.

Utilising the Area under Plantation Crops

Improving animal production under plantation crops is hampered by: (a) the farmers' limited knowledge on forage utilisation and animal management; (b) climatic limitations.

The farmers' priorities are usually to choose to utilise the land for food, growing grains and tubers (corn, dryland paddy, cassava tubers and others) that will produce yields in a relatively short time compared to improving their land for grazing. Because of their lack of knowledge in animal and forage production, they keep animals just for draught purposes and usually in limited numbers. Also, the farmers who own or who have access to large areas of plantation crops are still not confident of using the areas under plantation crops, because of their general lack of knowledge and their worry of the risk of animals dying, which arises from the lack of effective animal health services in some regions. The farmer may also lack information on the potential income resulting from keeping animals on plantations or associated with cash crops, because of a lack of extension and information services to the farmer.

The farmer is often unaware of the value of improved pasture (including the legume component) for feeding to animals, and the potential increase in the fertility of his land and the prevention of erosion (Mardiono and Hardjono 1984).

Shading by plantation crops results in the slow establishment of forages. Smith and Whiteman (1983) found that *Brachiaria decumbens* needed a minimum of 70% light for good establishment. Decreasing light transmission by shading by the plantation crop causes a decrease in forage yield. The growth of *Brachiaria decumbens* under shading has been found to be thinner and weaker compared with an open area (Winaya 1983).

Decreasing light intensity, day length and temperature have a direct effect on the generative growth (Humphreys 1979). Careful selection is required to get suitable species which are productive, seed well and are resistant to the effects of grazing.

Grazing in young plantation crops is not recommended because the animal can damage the young plants. Also, the physical structure of the soil

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can deteriorate by animal trampling that can cause soil erosion and impeded drainage.

Integration of Pastures with Crop Plantations

Much research has been done to increase the degree of utilisation and effectiveness of forages under plantation crops. The effect of stocking rate (SR) on improved pasture in grazing experiments has been related to animal production and coconut yield, and to the persistency of the improved pasture (grass and legumes) and the effect of the pasture on soil fertility.

Animal and Crop Production

Rika *et al.* (1981) in a grazing experiment on improved pasture (siratro, centrosema, green panic and *Brachiaria decumbens*) with 2.7, 3.6, 4.8 and 6.3 animals/ha found that the nut number and nut yield increased linearly with increasing SR. The nut number and nut yield at the lower SR (2.7) was 263 nuts (507 kg)/ha/month and at the highest SR was 454 nuts (776 kg)/ha/month, while on natural pasture the nut yield was 291 nuts (483 kg)/ha/month. Chen et al. (1978) found that increasing SR from 1 beast/ha to 2 beasts/ha on *Panicum maximum* and *Stylosanthes guianensis* cv. Schofield improved pasture caused an increase of palm oil production from 103 to 141 kg/palm. With natural pasture, without grazing, production was just 49 kg/palm.

An improved pasture *(Centrosema pubescens/ B.decumbens)* under a coconut plantation in Thailand with SR of 1.0, 1.5, and 2.5 beasts/ha resulted in 108.4, 116.8 and 96.8 kg/ha/year liveweight gain of cattle, compared to native pasture grazing of only 43.7 kg/ha/year (Manidool 1984). Stocking rates 2.7, 3.6, 4.8 and 6.3 beasts/ha on improved pasture (siratro, centrosema, green panic and *Brachiaria decumbens*) showed weight gains of 386, 497, 647 and 773 kg/ha respectively during the first grazing period (August 1974–August 1974), but during the second grazing period (November 1975–February 1978) weight gains were 541, 714, 834, and 904 kg/ha respectively (Rika et al. 1981).

In the Solomon Islands, animal production on improved pasture under coconut plantation *(Brachiaria mutica, Brachiaria decumbens, Brachiaria humidicola, Centrosema pubescens, Pueraria* and *Stylosanthes)* was compared with naturalised pasture *(Anonopus compressus, Mimosa pudica, Centrosema pubescens, Calopogonium muconoides)* (Watson and Whiteman 1981). The pastures were grazed by cattle at different SR (1.5, 2.5, and 3.5 animals/ha) which resulted in weight gain per head decreasing linearly with increas-ing SR. Despite this the highest liveweight gain of 437 kg/ha/year was obtained at the highest SR (3.5 head/ha) with no significant difference between the two kinds of pasture (improved and native. So both the native and improved pastures had a good effect on liveweight gain of cattle. In other circumstances it would depend on the composition of the native pasture, particularly the legume component and production continuity.

Not only large ruminants can be grazed under coconut plantations but also small animals like goats and sheep. On natural pasture the native grasses, legumes and weeds can be utilised by animals to increase the efficiency of use and profitability of land, and result in a more diversified agricultural system. Goats and sheep reared on rubber plantations with a stocking rate of 7–10 animals/ha showed satisfactory performance (Dahan and Hutagalung 1978).

Rearing goats on improved pasture (centrosema, siratro and *Brachiaria decumbens*) on coconut planta-tions in Bali, Indonesia, with a SR of 6, 9 and 12 head/ha and 6 head/ha on native pasture (dominated by native grass and calopo) resulted in very good animal performance and good healthy kids (Rika 1983). It was found that goats selected the legumes (siratro, centro) before the grasses.

Soil nutrient available also affects pasture, animal and plantation crop production. A sown pasture *(Brachiaria decumbens,* siratro, and *Centrosema pubescens)* which was fertilised with 310 kg urea/ha, 190 kg KCI/ha and 190 kg TSP/ha was grazed by Bali cattle for 252 days. An increase in the liveweight gain from 0.311 kg/day (on native pasture) to 0.379 kg/day (on improved pasture) was recorded (Winaya et al. 1983). Also, nut yield increased about 41% in both pastures after grazing.

Pasture Composition

Rika et al. (1981) found that increasing SR from 2.7 to 6.3 beasts/ha caused a significant decrease in the composition of introduced grass and legumes in an improved pasture under coconuts. At the two lowest SR (2.7 and 3.6 beasts/ha) the composition of improved legumes and grass was not much changed until about 3.5 years of continuous grazing, when the liveweight of cattle was 300–320 kg. At two higher SR (4.8 and 6.3 beasts/ha) the improved grass and legume components decreased after 2.5 years grazing, with a resulting increase of native grass and weeds when the liveweight of cattle was 200–240 kg. After 3.5 years (at 2.7 and 3.6 SR) and 2.5 years (at 4.8 and 6.3 SR) the improved pasture had markedly degenerated with the composition of sown species decreasing seriously and corresponding loss of production.

The production and composition of sown pastures are also affected by light intensity through the plantation crops. In an open area (in full light intensity) *Brachiaria decumbens* yielded 28 t/ha/year (Smith and Whiteman 1983). Shaded plants had thinner leaves and larger nitrogen concentration than unshaded ones. *Brachiaria decumbens* and *B. humidicola* are recommended as suitable forage species for open plantation (minimal light transmission 70%) (Smith and Whiteman 1983). Nitis and Rika (1978) found that an improved pasture was still performing well under 60 year old coconut palms (10m × 10m spacing), where light transmissions under the coconut palms in the morning (9.00 a.m.), noon (12.00) and afternoon (3.00 p.m.), during a clear sunny day, were 80, 85 and 82% respectively. In an experiment with sown pasture *(Brachiaria mutica, B. decumbens, B. humidicola, Centrosema pubescens, Pueraria phaseoloides)* and naturalised pasture under 60% of full sunlight in the Solomon Islands, pastures were grazed by 1.5, 2.5 and 3.5 beasts/ha for three years. All the improved grasses disappeared (changed from 28% to 0%), while centrosema decreased from 14 to 8% and puero from 20 to 16% (Watson and Whiteman 1981).

Value of Pastures in Plantations

The integration of animal production with plantation crops can provide additional income to the farmer with usually no adverse effect, and often some benefit, to plantation crop yield. Cattle have been run under coconut plantations as sweepers or brushers to keep natural grasses and weeds short, so preventing excessive nutrient and moisture competition with the coconut plantations and ensuring easier location and collection of fallen nuts (Reynolds 1978).

With cattle grazing a reasonably weed-free area of native grass under coconuts, a stocking rate of 0.5–1.0 animals/ha could be expected, with a daily gain of 0.25–0.30 kg/day. This would provide an annual liveweight gain/ha of about 59 kg (Ivory et al. 1984). With improved pasture grass/legumes, the stocking rate could be increased to 3–4 head/ha, and daily liveweight gain would be 0.3–0.4 kg, giving an annual liveweight increase of about 375 kg/ha (Rika et al. 1981). This would provide an additional good income to coconut plantation farming.

The return of nutrients in animal manure under plantation crops can be expected to increase coconut yields. In Bali, the orange or clove farmers tether cattle under their plantation crops, moving them regularly from one location to another on their land, hoping the manure will increase the yield of their plantation.

Cover crops have already been used under rubber plantations to improve the fertility of the area, to prevent erosion and maintain the soil moisture. Besides those purposes, the cover crop should be used, with good management, for animal feed to increase the farmer's income.

Prospects for Forages in Plantations

The scope for increasing animal production by intensive animal feeding systems is very small, because of the limited area of suitable land. One alternative to increase animal production is by integration of animal and plantation crop systems. Land under cash crops can be utilised more efficiently by companion cropping, and land under plantation crops can be utilised more efficiently by improved pasture or increasing the utility of native pasture by good pasture/animal management systems.

Much research has been done. Research in the Philippines (de Guzman and Allo 1975), in the Solomon Islands (Watson and Whiteman 1981), in Indonesia (Rika et al. 1981) and in Thailand (Manidool 1984), has shown that improved pastures under coconuts have no adverse effect on coconut yield. However, research is still needed to allow increased animal productivity in the future.

There is a need for the selection of suitable species under different plantation crops and in different regions, because each species requires a suitable climate (day length, temperature, humidity and rainfall), to maximise performance both in vegetative or generative growth.

More information is required on the persistency of species planted under plantation crops, and the relationship with grazing pressure and grazing management. It is very important to know the effect of the system of grazing (for example continuous grazing or intermittent grazing) on pasture stability because when a pasture is sown under plantation crops it is hoped that it will remain productive for a long time. Information is also required on native pastures (native grass and legumes), their persistency under grazing pressure and their effects on the growth performance of grazing animals.

Little information is available on the effect of improved pasture and grazing pressure on soil fertility and soil physical properties.

References

Anon. 1979. Data statistik perkebunan, menurut propinsi. Direktorat Jendral Perkebunan Jakarta, 1p.

Chen, C.P., Chang, K.C., Sindhu, A.S., and Wahab, H. 1978. Pasture and animal production under five year old oilpalm at Serdang. Proc., Seminar on Integration of Animals with Plantation Crops, 181–184.

Dahan Mohamed Mahyudin, and Hutagalung, R.I. 1978.

Integration of small ruminants with plantation crops. Proceedings, Seminar on Integration of Animals with Plantation Crops, 70p.

de Guzman, Jr. M.R., and Allo, S.V., 1975. Pasture production under coconut palm. ASPAC/FFTC: Taiwan.

Humphreys, L.R. 1979. Tropical pasture seed production. FAO Plant Production and Protection, 8, Rome.

Ivory, D.A., Bowman, G.W., and Rika I.K. 1984. A study of the potential for beef cattle development in Maluka Province, Indonesia. LTA, 72p.

Manidool, C. 1984. Pasture under coconut in Thailand. Asian Pastures. FFTC Book Series, No. 25, 240–214.

Mardiono, Djoko Soebroto, and Djoni Hardjono, G. 1984. Usaha konservasi tanah dalam kaitannya dengan pengembangan ternak dihulu daerah aliran sungai. Proc., Seminar Memanfaatkan Lahan Sempit untuk Meningkatkan Produksi Peternakan di Malang.

Nitis, I.M., and Rika, I.K., 1978. Bali cattle grazing improved pasture under coconuts. Proc., Seminar on Integration of Animals with Plantation Crops, 103–111.

Rika, I.K. 1983. Pengaruh pengembalaan kambing (pada berbagai ''sto-king rate'') dibawah pohon kelapa. Bull. Fapet UNUD, No.123/83.

Rika, I.K., Nitis, I.M., and Humphreys, L.R. 1981. Effect of stocking rate on cattle growth, pasture production and coconut yield in Bali. Trop. Grasslands, 15, 149–157.

Reynolds, S.G., 1978. Selection of grass and legume species for coconut areas. Proc., Seminar on Integration of Animals with Plantation Crop, 193–205.

Smith, M.A., and Whiteman, P.C. 1983. Evaluation of tropical grasses in increasing shade under coconut canopies. Expl Agric., 19, 153–161.

Wahab Hassan, and Izham Ahmad 1984. Status of pasture research development in Peninsular Malaysia. Asian Pasture FFTC, Book Series, No. 25, 30–39.

Watson, S.E., and Whiteman, P.C. 1981. Animal production from naturalized and sown pasture at three stocking rates under coconuts in the Solomon Islands. J. Agric. Sci. Camb, 97, 669–676.

Winaya Putu Djapa, Rika, I.K., and Nugari, I.K. 1983. Efek improved pasture terhadap produksi ternak sapi Bali dan produksi kelapa di Sumber Batok Bali. PSSR. Dep.Dik. Bud., Kontrak Penelitian No.425/PSSR/DPPM/175/81.

Forages in Extensive Grazing Systems

L. 't Mannetje*

GRASSLANDS are defined as vegetation types which consist of less than 40% tree cover, with a grassy understorey. This definition covers pure, i.e. treeless, and wooded grasslands, often referred to as savannas. These vegetation types are naturally associated with climates that have a fairly long dry season. In the region of Southeast Asian these are rare. The largest part of the area has a humid climate, with less than 2.5 dry months. Only parts of eastern Indonesia, northern Australian and the eastern part of the Indochinese subcontinent have dry seasons longer than 2.5 months (Troll 1966).

Grasslands in equatorial regions are mostly derived after a cropping phase for which rainforest was cleared. The soils of such grasslands are usually of low fertility.

The total area of permanent grasslands in Southeast Asia and the western Pacific islands is about 14 million hectares (FAO 1984). This small area (less than 3.5% of the total land area) is nearly completely unimproved grassland, and considering the climate, a major undeveloped resource in this region. Land use in Southeast Asia is generally quite intensive, but this does not apply to the existing grasslands, which are never fertilised, consist of indigenous or naturalised species and are communally and often overgrazed. In addition to the existing grasslands there are, according to Whiteman (1979), another 27.5 million hectares of potential grasslands in Southeast Asia.

In contrast to the small area of grasslands, the region possesses about 40 million cattle and buffaloes (FAO 1984, with adjustment for obviously wrong figures for Indonesia). It is characteristic for this region, that cattle and buffaloes are present in greatest concentrations in districts which are intensively used for rice production and have little land under grasslands. These animals are fed forage cut from waste lands, by-products from arable crops and tree leaves. The role of these animals is to provide draught power, some meat and otherwise mainly social security. They are not a major source of revenue earning to the people.

The total production of beef and veal in this region was roughly estimated at 500 000 t/annum and that of cow milk also at about 500 000 t (FAO 1984). It can safely be stated that beef and milk are not important sources of animal protein for the people of Southeast Asia. The average consumption of beef and milk in the region is about 2 kg/person/year. Nevertheless, there is a trend towards increased local consumption of these products as a result of tourism, and there are export markets for beef in Singapore, Japan and Korea. Also, if the local consumption of beef and milk would only rise by 1 kg/person/year this would require enormous amounts of beef and milk for the region, because of the large population.

The aim of this paper is to investigate the possible role that undeveloped grassland areas could play in the production of food, assuming that the land is not suitable for the production of arable crops.

Productivity of Existing Grasslands

There are no statistics on animal production from extensively managed pastures in Southeast Asia, nor are there many farmers who specialise in bovine production, although beef ranching is not unknown in the Philippines and has traditionally existed in parts of Indonesia. Cow milk production is only of limited importance near large cities, where a few, sometimes huge, enterprises produce milk from animals fed cut grass and concentrates.

The existing grasslands consist mainly of inferior grasses (e.g. *Imperata cylindrica*) or of not very productive species of poor quality (e.g. *Arundinaria* spp., *Saccharum* spp., *Sorghum* spp., *Heteropogon contortus*). The soils lack in mineral fertility, especially nitrogen and phosphorus. In addition, the species composition does not lend itself to improvement of edible dry matter production by means of fertilisation alone.

The level of unimproved pasture production in Southeast Asia and the Pacific islands can best be

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gauged from studies on *Imperata* pastures. Falvey (1981) reviewed the sparse information on yields, nutritive value and animal production of such pastures, of which he estimated there to be 200 million ha in Southeast Asia. Liveweight gains of cattle grazing *Imperata* pastures ranged from 0.04 to 0.27 kg/day, which relect the low digestibility and protein levels of the feed. The highest in vitro digestibility measured was 70% of very young regrowth, which was reduced to less than 40% after 150 days. Wet season regrowth, less than 60 days old, had digestibility values of 50–70%, whereas regrowth in the dry season had digestibilities of less than 45%. Nitrogen concentrations in the dry matter were seldom over 1% except during the first four to six weeks of regrowth, and up to 20 weeks in a cool region of Thailand. The rate of digestion was also found to be slow.

This low productivity of unimproved grasslands cannot only be blamed on the species composition, but also reflects the poor fertility of the soils. Replacing the species without correcting major soil nutrient deficiencies cannot be expected to lead to significant improvements in long term production.

Improvement of Extensive Grazing Lands

As already indicated in the foregoing, means of pasture improvement must be based on changing the pasture species and on improving the soil fertility. Various studies on pasture improvement in Southeast Asia have indicated that species are available, which, given appropriate nutrition and management, can lead to a several fold increase in animal production as a result of increased carrying capacity and growth of animals.

Three forms of pasture improvement can be indentified: (1) oversowing of a legume into existing pastures; (2) replacement of the existing vegetation by a grass-legume mixture; (3) establishment of a legume monoculture (protein bank) in association with existing pastures, or with improved pastures mentioned under (1) and (2). For long-term productivity and persistence, fertiliser use, based on mineral deficiencies of the soil, will be essential.

Legumes available for pasture improvement (reviewed by Henzell and 't Mannetje 1980) for the humid tropics are: *Centrosema pubescens, Stylosanthes guianenis, Pueraria phaseoloides, Leucaena leucocephala, Desmodium heterophyllum*. Species for regions with a dry-monsoonal climate are: *Macroptilium atropurpureum, Desmodium intortum* and *Leucaena leucocephala*.

Grasses for pasture improvement are: *Panicum maximum* and *Setaria anceps*. Other adapted species

are *Digitaria decumbens* and *Brachiaria decumbens, B.mutica* and *B. humidicola*, but these require nitrogen fertiliser as they have a low compatibility with legumes (with the exception of *D.heterophyllum*, of which it is difficult to obtain seed). *Pennisetum purpureum* is also well adapted to the region and used extensively as a cut-and-carry grass. It has the disadvantage, however, of requiring vegetative propagation, as is also the case with *Digitaria decumbens*.

Studies on legume oversowing have been published from Fiji by Partridge (1975) with siratro, and from Papua New Guinea by Chadokar (1977) with *S.guianensis*.

Pasture improvement by complete replacement has been reported from the Philippines by Magadan et al (1974), from Indonesia by Walandow and Bone (1952), Soewardi et al. (1974) and Saevoy (1975) and from Malaysia by Eng et al. (1978).

In all cases phosphatic and sometimes potassium fertilisers were applied as required.

Productivity of Improved Pastures

A pasture of *B. mutica* and *C.pubescens* in the Philippines (Magdan et al. 1974), fertilised with superphosphate and grazed at two Nellore-Brahman steers/ha, produced 260 kg/ha/year of liveweight gain. Eng et al. (1978), working with a pasture of *P.maximum, C.pubescens, S.guianensis* and *P.phaseoloides* and adequately supplied with non-nitrogenous fertiliser in Malaysia, grazed by 4 Kedah-Kelantan steers/ha over a period of 128 weeks, produced 424 kg/ha/year of liveweight gain. Disappointing results were obtained in Papua New Guinea by Chadokar (1977). *Imperata* pasture oversown with *S.guianensis*, but only fertilised with phosphate in the first year of a two year trial period, produced only 106 kg/ha/year of liveweight gain compared to 78 kg/ha/year on unimproved *Imperata* pasture. However, the two pastures were grazed at the same stocking rate of 0.8 Brahman heifers/ha for the first three months and 1.2/ha thereafter, whilst the legume oversown pasture could have carried more. In addition, the *Imperata* pasture contained some naturalised *M.atropurpureum* and *Calapogonium mucunoides*.

These few examples of animal production from pastures probably cover the range of potentially possible productivity. These were obtained under optimal management conditions, but in commerical practice lower production would be expected, because the land would be less homogeneously suitable for pasture compared to trial areas. The management of the pastures and the animals might also be less than necessary for maximum production.

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Management of Extensive Pastures

Published results and experience in Australia show that tropical pastures may be either continuously or rotationally grazed without detrimental effects on the persistence and long-term productivity of the pasture. The exception to this would be that protein banks should be grazed intermittently. These are meant to provide supplementary feed of high quality and should only be grazed for short periods daily, or during periods of feed shortage.

The main limitation with regard to grazing management is stocking rate. If the stocking rate is higher than the carrying capacity for extended periods, this will lead to legume elimination followed by weed invasion and general degradation of the pasture. In areas of high rainfall and soil fertility, the production potential of the pasture may be higher than the amount of herbage that grazing stock can consume. However, stocking rate must remain commensurate with legume persistence. In such cases there is a choice of stocking the pasture below its capacity and accepting a lower production, or at a higher stocking rate than the legume can stand, accepting legume disappearance and the need to resow. The use of a protein bank can also solve this problem. By restricting access to the supplementary area, the overall grazing pressure can be adjusted to allow the best utilisation of the legume and its long term persistence. Shrub legumes lend themselves well to this type of management. They have the added advantage over herbaceous legumes that they carry their leaves into the dry season, in contrast to herbaceous legumes which drop their leaves.

When animal production on seemingly good pastures is disappointing, a possible mineral deficiency may exist. This was the case with the pasture of Eng et al. (1978), immediately before the period this paper reported on. Cobalt deficiency appeared to be the cause for inital slow growth of the animals, followed by weight loss after six months on the pasture and eventual death of the animals ('t Mannetje et al. 1976). The provision of a cobalt bullet solved the problem for about a year. short term relief can be obtained from vitamin B_{12} injections.

The main limitation to large-scale extensive pasture improvement and management will be problems of land tenure, capital and management skill. Land use must be controlled. This can be achieved through long-term private or group lease or ownership. Communal grazing will lead to overgrazing and lack of maintenance. Economic animal production from extensive areas will only be possible if there is sufficient infrastructure in relation to marketing, transport and slaughter.

References

Chadokar, P.A. 1977. Establishment of stylo (*Stylosanthes guianensis*) in kunai (*Imperata cylindrica*) pastures, and its effect on dry matter yield and animal production in the Markham Valley, Papua New Guinea. Trop. Grasslds, 11, 263–272.

Eng, P.K., 't Mannetje, L., and Chen, C.P. 1978. Effects of phosphorous and stocking rate on pasture and animal production from a guinea grass–legume pasture in Johore, Malaysia. 2. Animal liveweight change. Trop. Grasslds, 12, 198–207.

Falvey, J.L. 1981. *Imperata cylindrica* and animal production in South-East Asia: a review. Trop. Grasslds, 15, 52–56.

FAO (1984). Production Yearbook. FAO Rome.

Henzell, E.F., and 't Mannetje, L. 1980. Grassland and forage research in tropical and subtropical climates. In: Perspectives in World Agriculture. Commonwealth Agricultural Bureaux, Farnham Royal, U.K.

Magadan, P.B., Javier, E.Q., and Madamba, J.C. 1974. Beef production on native (*Imperata cylindrica* (L.) Beauv. and para grass (*Brachiaria mutica* (Forsk.) Stapf pastures in the Philippines. Proc., 12th Int. Grassl. Congr., 3, 293–298.

't Mannetje, L., Sidhu, A.S., and Murugaiah, M. 1976. Cobalt deficiency in cattle in Johore. Liveweight changes and response to treatments. MARDI Res. Bull., 4, 90–98.

Partridge, I.J. 1975. The improvement of mission grass (*Pennisetum polystachyon*) in Fiji by topdressing superphosphate and oversowing a legume (*Macroptilium atropurpureum*). Trop. Grasslds, 9, 45

Seavoy, R.E. 1975. The origin of tropical grasslands in Kalimantan, Indonesia, J. Trop. Geogr., 40, 48–52.

Soewardi, B., Sastradipradia, D., Nasoetion, A.H., and Hutasoit, J.H. 1974. Studies on alang-alang (*Imperata cylindrica* (L) Beauv.) for cattle feeding. I. The effects of carbohydrate sources in urea-containing concentrate on feed utilisation. Biotr. Bull. 8, 1–24.

Troll, C. 1966. Seasonal climates of the earth. The seasonal course of natural phenomen in the different climatic zones of the earth. In: Rodenwaldt, E., and Justaz, H.J., ed., World Maps of Climatology, Springer-Verlag, Berlin.

Walandow, P.H., and Bone, S. 1952. Grassland in Indonesia. Proc., 6th Int. Grassl. Congr., 1498–1503.

Whiteman, P.C. 1979. Tropical pasture and livestock development—Australian opportunities in the ASEAN region. Trop. Grasslds, 13, 1–8.

Cutting Management of Tree and Shrub Legumes

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THE potential of tree and shrub legumes in the tropics to rapidly produce high protein leaf for animal consumption has been widely reported (see for example Pound and Martinez-Cairo 1983; Blom 1980). This is particularly important in areas where the majority of ruminants are currently fed low quality fodders and crop residues (Preston and Leng 1985). Consequently, many recent studies have examined the effects of supplementation of low quality feeds with the leaves of tree legumes. The species *Leucaena leucocephala* (Lam.) de Wit, (hereafter referred to as leucaena) has received the most attention and has proven to be a good source of nitrogen, minerals and high quality roughages when given as a supplement with low quality feeds (Jones 1979; Pound and Martinez-Cairo 1983). Recently, detailed information has appeared on the feeding value of other tree and shrub legume species (e.g. Tangendjaja and Lowry 1984). However, apart from the genus *Leucaena*, very little research has investigated the management systems most appropriate for optimal production of leaf and wood from these tree legumes.

Jones and Bray (1983) described a management system used in northern Australia, in which leucaena is established in rows 2–4 m apart, interplanted with grasses and rotationally grazed. For many parts of the tropics, however, the more intensive animal production systems, as well as the need for fuelwood, necessitate that tree legumes be cut by hand. Given the relatively high regrowth rates and longevity of tropical tree legumes, long term mangement for wood and fodder production essentially means control of the cutting regime (cutting height and cutting interval).

Cutting Management Studies with Leucaena

Table 1 summarises the results of fifteen experiments in which the cutting height and/or cutting interval of leucaena were varied with both the cutting height and cutting interval being quoted. Comparison of the yields is made difficult because of the different

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cultivars of leucaena used by the various researchers. The three basic 'types' of leucaena, 'Hawaiian' (shrubby), 'Salvador' (arboreal), and 'Peru' (low-branching), have distinct growth forms and the type used in each experiment influences the conclusions regarding the most appropriate cutting management. The Salvador types with high leaf:stem ratios have generally out-yielded the Peru and Hawaiian types, although this has been confounded by frequency and method of harvesting (Evensen 1984). Most of the yield figures agree with the assertion of Blom (1980) that annual yields of edible dry matter (DM) will be in the range of 6–18 t DM/ha/yr. However, results of research investigating the effects of cutting height and cutting frequency are often conflicting, with no apparent reasons to explain the inconsistent reports.

Cutting Height

The earliest reported study of cutting management of leucaena (Takahashi and Ripperton 1949) compared production at three cutting heights (5, 38, 76 cm) and obtained the highest yields from the lowest cutting height (5 cm). In contrast many researchers have found that higher cutting heights give better yields than lower cutting heights. Herrera (1967), Pathak et al. (1980), Perez and Melendez (1980) all found that the best cutting height for leucaena production was the highest under investigation and all were less than 75 cm. This suggests that their experiments may not have covered a wide enough range of cutting heights.

When Krishnamurthy and Mune Gowda (1982a) compared cutting heights of 15, 75 and 150 cm, they found that a cutting height of 150 cm gave the highest yields. In a further study Krishnamurthy and Mune Gowda (1982b) compared yields from leucaena cut at 60, 90, 120 or 150 cm and again the highest cutting height (150 cm) gave the best yields. Mendoza et al. (1975) compared cutting heights of 15 cm or 300 cm, and yields from the 300 cm treatment were more than twice that of the 15 cm treatment. Siregar (1983) compared heights between 5–150 cm and found that 100 cm gave optimum yields. All other results fell in the range of 90–120 cm.

Table 1. Cutting height and cutting frequency effects upon yield of leucaena.

Cutting Ht (cm)	Cutting Interval (d)	Yield (t/ha/year)	Reference
100	(40)	113.0 FW total	Siregar (1983)
(150)	(60)	28.7 FW total	Castillo et al. (1979)
90	90	12.5 DW total	Ozman (1981 a,b)
50*	30	14.6 DW total	Perez and Melendez (1980)
150*	70*	39.4 FW total	Krishnamurthy and Mune Gowda (1982a)
150*	70*	28.0 FW total	Krishnamurthy and Mune Gowda (1982b)
5	(120)	50.6 FW total	Takahashi and Ripperton (1949)
(5)	110*	13.0 DW leaf	Guevarra et al. (1978)
30*	40	5.4 DW leaf	Pathak et al. (1980)
120*	(30)	4.0 DW leaf	Isarasanee et al. (1985)
(100)	85	—	Semali et al. (1983)
(30)	30/60/90^{ns}	8.2 DW leaf	Savory and Breen (1979)
(10)	120*	9.0 DW leat	Ferraris (1979)
30–90^{ns}	42–84^{ns}	15.2 DW leaf	Evensen (1984)
75	60	14.2 DW leaf	Topark-Ngarm (1983)

Figures not in brackets are the best height/frequency used

( ) = only height/frequency used
* = maximum height or longest frequency used
ns = no significant differences

Cutting Frequency

Investigations into the effect of cutting frequency on leucaena yield also show widely varying results. Takahashi and Ripperton (1949), Guevarra et al. (1978) and Ferraris (1979) all found that longer cutting intervals with low cutting heights gave the best yields (see Table 1). However, Pathak et al. (1980) and Perez and Melendez (1980) both found that yield was maximised for high cutting height at shorter intervals of cutting.

A major problem with many research reports is the use of incorrect or ill defined terminology, which can be misleading. Many reports give leucaena yields as 'herbage' or 'forage' without making it clear whether this refers to edible material only (i.e. just leaf with perhaps thin shoots also included), or whether it refers to total yield (leaf + stem). In many cases it appears that what is actually meant is in fact total biomass production.

If those studies that report the effect of various cutting frequencies specifically on total dry matter yields are considered separately from investigations into the effects of cutting frequency on 'leaf' yields of leucaena, the situation becomes a little clearer. Generally most researchers investigating effects of cutting frequency on total dry matter yield of leucaena find that trees cut the least frequently give the highest yields of total DM (see Table 1). Osman (1981a) compared intervals of 30, 60, 90, 120 days and found 90 days to give optimum yields. The higher total DM production at a longer cutting intervals has been attributed by most workers to the much higher proportion of stem material. Guevarra et al. (1978) found the edible fraction of cut leucaena to vary from 60% at 110 days to 81% at 70 days. Similar examples of the lower leaf fraction at longer cutting intervals are: Ferraris (1979), 31% at 120 days and 54% at 60 days; Topark-Ngarm (1983), 60% at 60 days vs 69% at 40 days; Catchpoole et al. (unpublished), 53% at 60 days and 71% at 30 days. It would appear that less frequent cutting results in greater yields of total dry matter, and this can be largely attributed to a reduction in the leaf:stem ratio with longer cutting intervals.

However, results from studies of effect of cutting frequency on leaf yield, or the edible forage component, are much less consistent. Pathak et al. (1980) found that the most frequent cutting frequency imposed (40 days) gave the best leaf yields. Das and Dalvi (1981) also found that the shortest cutting intervals under study (60 days) resulted in the highest yields of leaf. Conversely, Semali et al. (1983) obtained the highest leaf yields with infrequent cutting (110 days). Topark-Ngarm (1983) reported that leaf yields were higher at a cutting frequency of 60 days than with a 40 day cutting interval. Evensen (1984) found that across cutting heights of 30, 60, and 90 cm with intervals of 40, 60 and 120 days, there were no differences in leaf dry matter production, although leaf made up 69% of the total yield at 40 days but only 44% at 120 days. Catchpoole et al. (unpublished) also found no differences in leucaena leaf dry matter production across three frequencies—regrowth of 50 cm (average 30 days), 100 cm (average 45 days), or 150 cm (average 60 days) above cutting height of 100 cm—although the

proportion of leaf in the total yield was less with the longer cutting intervals.

These results illustrate the greater production of wood at longer cutting intervals, and support the contention that management recommendations for leucaena should be made only after consideration of the intended uses. For example, if the results of Evensen (1984) and Catchpoole et al. (unpublished) are generally applicable, then infrequently cut leucaena could be used as a source of fuelwood without affecting forage yield. However, where leucaena is intended primarily as a source of forage, it might be desirable, especially with a limited number of trees, to cut more often in order to obtain a continuous supply of forage, i.e. a farmer may not have enough trees to enable him to apply long cutting intervals. This is particularly so in intensive farming systems where leucaena may only be grown as individuals or in hedge rows.

The nutritive value of the forage should also be considered, as material from less frequently cut trees will have higher proportions of older leaf with a lower nutritive value (Takahashi and Ripperton 1949). Semali et al. (1983) showed that calcium, phosphorus, and crude protein levels in leaf decreased as cutting interval was increased beyond 60 days. However Evensen (1984) found no significant effect of cutting height or interval on crude protein content, although he does state that his experiments were conducted on highly fertile soil.

Density

A further confounding factor in the published results is the density at which the trees are planted. Semali et al. (1983), who recommend a cutting interval of 85 days for leucaena at 1 m, used single rows of trees in their experiment. However, Guevarra et al. (1978) who recommend a similar cutting interval for leucaena cut at 5 cm, had trees at densities of $6/m^2$. Several authors have investigated the effect of planting density upon yield. Savory and Breen (1979) used three plant densities (6 trees/m^2, 3 trees/m^2 and 1 tree/m^2) and three harvest frequencies (60, 90 and 120 days) on leucaena cut at 30 cm. There was no effect of frequency on total DM production but highest yields occurred at the densest plantings (8.2 t DM/ha/yr of leaf). Castillo et al. (1979) used four densities (0.3 trees/m^2, 0.5 trees/m^2, 0.6 trees/m^2 and 1.0 tree/m^2) cut every 60 days at 1.5m. Significantly higher yields were recorded for the two higher density plantings (28.7t total DM/ha/yr). Pathak et al. (1980) reported higher dry leaf yields (5.4t/ha/yr) at densities of 4 trees/m^2 as compared to 1.5 trees/m^2 when cut at 30 cm every 40 days. Preliminary data from Ella et al.

(unpublished) indicate close spacing (0.5 × 0.5) gives better leaf yields than wider spacing.

Savory and Breen (1979) introduced a further factor by looking at the effect of inter-row versus intra-row spacing variation. The two inter-row spacings (60 and 100cm) had no significant effect upon leaf yield unlike the intra-row spacings (7.5, 15 and 30 cm) where yields were significantly higher at closer spacings (7 t DW leaf/ha/yr). This contrasts with Guevarra et al. (1978) who found that wider intra-row spacing (45 cm) gave better yields than closer spacings. Vilela and Pereira (1978) also recommended wide intra-row spacing, although for the first three harvests highest yields resulted from the closest spacing. It would seem then that 'evenness' of plant spacing is a factor, but uniformly spaced trees are often not practicable, as leucaena trees in hedgerows or small plots are often more easily managed and practical.

Generally, most researchers report that leucaena planted at higher densities gives better yields than at lower densities. There is not yet a clear indication of the effect of density on the leaf:stem ratio. Preliminary data from Ella et al. (unpublished) show that at wider spacings the number of stems per hectare is higher than at lower densities (with each tree at lower densities having many more stems than at closer spacings). However, there were no differences in leaf:stem ratios between densities.

Interactive Effects

With the wide variation in cutting management practices and plant densities employed by researchers it is difficult to make any clear recommendations from the literature. However, while remembering the strong interactive effects of cutting height, frequency and density on biomass production, some general principles can be said to apply. For example, the findings of most researchers that higher cutting heights give better regrowth indicates the importance of the size of stump remaining, from which reserves can be mobilised for regrowth. Higher densities will limit the soil volume that can be exploited by a single tree, therefore a low cutting height might severely impair the capacity of the trees for rapid regrowth. Another factor to consider is that low cutting heights might limit the number of buds from which regrowth can arise. Perez and Melendez (1980) showed that leucaena cut at 30 cm formed fewer buds (89) after each cut than those at 50 cm (112 buds). Very little has been reported on the effect of cutting management on subsequent growth habit and tree form. It is likely that regrowth will be more rapid from shoots remaining after cutting than if regrowth arises solely from new buds, but no information is yet

available to compare cutting sytems employing total vs partial removal of green material.

Nothing has been published concerning the effects of the age of the tree at the first harvest on subsequent yields. However, many workers recommend that an establishment period of one year be allowed, or that stem diameter be at least 10–15 mm before imposing a cutting regime, as the rate of increase of stem diameter after the imposition of a regular cutting regime slows down markedly (Catchpoole et al., unpublished). Another factor that warrants investigation is whether the first harvest should be at a lower cutting height than subsequent harvests. It is commonly observed that after cutting, new shoots arise mainly from the top 10–15 cm of the remaining trunk, just below the cutting height. If the first cut is lower than subsequent harvests, this might result in more buds from which regrowth can originate; as yet there are no reported studies of the effects of early cutting management on subsequent tree yields.

It seems reasonably clear from the literature that longer cutting intervals result in higher total biomass production, which can largely be explained by lower leaf/stem ratios with infrequent cutting. However research reports on the effect of cutting frequency on leaf yield are not consistent. The growth habit of trees is ultimately affected by the cutting frequency imposed: Savory and Breen (1979) and Catchpoole et al. (unpublished) found that with successive harvests, a larger number of branches were initiated at higher cutting frequencies than at lower cutting frequencies. Cutting frequency also affects the rate of increase of diameter of the stem. Catchpoole et al. (unpublished) found that trees cut less frequently had larger stem diameters than frequently cut trees.

There is a strong interaction between cutting frequency and density. Ideally, trees would be harvested when the canopies of trees in the stand had closed, and the leaf canopy had attained the maximum possible Leaf Area Index, just before leaf abscission from the lower levels of the canopy (due to shading) had begun. If harvesting is delayed beyond this optimum stage, considerable leaf yield loss can occur as a result of leaf fall. However, if the stand is harvested before this optimum state, the initial 'lag phase' before regrowth starts will take up a larger portion of the regrowth period, and yield will therefore not be maximised (Evensen 1984). This may explain why some workers have claimed that infrequent cutting gives better leaf yields. However, at higher densities the leaf canopy will close earlier so that at these densities, higher cutting frequencies should give optimum leaf yields.

Local Site Factors

Since climatic conditions in many tropical areas vary considerably throughout the year, growth rates will change and hence yields from a 'set' cutting frequency (e.g. 30 days, 60 days, etc) will also be very variable (Isarasanee et al. 1985, Guevarra 1976, Eriksen 1978, reported in Evensen 1984). For this reason several researchers investigating cutting frequency have used predetermined stages of regrowth (e.g. 50, or 100 cm above cutting height) as a benchmark of frequency, rather than a set time period. Evensen (1984), for example, found a strong linear relationship between incident radiation and leaf yield of leucaena. Data from cutting frequency experiments that use predetermined stages (e.g. height, stem diameter, onset of flowering etc) will be more meaningful and more readily applicable to other locations than fixed cutting intervals (Hegde 1983).

As well as climatic variability at individual sites, there are a range of geographical, climatic and edaphic factors between localities that can influence the performance of tree legumes under particular cutting managements. Experiments are being conducted by the Forage Research Project to investigate the performance of several tree legume species (in the genera *Leucaena, Calliandra, Sesbania, Gliricidia* and *Albizia*) at four sites in Indonesia. Initial results indicate high variability in performances between sites and emphasise the importance of selecting appropriate species for a given locality and environment.

Other Tree and Shrub Legume Species

There is very little information concerning productivity and regrowth ability of other tree and shrub legume species in response to different cutting regimes. Lazier (1981) applied 3 cutting heights (50, 25, 5 cm) and three intervals (14, 40 and 56 days) to *Codariocalyx gyroides*, a tropical shrub legume. Higher leaf and stem yields resulted from the two higher cutting heights (2700 kg dry leaf/ha/yr). Gore and Joshi (1976) report better yields of *Sesbania sesban* in plots fertilised with NPK and harvested every 5–6 weeks as compared to 7–10 weeks (max. yield 142 t fresh/ha/yr). Siregar (1983), using a range of cutting heights to 150 cm found that best yields of *Flemingia congesta* and *Calliandra calothyrsus* were obtained at a cutting height of 1 m.

Data from Catchpoole et al. (unpublished) in Table 2 show a comparison four species (*Calliandra calothyrsus, Gliricidia sepium* (Jacq.) Stend, *Leucaena leucocephala* (Lam.) de Whit cv. Cunningham and *Sesbania grandiflora*). Many sesbania trees

Table 2. Dry matter yield for 8-month period (7/5/84 – 22/1/85)* of four three legume species in South Sulawesi (Catchpoole et al., unpublished)

Species	Attainment height (m)	Av. time between harvests (weeks)	D.M.(t/ha) Leaf	D.M.(t/ha) Total
Calliandra	1.5	7	10.7	15.0
	2.0	14	9.7	18.0
	2.5	18	8.9	20.3
Gliricidia	1.5	5	11.1	15.3
	2.0	9	12.2	19.1
	2.5	12	10.1	18.8
Leucaena	1.5	4	12.1	17.2
	2.0	6	11.8	18.2
	2.5	9	12.0	22.8
Sesbania	1.5	7	4.7	7.1
	2.0	12	5.2	11.5
	2.5	12	5.2	12.4

Tree density: $4/m^2$
Cutting height: 1.0m
* Mean of 3 replicates, except for *Sesbania*, which was unreplicated after August (due to death of trees).

died after an initial harvest, indicating an adverse response to the cutting maagement used. Occasionally a calliandra or gliricidia tree died after a harvest during the 8-month sampling period but no deaths of leucaena were recorded and leucaena was the first species to exhibit new shoots after a harvest. The highest leaf yields over the 37 weeks period were obtained from *Gliricidia sepium*, cut on attainment of a height of 2.0 m (i.e. 100 cm of regrowth about 100 cm cutting height). However, all leucaena treatments gave similarly high leaf yields. The least frequently cut leucaena treatment (attainment of 2.5 m height before cut to 1 metre) gave the highest total DM yields. Calliandra (2.5 m) gave the highest wood yield (11.4 t DM/ha).

Future Research

(1) In nearly all published experiments involving cutting management of leucaena, not enough factors have been taken into account. Height and interval have been considered independently, or else in combination, with no consideration given to plant density. There is a need for further experimentation concerning the interaction of cutting height, cutting interval and plant density and their effects upon growth, persistence, forage yield, N_2 fixation and nutritive value of edible dry matter.

(2) Regional evaluations of tree legumes show the importance of selecting tree legume species suitable for particular sites. Recommendations made for one climatic/edaphic zone have often been accepted for others, resulting, for example, in widespread plantings of leucaena in higher altitude areas where it exhibits poor growth. If rational cutting management recom-

mendations for particular species are to be made, local site factors cannot be ignored.

(3) There is little data available on the effects of total vs partial removal of green material on rapidity of regrowth. Kitamura et al. (1981) quoted in Blom (1980) indicate that regrowth of leucaena may be enhanced when there is residual leaf after cutting.

(4) Information is required about the best cutting management system to employ initially, in order that yield from subsequent harvests is optimised.

(5) Age or size of trees at the first cut after establishment might have an important bearing on subsequent yield and productive lifetime, for any given tree legume species.

References

Blom, P.S. 1980. Leucaena, a promising versatile leguminous tree for the tropics. Abstracts on Tropical Agriculture, 6(3) review article.

Castillo, A.C., Moog, F.A., and Avante, D.C. 1979. Effects of row arrangement and plant density on herbage production and growth of ipil-ipil. Paper presented at the 16th Annual Convention of the Philippine Society of Animal Science, Manila.

Das, R.B., and Dalvi, G.S. 1981. Effect of interval and intensity of cutting on *Leucaena leucocephala*. Leucaena Research Report, 2, NFTA, Hawaii.

Evensen, C.L.I. 1984. Seasonal yield variation, green leaf manuring and eradication of *Leucaena leucocephala* (Lam.) de Wit. Unpublished Masters thesis, University of Hawaii, Manoa, Hawaii.

Ferraris, R. 1979. Productivity of *Leucaena leucocephala* in the wet tropics of north Queensland. Trop. Grassl., 13(1), 20–27.

Gore, S.B., and Joshi, R.N. 1976. Effect of fertilizer and frequency of cutting on the extraction of protein from Sesbania. Indian J. Agron., 21 (1), 39–42

Guevarra, A.B., Whitney, A.S., and Thompson, J.R. 1978. Influence of intra-row spacing and cutting regimes on the growth and yield of Leucaena. Agron. J., 70 (6), 1033–1037.

Hegde, N. 1983. Leucaena forage management in India. In: Leucaena Research in the Asian–Pacific Region. Proceedings of the workshop held in Singapore, November 1982. IDRC, Canada, 73–78.

Herrera, P.G. 1967. Effect of height of cutting on pigeon pea and koa kaole. Agricultura Trop., 23, 34–42.

Hill, G.D. 1971. Studies on the growth of *Leucaena leucocephala*. 3. Production under grazing in the New Guinea lowlands. Papua and New Guinea Agric. J., 22 (2), 73–76.

Isarasanee, A., Shelton, H.M., Jones, R.M., and Bunch, G.A. 1985. Accumulation of edible forage of leucaena dry season feed. Leucaena Research Report, 5, 3–4. NFTA, Hawaii.

Jones, R.J. 1979. The value of *Leucaena leucocephala* as a feed for ruminants in the tropics. World Anim. Rev., 31, 13–23.

Jones, R.J., and Bray, R.A. 1983. Agronomic research in the development of leucaena as a pasture legume in Australia. In: Leucaena Research in the Asian–Pacific Region. Proceedings of the workshop held in Singapore, November 1982. IDRC, Canada, 41–48.

Kitamura, Y., Samejima, M., and Abe, J. 1981. Vegetative regrowth, nodule development and nitrogen fixation of a tropical legume after harvest (*Leucaena leucocephala*). J. Jap. Soc. Grassl. Science, 27 (3) 277–284.

Krishnamurthy, K., and Mune Gowda, M.K. 1982a. Effect of cutting and frequency regimes on the herbage yield of leucaena. Leucaena Research Depart, 3, 31. NFTA, Hawaii.

1982b. Forage yield of leucaena, var. K8, under rainfed conditions. Leucaena Research Report, 3, 25. NFTA, Hawaii.

Lazier, J.R. 1981. Effect of cutting height and frequency on dry matter production of *Codariocalyx gyroides* (syn. *Desmodium gyroides*) in Belize, Central America. Trop. Grassl. 15(1), 10–16.

Mendoza, R.C., Altamarino, T.P., and Javier, E.Q. 1975. Herbage, crude protein, and digestible dry matter of ipil-ipil (*Leucaena latisiliqua* (L.) Gilis cv. Peru) in hedge rows. Phil. J. Crop. Sci., 1(3), 149–153.

Ozman, A.M. 1981a. Effects of cutting interval on the relative dry matter production of four cultivars of leucaena.

Leucaena Research Report, 2, 33–34. NFTA, Hawaii.

1981b. The effects of cutting height on the dry matter production of leucaena. Leucaena Research Report, 2, 37–38. NFTA, Hawaii.

Pathak, P.S., Rai, P., and Roy, R.D. 1980. Forage production from koo-babool (*Leucaena leucocephala* (Lam.) de Wit). (1) Effect of plant density, cutting intensity and interval. Forage Research, 6 (1), 83–90.

Perez, P., and Melendez, P. 1980. The effect of height and frequency of defoliation on formation of buds of *Leucaena leucocephala* in the state of Tabasco, Mexico. Trop. Anim. Prod., 5(3), p.280.

Pound, B., and Martinez Cairo, L. 1983. Leucaena. Its cultivation and uses. Overseas Development Administration, London. 287 p.

Preston, T.R., and Leng, R.A. 1985. Matching livestock systems to available feed resources in developing countries. ILCA, Addis Ababa.

Savory, R., and Breen, J. 1979. The production of *Leucaena leucocephala* in Malawi. (iii) Plant population studies. UNDP/FAO Project MLW/75/020, Working Paper 17, Lilongwe, Malawi. 33p.

Semali, A., Syamsimar, D., and Manurung, T. 1983. Forage production of lamtoro (*Leucaena leucocephala*) at various cutting intervals. Proceedings, 5th World Animal Production Conference, Tokyo, Japan, 611–612.

Siregar, M.E. 1983. Effect of cutting management on the yield and quality of tropical forage species. Proceedings, 5th World Animal Production Conference, Tokyo, Japan, 613–614.

Takahashi, M·, and Ripperton, J.C. 1949. Koa haole (*Leucaena glauca*): its establishment, culture and utilization as a forage crop. Bulletin 100, Hawaii Agric. Exp. Stn., p. 56.

Tangendjaja, B., and Lowry, J.B. 1984. Leucaena in animal and human nutrition in Indonesia. In: Craswell, E.T., and Tangendjaja, B., ed., Shrub legume research in Indonesia and Australia. Proceedings of an International Workshop held at Balai Penelitian Ternak, Ciawi–Bogor, Indonesia. ACIAR/AARD.

Topark-Ngarm, A. 1983. Testing shrub legumes for forage crops in northeast Thailand. Leucaena Research Report, 4, 77–78.

Vilela, E., and Pereira, J.V.S. 1978. A densidade de semeadura ra producao de materia seca de *Leucaena leucocephala* (Lam.) de Wit. Boletin de Industria Animal, 35 (2), 227–233.

Introducing New Forage Species into Existing Vegetation

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SUCCESSFUL livestock production depends principally upon the availability of quality forages. The Southeast Asian and South Pacific region, in common with many other regions of the world, has the potential to greatly increase its livestock production if improved forage species can be established and maintained on significant areas of land. This paper considers the areas in need of new forage species and describes those methods of plant establishment currently used or recommended. An attempt is then made to analyse the limitations of these methods and finally, options to overcome the identified limitations are discussed.

Areas Requiring New Forage Species

Almost all areas of vegetation which have been cleared of forests can be included within the scope of this paper as potential sites for new forage species. These sites include an enormous range of situations from house gardens to paddy fields and banks, roadside edges, common grazing land, areas under plantation crops and extensive areas of grassland. The sites differ greatly in their topography, climate, soil type, vegetation, degree of management and area involved; consequently there can be no single method of establishing new species which is suited to all these diverse situations.

In much of this region land is an extremely scarce resource, and improved and economic means of forage establishment are needed for all the abovementioned areas. Because land is scarce, areas used for crops must not remain unproductive for an extended period, and hence there is a need to establish useful forage species within some actively growing crops or just prior to their harvest, provided crop yields are not reduced. House gardens may be small in area but they can be very productive, due to the close management which can be applied. Communal grazing areas, roadside edges, and areas under plantation crops are a very large forage resource and have the potential to be far more productive, particularly if better management is applied. The largest area of vegetation requiring improved species is that of unimproved native grassland which is often dominated by *Imperata cylindrica*. In Indonesia alone there are 16 million hectares of *Imperata* grassland which is increasing at 150 000 ha per year (Ivory and Siregar 1984). Throughout the tropics, such grasslands cover some 200 million hectares, and support low levels of animal production with minimal inputs (Falvey 1981a). There is great potential for increasing animal production by improving such grasslands (Ivory and Siregar 1984).

Soils are typically acid and often deficient in nitrogen and phosphorus, less often in sulfur, potassium, molybdenum, calcium and magnesium. The climate is dominated by rainfall; the wet season varies from sites with a distinct rainy season (and a dry season of 3–6 months) to those which receive substantial rainfall throughout the year. Temperature varies little during the year in most of the region, and is rarely limiting to plant growth. Moisture stress is the most commonly cited factor limiting forage production.

Establishing New Forage Species

Although the literature contains some general information on forage establishment in the tropics (e.g. Sanchez 1976), there is little information available concerning what techniques farmers actually use to establish new forage species; most of the literature on establishment is concerned with results of specific experiments. These results collectively form the basis of what could be termed 'current recommendations' for establishing new species.

The most common management practice in extensive grasslands is burning (Guzman 1984) which has been found to be necessary to reduce the bulk of unpalatable and low quality dry matter which can accumulate over one or more seasons. In these extensive grasslands, burning tends to maintain or increase the dominance of *Imperata* due to its rhizomatous root system being little affected by burning. The ash from such burning can form a suitable seedbed for

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surface sowing of pasture seeds, particularly legume seeds (Douglas 1965; Chadhokar 1977; Thomson et al. 1983). Light cultivation following burning can further improve establishment (Chadhokar 1977). Where grasses are sown, the regrowth following burning of native grasslands can be sufficiently competitive to warrant further treatment, either by grazing (Anon. 1981), cultivation (McIvor and Gardener 1981) or by the use of herbicides (Thomson et al. 1983).

The use of fertilisers containing phosphorus (and often sulfur) at sowing is widely recommended (Douglas 1965; Andrews and Rajani 1979; Anon. 1981; Guzman 1984; Hassan and Izham 1984; Shelton and Wilaipon 1984; Wilaipon and Pongskul 1984).

Where the bulk of dry matter at sowing can be controlled by grazing or slashing, oversowing of legumes without burning can sometimes be successful, particularly if accompanied with fertiliser applications and if sowing is carried out at the beginning of the wet season (Topark-Ngarm 1984).

Sowing of improved forage species is most commonly from seed. Examples include the sowing of legumes into *Imperata* grasslands (Blair et al. 1978; Topark-Ngarm 1984; Wilaipon and Pongskul 1984) and into *Brachiaria* spp. under coconut plantations (Manidool 1984). The establishment of grasses from seed is widely recognised as more difficult than that of legumes (Andrews 1982a; Thomson et al. 1983; Topark-Ngarm 1984). Greater establishment of grasses using vegetative propagation, compared to establishment from seed, has been reported by Liyanage (1980) and Andrews (1982a).

Limitations to Establishment

Factors limiting pasture establishment have been described by Leach et al. (1976) and reviewed by Cook (1980). The limitations to successful establishment must be identified if improvements to current techniques are to be made (Silcock 1980). The various climatic, soil, weed, disease, microbiological and species factors governing establishment will be briefly discussed in relation to recent research.

CLIMATE

Light is rarely limiting to plant establishment in this region (low light due to weed competition is discussed below), except perhaps under plantation crops, or in shaded house gardens. In such situations, species which tolerate low light (as low as 18% of full sunlight) can be selected for sowing (Hassan and Izham 1984). Establishment is rarely limited by low temperatures but, particularly where the surface cover has been removed by burning, the soil surface temperature can reach temperatures which are lethal to

establishing plants; the retention of some surface cover is very effective in lowering temperatures (from above 60°C) and improving establishment (Mott et al. 1976). Grass and litter cover on the soil surface can also help to maintain a higher humidity in the seed microenvironment, and reduce the rate of drying of the surface soil (McWilliam and Dowling 1970). Moisture stress is the single biggest constraint on plant establishment (Ivory and Siregar 1984) and consequently establishment efforts are generally best attempted early in the wet season when young plants are not likely to be subjected to long and severe dry periods.

SOILS

Soil chemical fertility has been found to be one of the major constraints to forage establishment and production. Phosphorus deficiency can severely limit seedling growth in the immediate post-germination stage (McWilliam et al. 1969; Blair et al. 1974; Silcock 1980). The supply of phosphorus at the seedling stage can result in greatly increased growth (Silcock 1980) and reduced susceptibility to drought (Humphreys 1959). Further responses can be gained in the presence of nitrogen (Humphreys 1959; McWilliam et al 1969; Blair et al. 1974). The need for phosphorus at establishment is emphasised by the work of Fox et al. (1974) (cited by Sanchez 1976) who showed the critical external concentration of phosphorus in the soil solution during the establishment of *Desmodium aparines* was 0.2 ppm, but fell to just 0.01 ppm after the second cutting. Lowe et al. (1981) obtained establishment responses to phosphorus on soils with extractable P levels of up to 20 ppm (many tropical acid soils are below this level). Establishment responses to phosphorus and sulfur have been obtained in Thailand by Andrews and Rajani (1979) and Shelton and Wilaipon (1984), and similar responses have been reported in Malaysia by Hassan and Izham (1984) and in Indonesia by Blair et al. (1978), who also obtained responses to molybdenum.

The use of lime to aid the establishment of tropical forage species is not widely recommended although some large responses to lime have been reported. The contrasting results obtained from liming are usefully discussed by Snyder and Kretschmer (1983).

There is little information on the effect of physical fertility or soil structural effects on establishment in this region. Shelton (1980) suggested that the successful establishment and subsequent production of *Crotalaria juncea* in dry season paddies was due to its adaptation to the high bulk density of the soil following rice production.

The effects of tillage on forage establishment into existing vegetation are difficult to assess, because such

tillage is usually inextricably linked with weed control (discussed below). Numerous responses to tillage and seed placement have been reported, with some form of cultivation generally being found more successful than no cultivation, especially with grass establishment. Thomson et al. (1983) in North Queensland found cultivation of the seedbed prior to sowing had a relatively slight beneficial effect on the germination and emergence of seedlings, but markedly affected subsequent survival (indicating weed control was the chief benefit). In contrast, Gomes (1979) in Florida found that increased tillage of *Digitaria decumbens* and *Hemarthria altissima* swards improved the establishment of sown legumes but had little effect on the long-term persistence of the legumes. Andrews and Comudum (1979) found no effect of cultivation (by chipping) on the establishment of oversown legumes in *Imperata* grassland at 1400 m elevation in Thailand, but at 1000 m elevation where *Imperata* grows more vigorously, chipping did improve legume establishment (Andrews and Rajani 1979). Izham and Hassan (1982) found that hoeing or creating furrows aided the establishment of *Stylosanthes guianensis* oversown into *Paspalum conjugatum* swards, suggesting that this soil disturbance may have improved the microenvironment and moisture relationships of the sown seeds. Mott et al. (1976) failed to get an effect of tillage on *Stylosanthes* spp. establishment which they attributed to high intensity rainfall quickly returning the tilled soil to a relatively hard surface crust.

WEEDS

Competitive interference imposed by weeds on the growth of establishing forage species can markedly limit the biological 'space' which a seedling can occupy. Supplies of moisture, light and nutrients can become extremely limiting because of the competition for these resources by either existing or newly emerging weeds. Common sowing rates of forage species are 100–700 seeds/m^2, whereas weed seed loads within the soil may be 5000–50 000 seeds/m^2 (Silcock 1980). Even if the top growth of existing weeds is removed, the amount of root matter remaining can still impose formidable stress on developing seedlings. Khybri and Mishra (1967) (cited by Blair et al. 1978) found *Imperata* root production in the second year to be over 4700 kg DM/ha in the 0–7.5 cm root zone alone.

Cook and Ratcliff (1985) examined the relative competitive effects of the root and shoot fractions of *Heteropogon contortus* on the establishment of surface sown siratro (*Macroptilium atropurpureum*) and green panic (*Panicum maximum* var. *trichoglume*). Even though in this study moisture was not limiting, the removal of either shoot competition or root competition, or both shoot and root competition increased yields by 5-fold, 25-fold and 45-fold respectively. They attributed most of the competitive effect to competition for nutrients (particularly N but perhaps P and S also). In the absence of root competition, the yield of the sown siratro was equal to that of the green panic but, with root competition from the *H. contortus*, the yield of the sown siratro was 11 times that of the panic, suggesting that the difference was due to the siratro's independent supply of nitrogen.

The important weeds of this region are listed by Holm et al. (1979). This listing shows, for example, that Indonesia has 30 'serious' weed species, many of which are common to numerous other countries. Of these 30 serious weeds, 15 are within the family Poaceae, 3 in Asteraceae, 2 in each of Cyperaceae and Pontederiaceae and the remaining 8 are from 8 other families. The literature on weed control in forage areas in this region is concerned mostly with the control of *Imperata cylindrica* (Poaceae) which is listed as a serious weed in 18 countries throughout the world (Holm et al. 1979). *Imperata* dominance can often be reduced by establishing legumes and fertilising to encourage their dominance (Blair et al. 1978; Izham and Hassan 1982) and this effect can be aided by post-sowing slashing (Andrews and Rajani 1979).

The use of herbicides for weed control to enable forage establishment in this region has received relatively little attention. In North Queensland, Thomson et al. (1983) found that the establishment of improved grasses required burning of the native grasses followed by either cultivation or herbicide (glyphosate) to control regrowth prior to planting. Again in Queensland, Cooksley (1974) found that chlorthal, trifluralin or benfluralin suppressed weeds without harming *Leucaena leucocephala* in a pot trial but, in the field, the herbicides were ineffective and burning and post-emergence cultivation of weeds was needed to enable the *Leucaena* to survive. McIvor and Gardener (1981) also found that burning and cultivation enabled the establishment of grasses, whereas the use of glyphosate alone was not as effective; this was thought to be due to the considerable germination of weeds which followed herbicide treatment (prior to sowing they identified a total weed seed load in the soil of 3000–8000 seeds/m^2). The competitive effects of germinating weeds has also been noted by Jones (1975) to have a great effect on the establishment of sown grasses.

In Colombia, Doll et al. (1974) have reported the success of glyphosate and dalapon in controlling *Paspalum fasciculatum* (a serious pasture weed of the tropical Americas) and enabling the successful estab-

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lishment of *Panicum purpurascens* 60 days after treatment.

A more novel approach to weed control has been reported by Akobundu (1980) in Nigeria where a 'live mulch' of *Centrosema pubescens* or *Psophocarpus palustris* has been used to control weeds prior to sowing and during the growth of a maize crop. Prior to sowing, the live mulch was sprayed with paraquat in 15 cm wide bands and, three days after sowing, a growth retardant was sprayed over the remaining live mulch. In the live mulch plots, yields of maize were significantly higher than, or equal to, those in no-till or conventional tillage plots, even when fertiliser was applied.

Literature on the economics of weed control in forage areas in the tropics is scarce. Sundaru (1981) notes that in Indonesia herbicides have been used for weed control in plantation crops for many years and, since 1972 in lowland rice. However, in upland areas, herbicides are not yet used to a significant extent. Binswanger and Shetty (1977) considered the economics of weed control in the semi-arid tropical areas of India and found no economic advantage was offered by herbicides for weed control in cropping areas. This was in spite of hand weeding labour times of eight working days per weeding per hectare (with 6–7 hand weedings required per crop) and interculture weeding times with buffaloes of seven bullock-pair hours per hectare. Wijewardene (1981), however, concludes that appropriate methods of applying herbicide at low rates can have considerable economic advantages.

DISEASES AND PESTS

There is relatively little reported on the influence which pests and diseases can have on forage establishment in the tropics. Weber (1973) has described plant diseases in tropical areas but, in common with other texts, no mention is made of diseases of forage plants. Wellman (1972) has noted that infections of forage grasses in the tropics have largely been ignored and as yet are 'woefully unknown'. More recently Lenne et al. (1980) have briefly reviewed diseases and pests of tropical pasture species and conclude that the best long-term solution for their control is through the selection of resistant varieties, combined with integrated control practices.

GRAZING

Grazing, both before and after sowing, can greatly influence forage establishment. Prior to sowing, grazing can assist establishment by reducing the competitive effects of existing vegetation, particularly when regrowth of *Imperata cylindrica* is grazed following buring (Anon. 1981). Following sowing, Wilaipon (1979) found that control of grazing by fencing improved establishment, as did ploughing of the area prior to sowing. Andrews and Rajan (1979) found post-sowing slashing helped in weed control without affecting legume yields, and Andrews and Comudum (1979) found that grazing control encouraged the establishment of tropical and subtropical legumes in *Imperata* grasslands. Uncontrolled grazing was found by Shelton and Wilaipon (1984) to be the primary cause of poor legume persistence observed in some communal grazing areas.

LEGUME INOCULATION

In recent years, legume inoculation in tropical regions has been widely studied. Numerous papers by Norris (1967, 1971a, 1971b, 1972, 1973a, 1973b) have examined the issue of appropriate pelleting materials for the range of tropical legumes. These results and general recommendations for the inoculation of tropical legumes have been well summarised by Date (1976). Several other detailed texts exist on the inoculation of legumes in general (e.g. Brockwell 1977). Provided the appropriate strains of *Rhizobium* are used to produce high quality inoculants and provided proper inoculation procedures (as mentioned in the above texts) are followed, the prompt nodulation of sown legumes should not normally limit forage establishment. Details of inoculation trials designed to aid the introduction of forage legumes are given by Sylvester-Bradley (1984).

SPECIES ADAPTATION

In order to establish and survive in a competitive situation, new forage species need to be well adapted to the environment. Anning (1982) found that, from a total of 50 different legumes tested at four sites in Northern Australia, only seven showed promise. Cameron (1980) has suggested a method of selecting the most appropriate species for any area (including establishment ability) by weighting various criteria of merit to give a measure of objectivity to the process of species selection. Cook (1980) considers establishment ability to be a highly desirable character, particularly for oversowing into competitive situations, although establishment ability alone is no guarantee of success (Crowder and Chow 1974).

As well as grasses being generally more difficult to establish than legumes, seed of many tropical grasses may not be readily available and can also have poor germination and viability. Even when germination can be improved, such as the treatment of *Cenchrus ciliaris* seed with sulfuric acid, seedlings may germinate too readily after a shower of rain only to die of drought soon after (Humphreys 1959). Such problems only add to the difficulty of economically establishing improved grasses into existing vegetation.

Options to Overcome Limitations

From the foregoing discussion of the limitations to establishment, many solutions can be identified and will be summarised here.

Where light is limiting, such as under plantation crops, or under trees in house gardens, the selection of species tolerant to such conditions is most appropriate. Some suitable legumes have been identified (Hassan and Izham 1984) and some grasses can be established from seed provided that high sowing and fertiliser rates are used (Manidool 1984).

Where full sunlight can reach surface-sown germinating seedlings, soil surface temperatures can get extremely high and some retention of vegetation or litter is desirable (Mott et al. 1976). Moisture stress can be minimised by controlling actively growing competition, and by permitting some shading of the surface soil. Rapidly germinating species may be sown at the beginning of the wet season, but slower germinating species, such as the perennial stylos (*Stylosanthes scabra* and *S. viscosa*), may need to be sown later in the wet season when prolonged periods of adequate moisture can be more assured (Mott et al. 1976).

Sufficient appropriate fertilisers need to be applied at establishment. Fertilisers containing phosphorus and sulfur have commonly been found to be effective, particularly for legume establishment. For grass establishment, nitrogen can also be· of great benefit (Kitamura 1982). Responses to molybdenum, potassium, calcium and magnesium have been reported in some areas.

Cultivation is usually beneficial in reducing the competitive effects of existing vegetation and in creating a suitable seedbed for sown species. If weeds are actively growing, some means of destroying or weakening the weeds, such as burning followed by grazing the regrowth, or by the use of cultivation or herbicides, must be employed. Control of competition during both the germination/emergence stage and the growth/survival stage of establishment is essential for successful establishment. Grasses are generally more susceptible to competition than legumes, due largely to the independent nitrogen supply of legumes (Cook 1980).

Grazing control is essential to prevent the loss of desirable established species.

Inoculation with high quality inoculants is recommended particularly for legume species with specific *Rhizobium* requirements. Lime pelleting of legume seeds may be an effective method of aiding the establishment of some species.

Forage species need to be well adapted to the specific area in establishment ability, as well as in productivity and in persistence qualities. The use of high quality seed is essential if forages are to be established from seed. For some grass species, vegetative propagation has been shown to be much more effective than establishment from seed, provided that the cuttings include roots (Andrews 1982a) or that the cuttings are from the base of plants and are aged for 5–10 days prior to planting (Liyanage 1980). Nada and Sirikiratayanond (1979) found that, when establishing a mixed pasture of grass from vegetative cuttings (*Panicum maximum* or *Brachiaria mutica*) and legume from seed (*Centrosema pubescens* or *Stylosanthes humilis*), it was preferable to sow the legume first, and 2–5 weeks later plant the grass cuttings, rather than sow both simultaneously.

Cook (1980) points out the need for detailed studies of establishment which follow known numbers of sown seeds from the stages of germination and emergence through those of growth and survival, and which continue at least up to the commencement of the second growing season. Without such detailed observations, few conclusions can be drawn regarding the fate of the sown seedlings. Understanding aspects of competition between species is a necessary prerequisite before we can hope to improve the competitive ability of the sown seedlings, as suggested by Cook (1980). McIvor and Gardener (1981) suggested that the major determinants of establishment of improved grasses in a competitive environment had a greater effect at the stage of seedling growth and survival than at the germination and emergence stage. Survival of plants, over a period of moisture stress, has been shown by Hoen (1968) to be closely related to plant size, with bigger plants presumably being able to exploit more soil moisture than small plants. Similarly, Silcock (1980) has noted that tillering of plants is related to a plant's ability to survive a period of stress. Cook (1984) found that plant survival was related to plant size at about 20 weeks after sowing. The survival of *Leucaena leucocephala* seedlings was improved if weed competition could be controlled until the leucaena plants were taller than the grass weeds (Falvey 1981b). As sown plants need to be large relative to their neighbours in order to survive, establishment strategies should aim to maximise any opportunities for growth and development of the sown species from sowing through to establishment. Options for maximising growth will be discussed below.

At the germination stage some opportunities exist to follow on the work of Heydecker et al. (1975) in

osmo-conditioning of seeds and Lush et al. (1981) in presowing 'priming' of seeds for prompt germination. Also, a better understanding of the moisture relations of seeds at germination and the influence of seed coatings on germination (Dowling et al. 1971) may lead to more reliable germination of oversown seeds.

Although the application of fertilisers at sowing can markedly improve forage establishment and production, the cost of the fertilisers can be prohibitive to farmers with limited financial resources. Seedlings have been shown to respond to externally available nutrients within a few days of emergence (McWilliam et al. 1969; Blair et al. 1974; Cook and Ratcliff 1985). Coating seeds with nutrients is one way of ensuring that the sown seedlings have uniform, early and preferential access to nutrients compared to neighbouring weeds. Younger and Gilmore (1978) found superphosphate coatings on *Cenchrus ciliaris* depressed emergence but nevertheless increased yield. Silcock and Smith (1982) improved seedling growth of *Cenchrus ciliaris* with various phosphate coatings. Scott and Blair (1985b) also found phosphate seed coatings to promote seedling growth of *Phalaris aquatica* compared to broadcast or drilled applications. Paterno and Espiritu (1978) found that a lime/ superphosphate coating on *Centrosema pubescens* produced equivalent yields to a soil incorporated application of 5 t lime and 150 kg of superphosphate/ ha. Coating seeds of *Stylosanthes guianensis* with sulfur was also found to be more effective than equivalent rates of broadcast sulfur (Gilbert and Shaw 1979). In the case of trace elements, Boswell (1980) obtained a response from coating soybean seeds with 17 g of Mo/ha which produced a similar response to that of liming the soil to a pH of 6.2.

In view of the many establishment responses to nutrients such as phosphorus, sulfur and molybdenum, there would appear to be excellent opportunities to explore the area of nutrient seed coating further (including coatings containing several nutrients), particularly as such a supply of nutrients may be preferentially available to the sown seedlings.

The liming of soils for the establishment of *Leucaena leucocephala* may be prohibitive economically, but the work of Olvera and Blue (1985) warrants further investigation. They have found it possible to establish leucaena plants in tubes of acid soil (30 cm deep) which have had lime and nutrients supplied and which can than be transplanted into acid ultisols, spodosols or oxisols. Early results show that the roots of the leucaena plants are then capable of exploring the unamended underlying acid soil.

Several studies have shown that inoculation of soils with vesicular arbuscular mycorrhizae (VAM) can lead to promotion of plant growth. An interesting development in this area is the recent work of Manjunath and Bagyaraj (1984) and Manjunath et al. (1984), who report a synergistic effect caused by the dual inoculation of pigeon pea, cowpea and *Leucaena leucocephala* with *Rhizobium* and VAM inoculants. This effect was stimulated further by the application of phosphorus. The inoculation of seeds with VAM is, as yet, not readily achieved and thus such dual inoculation may require alternate methods of soil inoculation to be developed.

The control of native vegetation and weeds in this region could possibly be assisted by the further development of 'live mulch' (Akobundu 1980) and by investigations into the use of economic quantities of herbicide applied by appropriate means (such as hand-held rope-wick applicators or low volume sprayers). The control of seedling weeds in areas where legume seeds are to be sown could possibly be aided by herbicide-treated seeds (Dawson 1979; Scott and Blair 1985a). In addition, the use of herbicide antidotes to protect sown species from herbicide injury may be appropriate for some siutations (Parker 1983).

Andrews (1982b) explored a method of sowing improved pastures in contour strips, but the spread of the legume was halted by the invasion of the unsown areas by weeds. Perhaps such a technique could be more successful if appropriate control measures could be found for controlling the weeds to permit further spread of the pasture.

The vegetative propagation of species warrants further study as it has been shown to be very successful in the establishment of grasses in quite competitive situations. Such a techniue is well suited to the establishment of new species in small areas (such as house gardens) which can be managed closely and can serve as productive 'cut-and-carry' forage resources. For vegetative propagation on a larger scale, further study is needed to find suitable procedures. The introduction of improved grasses into *Imperata*-dominated grasslands by vegetative progagation may be aided by transplanting the grasses 1–2 years after a suitable legume is established. Such a procedure could reduce the competitiveness of the *Imperata* while improving the nitrogen status of the soil.

Finally, the area of grazing management as it affects establishment and persistence could be studied further so that appropriate but effective methods of controlled grazing could be developed. Living fences (Anon. 1975) could perhaps be developed further particularly if the fence species itself can be used as a forage resource. Recently, electric fencing has improved and has become relatively less expensive. If electric fences proved economically feasible, great gains could be

made in the management of communal grazing areas.

If some of the options outlined above can be developed, they could be combined to improve the competitive ability of newly sown species, and hence improve the establishment of forages and subsequently lead to greater gains in animal production in this important region.

Acknowledgments

References

Akobundu, I.O. 1980. Live mulch: a new approach to weed control and crop production in the tropics. Proceedings, 1980 British Crop Protection Conference — Weeds, 377–382.

Andrews, A.C. 1982a. Vegetative propagation of grasses in the highlands of Northern Thailand. Thai Journal of Agricultural Science, 15, 199–205.

1982b. Establishment of pasture legumes in the highlands of Northern Thailand. III. The use of cultivated contour strips. Thai Journal of Agricultural Science, 15, 295–300.

Andrews, A.C., and Comudum, Y. 1979. Establishment of pasture legumes in the highlands of Northern Thailand, II. The effects of fencing and grazing pressure. Thai Journal of Agricultural Science, 12, 269–276.

Andrews, A.C., and Rajani, B. 1979. Establishment of pasture legumes in the highlands of Northern Thailand. I. The effects of land preparation and fertilizers. Thai Journal of Agricultural Science, 12, 51–59.

Anning, P. 1982. Evaluation of introduced legumes for pastures in the dry tropics of North Queensland. Tropical Grasslands, 16, 146–155.

Anon. 1975. Thai-Australia Highland Agronomy Project — First Report. Australian Development Assistance Bureau.

1981. Final report on agricultural research and development in the highlands of Northern Thailand. University of Queensland, Australia.

Binswanger, H.P., and Shetty, S.V.R. 1977. Economic aspects of weed control in semi-arid tropical areas of India. Occasional Paper 13. Economics Department, ICRISAT. Hyderabad, India, 31p.

Blair, G.J., Hughes, R.M., Lovett, J.V., and Causley, M.G. 1974. Temperature, seeding depth and fertilizer effects on germination and early seedling growth of kikuyu grass. Tropical Grasslands, 8, 163–170.

Blair, G.J., Pualillin, P., and Samosir, S. 1978. Effect of fertilizers on the yield and botanical composition of pastures in South Sulawesi, Indonesia. Agronomy Journal, 70, 559–562.

Boswell, F.C. 1980. Factors affecting the response of soybeans to molybdenum application. In: Corbin, F.T., ed., World Soybean Research Conference. II. Proceedings. Westview Press, Boulder Colorado, USA.

Brockwell, J. 1977. Application of legume seed inoculants. In: Hardy, R.W.F., ed., A Treatise on Dinitrogen Fixation. John Wiley, New York, 277–309.

Cameron, D.G. 1980. Criteria of merit for pasture species

with particular reference to legumes. Tropical Grasslands, 14, 130–135.

Chadhokar, P.A. 1977. Establishment of stylo (Stylosanthes guianensis) in kunai (Imperata cylindrica) pastures and its effect on dry matter yield and animal production in the Markham Valley, Papua New Guinea. Tropical Grasslands, 11, 263–272.

Cook, S.J. 1980. Establishing pasture species in existing swards: a review. Tropical Grasslands, 14, 181–187.

1984. Establishment of four pasture grasses and siratro from seed oversown into dense and open speargrass pastures. Australian Journal of Experimental Agriculture and Animal Husbandry, 24, 360–369.

Cook, S.J., and Ratcliff, D. 1985. Effect of fertilizer, root and shoot competition on the growth of siratro (Macroptilium atropurpureum) and green panic (Panicum maximum var. trichoglume) seedlings in a native speargrass (Heteropogon contortus) sward. Australian Journal of Agricultural Research, 36, 233–245.

Cooksley, D.G. 1974. A study of preplanting herbicides, nitrogen, burning and post-emergence cultivation on the establishment of Leucaena leucocephala cv. Peru. Queensland Journal of Agricultural and Animal Science, 31, 271–278.

Crowder, L.V., and Chow, K.H. 1974. Seedling vigor and establishment of tropical and subtropical legumes. Nigerian Agricultural Journal, 11, 157–164.

Date, R.A. 1976. Inoculation of tropical pasture legumes. In: Vincent, J.M., Whitney, A.G., and Bose, J., ed., Exploiting the Legume — Rhizobium Symbiosis in Tropical Agriculture. University of Hawaii, College of Tropical Agriculture, Miscellaneous Publication No. 145, 293–311.

Dawson, J.H. 1979. EPTC applied to crop seeds for selective weed control. Abstracts, 1979 Meeting of the Weed Science Society of America, 31–32.

Doll, J.D., Argel, P., and Camacho, A. 1974. Bullgrass (Paspalum fasciculatum Willd.) control with glyphosate and dalapon. Abstracts, 1974 Meeting Weed Science Society of America, 116.

Douglas, N.J. 1965. Tropical legumes on a blady grass burn. Queensland Agricultural Journal (January), 91, 36–39.

Dowling, P.M., Clements, R.J., and McWilliam, J.R. 1971. Establishment and survival of pasture species from seeds sown on the soil surface. Australian Journal of Agricultural Research, 22, 61–74.

Falvey, J.L. 1981a. Imperata cylindrica and animal production in South East Asia: A Review. Tropical Grasslands 15, 52–56.

1981b. Establishment studies on Leucaena leucocephala in northern Australia. The International Tree Crops Journal, 1, 237–243.

Gilbert, M.A., and Shaw, K.A. 1979. A comparison of sulphur fertilizers and sulphur seed pellets on a Stylosanthes guianensis pasture on a euchrozem in North Queensland. Australian Journal of Experimental Agriculture and Animal Husbandry, 19, 241–246.

Gomes, D.T. 1979. Establishment methods and comparative persistence of five tropical legumes in grass sods. Dissertation Abstracts International, B, 39(12), 5696.

Guzman, M.R. de 1984. Pasture research and development in the Philippines. In: Asian Pastures: Recent Advances in Pasture Research and Development in Southeast Asia. (ASPAC, Taiwan), 44–57.

Hassan, W., and Izham, A. 1984. Status of pasture research and development in Peninsular Malaysia. In: Asian Pastures: Recent Advances in Pasture Research and Develop-

ment in Southeast Asia. ASPAC, Taiwan), 30–43.

Heydecker, W., Higgins, J., and Turner, Y.J. 1975. Invigoration of seeds? Seed Science and Technology, 3, 881–888.

Hoen, K. 1968. The effect of plant size and developmental stage on summer survival of some perennial grasses. Australian Journal of Experimental Agriculture and Animal Husbandry, 8, 190–196.

Holm, L., Pancho, J.V., Herberger, J.P., and Plucknett, D.L. 1979. A Geographical Atlas of World Weeds. John Wiley and Sons, N.Y., 391p.

Humphreys, L.R. 1959. Studies on the germination, early growth, drought survival and field establishment of Buffel grass (*Cenchrus ciliaris*) and of Birdwood grass (*C. setigerus* Vahl), with particular reference to the Yallaroi district. Journal of the Australian Institute of Agricultural Science, 25, p.321.

Ivory, D.A., and Siregar, M.E. 1984. Forage research in Indonesia: past and present. In: Asian Pastures: Recent Advances in Pasture Research and Development in Southeast Asia. (ASPAC, Taiwan), 12–29.

Izham, A., and Hassan, W. 1982. Oversowing of *Stylosanthes guianensis* into native pastures: Comparison of establishment techniques. Malaysian Agricultural Research and Development Institute Research Bulletin, 10(1), 33–42.

Jones, R.M. 1975. Effect of soil fertility, weed competition, defoliation and legume seeding rate on establishment of tropical pasture species in south-east Queensland. Australian Journal of Experimental Agriculture and Animal Husbandry, 15, 54–63.

Kitamura, Y. 1982. Use of starter nitrogen for establishing tropical legume–grass pasture. Japan Agricultural Research Quarterly, 15, 253–260.

Leach, G.J., Jones, R.M., and Jones, R.J. 1976. The agronomy and ecology of improved pastures. In: Shaw, N.H., and Bryan, W.W., ed., Tropical Pasture Research. Commonwealth Agricultural Bureaux, Farnham Royal, U.K., 277–307.

Lenne, J.M., Turner, J.W., and Cameron, D.F. 1980. Resistance to pests and diseases of tropical pasture plants. Tropical Grasslands, 14, 146–152.

Liyanage, L.V.K. 1980. Factors influencing seed production and establishment of *Brachiaria* species. M.Sc.Agr. Thesis, University of New England, NSW Australia.

Lowe, K.F., Bruce, R.C., and Bowdler, T.M. 1981. Effect of phosphorus on the establishment of siratro and green or Catton panic pastures on duplex soils of sub-coastal south-eastern Queensland. Tropical Grasslands, 15, 101–106.

Lush, W.M., Groves, R.H., and Kaye, P.E. 1981. Presowing hydration/dehydration treatments in relation to seed germination and early seedling growth of wheat and ryegrass. Australian Journal of Plant Physiology, 8, 409–425.

Manidool, C. 1984. Pastures under coconut in Thailand. In: Asian Pastures: Recent Advances in Pasture Research and Development in Southeast Asia. (ASPAC, Taiwan), 204–214.

Manjunath, A., and Bagyaraj, D.J. 1984. Response of pigeon pea and cowpea to phosphate and dual inoculation with vesicular arbuscular mycorrhiza and *Rhizobium*. Tropical Agriculture, 61, 48–52.

Manjunath, A., Bagyaraj, D.J., and Cowda, H.S.G. 1984. Dual inoculation with VA mycorrhiza and *Rhizobium* is beneficial to *Leucaena*. Plant and Soil, 78, 445–448.

McIvor, J.G., and Gardener, C.J. 1981. Establishment of introduced grasses at different stages of pasture development: effects of seedbed. Australian Journal of Experimental Agriculture and Animal Husbandry, 21, 417–423.

McWilliam, J.R., Clements, R.J., and Dowling, P.M. 1969. Some factors influencing the germination and early seedling development of pasture plants. Australian Journal of Agricultural Research, 21, 19–32.

McWilliam, J.R., and Dowling, P.M. 1970. Factors influencing the germination and establishment of pasture seed on the soil surface. Proceedings, 11th International Grassland Congress, Surfers Paradise, Australia, 578–583.

Mott, J.J., McKeon, G.M., and Moore, C.J. 1976. Effects of seedbed conditions on the germination of four *Stylosanthes* species in the Northern Territory. Australian Journal of Agricultural Research, 27, 811–823.

Nada, Y., and Sirikiratayanond, N. 1979. Studies on the establishment of mixed pastures in Thailand. Journal of Japanese Society of Grassland Science, 24, 325–330.

Norris, D.O. 1967. The intelligent use of inoculants and lime pelleting for tropical legumes. Tropical Grasslands, 1, 107–121.

1971a. Seed pelleting to improve nodulation of tropical and sub-tropical legumes. 2. The variable response to lime and rock phosphate pelleting of eight legumes in the field. Australian Journal of Experimental Agriculture and Animal Husbandry, 11, 282–289.

1971b. Seed pelleting to improve nodulation of tropical and sub-tropical legumes. 3. A field evaluation of inoculant survival under lime and rock phosphate pellet on *Dolichos lablab*. Australian Journal of Experimental Agriculture and Animal Husbandry, 11, 677–683.

1972. Seed pelleting to improve nodulation of tropical and sub-tropical legumes. 4. The effects of various mineral dusts on nodulation of *Desmodium uncinatum*. Australian Journal of Experimental Agriculture and Animal Husbandry, 12, 152–158.

1973a. Seed pelleting to improve nodulation of tropical and sub-tropical legumes. 5. The contrasting response to lime pelleting of two *Rhizobium* strains on *Leucaena leucocephala*. Australian Journal of Experimental Agriculture and Animal Husbandry, 13, 98–101.

1973b. Seed pelleting to improve modulation of tropical and sub-tropical legumes. 6. The effects of dilute sticker and of bauxite pelleting on nodulation of six legumes. Australian Journal of Experimental Agriculture and Animal Husbandry, 13, 700–704.

Olvera, E., and Blue, W.G. 1985. Establishment of *Leucaena leucocephala* (Lam.) de Wit in acid soils. Tropical Agriculture, 62, 73–76.

Parker, C. 1983. Herbicide antidotes — a review. Pesticide Science, 14, 40–48.

Paterno, E.S., and Espiritu, B.M. 1978. Phosphate pelleting of *Centrosema pubescens* Benth. Philippine Journal of Crop Science, 3, 46–52.

Sanchez, P.A. 1976. Properties and Management of Soils in the Tropics. John Wiley and Sons, New York, 618 p.

Scott, J.M., and Blair, G.J. 1985a. Seed-applied herbicides and antidotes for the establishement of lucerne and phalaris. Proceedings, 3rd Australian Agronomy Conference, Hobart, Tasmania, p.2.

1985b. Nutrient seed coating of phalaris and lucerne. Proceedings, 3rd Australian Agronomy Conference, Hobart, Tasmania, p.3.

Shelton, H.M. 1980. Dry-season legume forages to follow

paddy rice in N.E. Thailand. II. Soil fertility and planting methods. Experimental Agriculture, 16, 67–73.

Shelton, H.M., and Wilaipon, B. 1984. Establishment of two *Stylosanthes* species in communal grazing areas of Northeast Thailand. Tropical Grasslands, 18, 180–185.

Silcock, R.C 1980. Seedling characteristics of tropical pasture species and their implications for ease of establishment. Tropical Grasslands, 14, 174–180.

Silcock, R.G., and Smith, F.T. 1982. Seed coating and localised application of phosphate for improving seedling growth of grasses on acid, sandy red earths. Australian Journal of Agricultural Research, 33, 785–802.

Snyder, G.H., and Kretschmer, A.E.Jr. 1983. Liming for tropical legume establishment and production. Proceedings, XVI International Grassland Congress. Lexington, Kentucky, 302–305.

Sundaru, M. 1981. Weeds in paddy fields and their control in Indonesia. In: Weeds and Weed Control in Asia. (ASPAC Food and Fertilizer Technology Center, Taiwan), 57–61.

Sylvester-Bradley, R. 1984. *Rhizobium* inoculation trials designed to support a tropical forage legume selection programme. Plant and Soil, 82, 377–386.

Thomson, D.P., McIvor, J.G., and Gardener, C.J. 1983. The effect of seedbed type on the establishment of legumes and grasses at four sites in North Queensland. Tropical Grasslands, 17, 3–11.

Topark-Ngarm, A. 1984. Pasture research and development in Thailand. In: Asian Pastures: Recent Advances in Pasture Research and Development in Southeast Asia. (ASPAC Taiwan), 58–64.

Weber, G.F. 1973. Bacterial and Fungal Diseases of Plants in the Tropics. Univ. of Florida Press, Gainesville, 673p.

Wellman, F.L. 1972. Tropical American Plant Disease. Scarecrow Press Inc., N.J., 989p.

Wijewardene, R. 1981. Low energy farming systems and appropriate tools for farming in the humid tropics. Proceedings, Appropriate Mechanization for Rural Development Seminar, Jakarta. Bogor Agricultural University, Indonesia, 10p.

Wilaipon, B. 1979. In: Annual Report — Pasture Improvement Project — Khon Kaen University, Thailand. Australian Development Assistance Bureau, p.42.

Wilaipon, B., and Pongskul, V. 1984. Pasture establishment in the farming systems of northeast Thailand. In: Asian Pastures: Recent Advances in Pasture Research and Development in Southeast Asia. ASPAC, Taiwan, 65–85.

Younger, D.R., and Gilmore, J.M. 1978. Studies with pasture grasses on the black cracking clays of the Central Highlands of Queensland. 2. Sowing methods. Tropical Grasslands, 12, 163–169.

Soil Fertility Constraints — Amelioration and Plant Adaptation

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SOIL fertility constraints on forage production should be considered, not only in terms of nutrient deficiencies and excesses that affect plant growth, but also in terms of how they affect the quality of feed for animals. They also need to be considered in relation to the species being grown. A major strategy in overcoming nutrient deficiencies and excesses is to use edaphically adapted species which can decrease the need for amelioration.

Considerable work has been done in Southeast Asia and the South Pacific, in defining nutrient requirements for forages for specific areas. However, recognition of soil fertility constraints still needs closer attention. A knowlegde of soil fertility status is necessary in the planning and implementation of any forage improvement program.

Amelioration is considered in relation to the fertiliser and species resources available and the farming system to which it is to be introduced. Limitations in knowledge or ability to carry this out are suggested as priorities for future attention.

Constraints

Nutrient Deficiencies and Excesses

Soil fertility varies widely over the region. There are higher fertility soils, which include those derived from basic volcanic rocks in Indonesia, the Philippines and the Pacific Islands, the coralline derived soils of the Pacific Islands and the alluvial soils. These are the areas which are intensively farmed and where the highest ruminant animal populations occur (Ivory and Siregar 1984). In contrast, 59 percent of the area in Southeast Asia consists of soils that have severe nutrient deficiencies or toxicities (Dent 1980). The most important problem soils are the acrisols (von

Uexkull 1984) which are estimated to cover 197 million ha, or about 50 percent of the region (FAO–UNESCO 1979). In Malaysia, similar soils have been classified as oxisols or ultisols (Paramananthan and Eswaran 1984), in Indonesia as red-yellow podsolics and latosols (Sudjadi 1984), in Thailand as reddish-brown lateritic soils (Tawonmas et al. 1984) and in Taiwan as reddish-brown latosols (Wang 1984). The fertility constraints of a typical acrisol are low pH, low cation exchange capacity (CEC) with low base and high Al saturation, and low levels of available plant nutrients. They have been used successfully for tree crops but are marginal for arable cropping and a large portion remains under primary or secondary forest. It is on these soils that there is a potentially large and complementary role for forage-based ruminant production. This could occur in conjunction with tree crops or in mixed farming systems where leguminous forages would play a role in soil fertility maintenance and provision of fodder for draught animals. Other problem soils include saline, peat and acid sulfate soils (Dent 1980). They occur in low-lying coastal areas and are often flooded. Because of the expense of reclamation they would be little used for forage production.

Given the extent of infertile soils, it is not surprising that deficiencies of N, P, S, K, Ca, Mg, Cu, Mo and B, and responses to lime have been reported in forage crops (Table 1). Nitrogen is the most limiting nutrient, while P deficiency, excessive Al and low Ca, and deficiencies of K, S and Mo are next in order of importance. For animal production, deficiencies of Na and Co ('t Mannetje et al. 1976; Little 1985) also occur. The severity and extent of these deficiencies is determined by soil type, the species grown and the intensity of production. Many deficiencies will not be evident until other deficiencies or excesses have been corrected. The nature and correction of these deficiencies and excesses is similar to that occurring in other subhumid and humid tropical zones in northern Australia, South and Central America and Africa, Thus, results of research in these regions will have relevance to the development of solutions to remove fertility constraints for forage crop production in

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Table 1. Some examples of nutrient response by forage species in Southeast Asia and the Pacific.

Country	Region	Deficiency/Excess	Test Species	Source
Indonesia	Java,	N, P, S, K, Mo, lime,†		Ivory and Siregar 1984
	Sulawesi	S, (Mo)	C. pubescens	Blair et al. 1978
Malayasia	P. Malaysia	P, K, Mo, Ca, Mg, Cu, lime (B)	S. guianensis	Tham and Kerridge 1979, 1982
			C. pubescens	
			P. phaseoloides	
		N, P, K. Lime, Mg	N-fertilized grass	Tan and Pillai 1975
Philippines	Mindoro	P	C. pubescens	Sena and Moog 1977
Thailand	Northeast	N, P, S, K (Cu), B	S. humilis	Shelton et al. 1979
				Keerati-Kasikorn 1984
	North	P, S	M. atropurpureum	Gibson and Andrews 1978
Papua New Guinea		Lime	L. leucocephala	Hill 1970
Fiji		P, S, K, Mo	M. atropurpureum	Partridge 1978
Solomon Islands	Guadalcanal	P, K	S. guianensis	Gutteridge and Steel 1985

† underline, major deficiency; ( ) minor deficiency.

Southeast Asia and the Pacific (e.g. see Sanchez 1978). Likewise, it is imperative to be aware of research on soil-related constraints for food and tree crop production in the region (IRRI 1980; Pushparajah and Amin 1977). A larger research effort is directed towards these commodities than to forage production, and there is close integration of ruminant animal production with these cropping systems. Subsistence farmers place a higher priority on producing food than on animal production.

Recognition

Despite widespread experimentation with fertilisers the actual recognition of nutrient deficiencies remains a major constraint. There are several reasons for this.

1. There is a lack of knowledge and experience in the area of plant nutrition at the regional level, where much of the forage research and extension is carried out in animal husbandry departments. The officers have primary training in animal management, and little basic training in the agronomy of forage crop production.

2. A major portion of the fertiliser research with crops has been with mixtures of N, P, and K, and the importance of S, micronutrients and problems associated with soil acidity has often been overlooked.

3. General recommendations have been made for widespread areas without consideration to soil variability.

4. There is a lack of baseline information to assess whether forage species are restricted in growth by a nutrient deficiency or excess. Descriptions of nutrient deficiency symptoms of forage species are not readily available, and there is a shortage of reliable chemical data on soils and plants which can be interpreted in relation to animal requirements.

The first step in recognition is to determine whether nutrients are limiting growth. The use of a model which predicts growth from water and temperature indices (Williams and Probert 1984) could be of assistance in this regard. Once a nutrient limitation has been recognised, the usual diagnostic procedures can be applied. For a regional situation these might be: (i) observations of deficiency symptoms; (ii) comparison of plant chemical analyses against known standards for healthy tissue; (iii) soil tests; (iv) omission trials. In many areas, lack of laboratory facilities will restrict the use of an analytical approach to diagnosis. However, the development of rapid field tests for N (Schaefer and Barrs' 1985), P (Bouma and Dowling 1982), K (Spencer 1982) and Cu (Delhaize et al. 1982) may help to overcome this limitation.

To improve the ability to recognise nutrient requirements further attention should be given to training, coordinated research and information exchange. A procedural manual could be developed. Currently a nutrient analysis handbook, which would contain much relevant information for such a manual, is being compiled for Australia.

While placing emphasis on the aspect of recognition, it is acknowledged that others realise the problem and that recent activities will assist in overcoming the information gap. These include symposia on soil-related constraints to food crop production in the tropics (IRRI 1980), P and K (Pushparajah and Shariffudin 1982) and S (Blair and Till 1983), and the establishment of the network on management of acid tropical soils under the auspices of The International Board for Soil Research and Management (IBSRAM) and The Australian Centre for International Agricultural Research (ACIAR). However, it is the implementation of present knowledge, in situations where forages

Table 2. Species or varietal differences in response to correction of low or excessive nutrient supply.

Nutrient	Plant	Mechanism	Source
P	legumes	Rate of absorption	Andrew and Robins 1969
	grasses	Growth potential	Asher and Edwards 1978
			Sanchez and Salinas 1981
S	legumes	Growth potential	Begg 1963
			Jones and Quagliati 1970
K	grass vs legumes	Rate of absorption	Hall 1971
			Whelan and Edwards 1975
Mo	legumes	Rate of absorption	Johansen et al. 1977
			Tham and Kerridge 1982
Zn	legumes	Rate of absorption	Gladstones and Loneragan 1967
Cu	legumes	Rate of absorption	Andrew and Thorne 1962
	Stylosanthes		
Ca	grasses vs legumes	Rate of uptake	Loneragan and Snowball 1969
Al excess	legumes	Exclusion	Andrew et al. 1973
			Murphy et al. 1984
	grasses		Spain 1979
Mn excess	legumes	Low absorption Tolerance	Andrew and Hegarty 1969
Salinity	legumes	Exclusion	Wilson 1967
			Russell 1975

are being tested and grown at the regional level, that needs to be achieved.

Edaphic Adaptation of Species

There is now a widespread awareness of differences between and within species to tolerance of conditions of low or excessive nutrient supply (Table 2). This has become known through species comparison experiments but is also evident in the effects of fertiliser on botanical composition and of soil type on distribution of species (Bryan and Evans 1973). Variation also exists within species for mineral nutrient concentration (Hacker 1982). How can such differences best be exploited so as to reduce the need to ameliorate soils chemically? Active selection will need to be carried on locally, as adaptation is required for characteristics other than nutrient tolerance and concentration. It will assist such selection to have some understanding of the reasons for the differences in tolerance where they are known.

The ability to grow adequately at low levels of nutrient supply may be attributed to efficiency in absorption by roots, transport to tops or in utilisation for growth (Table 2). Plants can also grow well at low nutrient supply because of the low demand associated with a low growth rate or growth potential (McIvor 1984). Species or varietal differences in absorption of nutrients can result from variation in the physiological ability to absorb ions from low concentrations (Asher and Edwards 1978), or because of variation in rooting intensity and depth. Mycorrhizal associations enhance the absorption of P, Zn and Cu from soils low in these nutrients and may account for some of the species and varietal differences that have been observed.

One aspect that is often overlooked is that many forage species are grown as mixtures, and thus the ability to compete for nutrients is important in the choice of species. The inability of *Macroptilium atropurpureum* to compete with *Setaria anceps* (Hall 1971) may be due both to the ability of setaria to absorb K at a greater rate (Whelan and Edwards 1975) and to a higher density of grass roots. Competition for nutrients is a major factor affecting seedling establishment within swards. A weakness of the acid-soil-tolerant, P-efficient legume, *Stylosanthes capitata* (Grof et al. 1979) grown with *Andropogon gayanus* in Colombia is failure to reestablish because of grass competition for K (Toledo, J.M., pers. comm).

ADAPTION OF LOW P SUPPLY

Phosphorus is the major nutrient deficiency in tropical forage systems where N is supplied by the legume component. The P nutrition of tropical legumes has been reviewed by Andrew and Jones (1978) and of the genus *Stylosanthes* by Probert (1984). There are marked differences between legumes in their ability to grow under conditions of low soil P. Thus *S. humilis* and *Lotononis bainesii* had a lower response to applied P, and required less P to achieve maximum yield than several other legumes (Andrew and Robins 1969). Their internal critical P concentration of 0.17% was much lower than that of most of
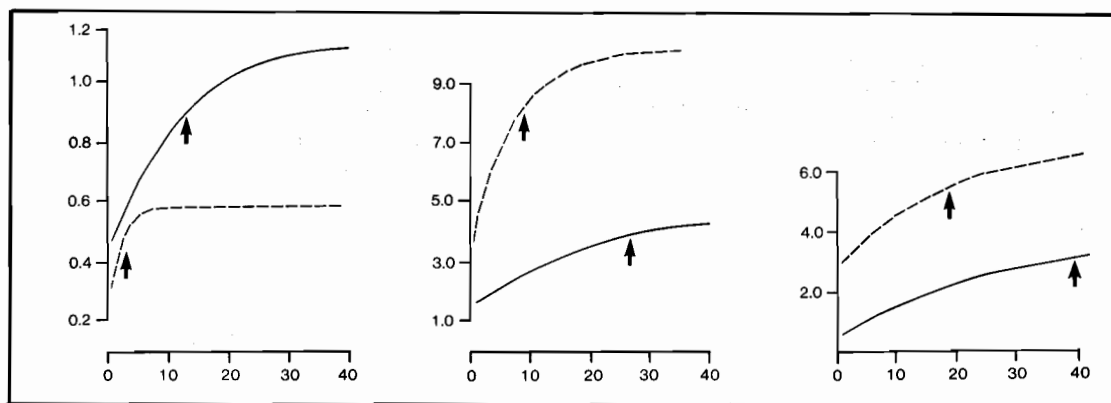
Fig. 1. Response curves for dry matter yeilds of *S. hamata* cv. Verano (——) and *S. scabra* cv. Seca (----) growing on a red earth. The P was applied in year 1. The arrows indicate 80% of maximum yields (Probert 1984).

the other species. But a low internal requirement does not necessarily reflect an external requirement. The internal critical P concentration of *Centrosema pubescens* was 0.16% (Andrew and Robins 1969). In another study, *C. pubescens* was more responsive to applied P than *Pueraria phaseoloides* and *S. guianensis*, which also had critical concentrations of 0.16% (Kerridge and Ratcliff 1982). In this study, *D. heterophyllum*, which occurs widely in Southeast Asia and the Pacific, gave the highest increments of N yield at the lower levels of P application. Large differences in response to small additions of P have been observed within the genus *Stylosanthes* in field experimentation (Probert 1984) and pot culture (Grof et al. 1979; Jones 1974) (Fig. 1).

Studies with ^{32}P show that although plants differ in their ability to absorb and utilise P, they draw their P from a common pool of soil P (Smith 1983). Their efficiency in obtaining P appears to be related to their root absorption power and to their ability to reduce concentrations at the root soil interface to low values (Probert 1984). Mycorrhizae play a role in extending the root system (diffusion of P through the soil is a rate-limiting step in P uptake) and perhaps in lowering the threshold concentration at which plants can take up P (Mosse et al. 1973).

This ability to utilise P is demonstrated by *S. guianensis*, being the dominant component in a grass-legume mixture at low but not high P status (Kerridge and Tham 1983) (Fig. 2). In the rock phosphate treatment (Fig. 2), utilisation of P would have been enhanced by the low pH (4.5) and base status (<1.0 me/100 g) of the soil, and an effective mycorrhizal association (Mosse et al. 1976). Legumes that are dependent on symbiotic N fixation acidify the rhizosphere because they take up an excess of cations over anions, and this factor could also be important in
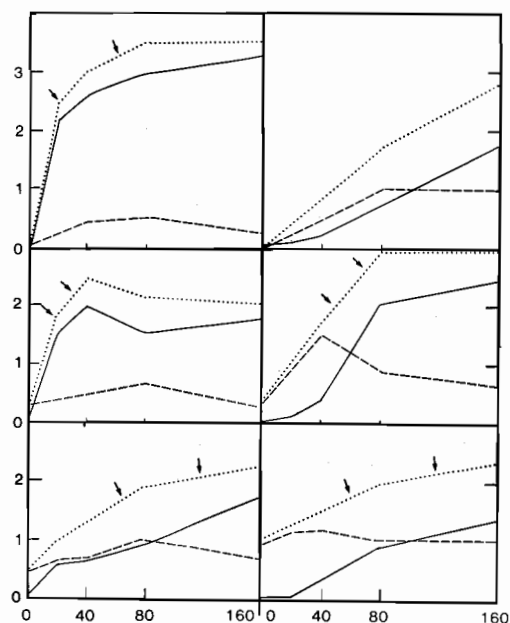

Fig. 2. Component dry matter yields of *S. guianensis* (----), *Panicum maximum* (——) and total yield (····) from eight-weekly harvest intervals at three occasions, when fertilized with triple superphosphate (TS) and Christmas Island rock phosphate (RP). The trial was on an ultisol and P was applied at planting. The arrows indicate 70% and 90% of maximum yield (Kerridge and Tham 1984, and unpublished data).

utilisation of rock phosphate in less acidic soils (Aguilar and van Diest 1981).

ADAPTATION TO ACID SOILS

Soil acidity is associated with a number of growth-limiting factors, which may include the adverse effect of low pH, toxicities of Al and Mn, deficiency or low availability of Ca, P, Mg and Mo, all of which can be

remedied by liming. Substantial differences exist between and within crop and pasture species in their tolerance of one or more of these growth-limiting factors. The mechanisms that may explain such tolerance (Foy 1983) include an ability to exclude Al or Mn, to tolerate larger amounts of Al or Mn in the tissue, or to absorb low levels of Ca, P, Mg and Mo, often in the presence of high soil solution concentrations of Al. Tolerance of Al is of particular interest, because it is more widespread than Mn toxicity, has a marked effect on nodulation and diagnosis is difficult. Kamprath (1984) has suggested the use of Al saturation, as determined by 1N KCl, to indicate potential toxicity for crop species. However, the determination of pH, ionic strength and Al and Ca concentrations of the soil solution appears to be a more useful approach for forage species (Adams 1978). The problem is further compounded by the presence of both monomeric and polymeric forms of Al being present in the soil solution, with monomeric Al being the toxic form (Blamey et al. 1983). Better knowledge of the conditions affecting the proportion of these forms and the significance of soluble organic Al will clarify our understanding of the Al limitations to plant growth in acid soils and our interpretation of estimates of soil Al.

Widespread use has been made of the acid-soil-tolerant legumes *Calapogonium muconoides, P. phaseoloides, Desmodium ovalifolium* and *C. pubescens* as cover crops in the plantation industry in Southeast Asia. *C. pubescens* is the most suitable and persistent under grazing (Eng et al. 1978a) but the least tolerant of acid soils. A program has commenced in Colombia and Brazil to improve the acid soil tolerance of *C. pubescens* by crossing it with the highly acid-tolerant *C. macrocarpum* (Hutton 1983). Among the *Desmodium* species, *D. ovalifolium* is more tolerant of soil acidity than *D. heterophyllum* (Sanchez and Salinas 1981).

The genus *Stylosanthes* includes many species that are tolerant of acid soil conditions other than low soil P. *S. humilis* was superior to four other tropical legumes in its ability to extract Ca from the soil (Andrew and Norris 1961). *S. guianensis* and *S. fruticosa* responded the least to liming among 16 other legume species on an oxisol with low soil Al (Munns and Fox 1977). Nevertheless, responses to Ca can occur on soils of very low Ca status (Probert 1980; Tham and Kerridge 1982). Differences in acid tolerance occur between species, as shown by a lower toxic effect of Al on nodulation in *S. hamata* and *S. fruticosa* than four other species (Carvalho et al. 1981), and within species, as evidenced by better growth of some lines of *S. capitata* than others under conditions of high Al saturation of the soil (Sanchez

and Salinas 1981). *Stylosanthes* species are more efficient in obtaining Mo from low Mo soils than other species (Johansen et al. 1977; Tham and Kerridge 1982), and no responses to this nutrient have been reported under field conditions.

Progress has also been made in the search for a productive shrub or tree legume tolerant of acid soil conditions. Some programs are aiming to improve the acid soil tolerance of *Leucaena leucocephala*, which is naturally adapted on fertile neutral to alkaline soils of high base status. In Malaysia, screening lines from different sources has resulted in one line with a 30% yield increase over the released cultivars (Wong et al. 1982). In Brazil, crossing *L. leucocephala* with the more acid tolerant *L. diversifolia* has given promise of higher yielding lines (Hutton 1984). Oakes and Foy (1984) found differences in acid tolerance between species and lines of leucaena in a pot culture study in which mineral N was supplied. Another program has been screening germplasm of different species on an ultisol in South Sumatra, where two species, *Cassia sismea* and *Acacia auriculiformis*, gave a two–fourfold increase in leaf production over the K8 line of *L. leucocephala* (Blair, G.J., pers. comm.).

There is considerable scope for continued selection for edaphic tolerance from among the germplasm which exists in several large collections. A recent example is the selection of an alkaline-soil-tolerant line of *S. hamata* (CPI 61670) for Timor, where the available cultivar, Verano, which had been selected from a acid soil, developed Fe chlorosis on a high pH soil. This was possible because it was known some forms of *S. hamata* were adapted to alkaline soils (Burt and Miller 1975) and were available to the CSIRO germplasm collection. Yield of CPI 61670 was 7300 kg/ha compared with 3600 kg/ha for Verano (Piggin 1985).

Selection for edaphic tolerance would best be incorporated into the goals of broad selection programs for other factors such as climate, disease and insect tolerance, forage quality and persistence. Plant nutrition research can contribute by demonstrating varietal or species differences, studying mechanisms of nutrient use and tolerance, and developing selection procedures. It is desirable that selection procedures include at least one low input rate as well as the usual zero and high input of the nutrient or amendment in question (Sanchez and Salinas 1981).

Management of Fertility Constraints

The aim should be to minimise the effect of the constraint by soil and fertiliser management and use of species that are adapted to the fertility constraints. The extent to which this can be achieved will depend on the

nature of the farming system, the availability of fertilisers and suitable species and the economic value of the products. There will be different solutions for particular situations, and there needs to be some form of continual assessment just as with management practices such as weed and disease control.

In many situations there will be a gross nutrient deficiency or excess, and large responses can be achieved by partial correction (Kerridge 1978; Sanchez and Salinas 1981). In Fig. 2, it can be seen that six months after applying TS, 70% of the maximum yield was achieved at 20 kg P/ha, which is only 33% of the requirement for 90% of the maximum yield. This principle has application both for correction of P deficiency and for liming to overcome acidity, and in these cases may be combined with the use of P-efficient or acid-tolerant legumes or grasses to maximise production per unit of added fertiliser. Low rates of lime may have a large impact on legume growth through enhancing N_2 fixation, because the nodulation process has a greater sensitivity than the host plant to excess Al (Carvalho et al. 1982). Use of P will often be warranted during establishment, when plants are most responsive because of limited root systems. For example, the required P concentration in the soil solution for the forage legume *Desmodium aparines* is high during the establishment period, 6.5 μM P, but decreases to 0.3 μM P after the second cutting (Fox et al. 1974). Placement of P near the seed can optimise fertiliser response, reduce effects of plant competition, and reduce the total seed requirement through better seedling survival.

The use of P-efficient forage species may result in low P concentrations in the plant tops to the point where reduced P intake limits animal production. In northern Australia, it has been possible to introduce *Stylosanthes* species into native grasslands of low P status without fertilisation. But small additions of fertiliser (25 kg single superphosphate annually) have increased legume growth and greatly increased legume intake (McLean et al. 1981). However, in several instances, additional P supplementation of beef cattle has further increased liveweight gain (Winter et al. 1985). This success of small inputs of P will be greatest on soils with a low capacity to absorb P, but even on soils of high P sorption capacity it may be possible to restrict the input of P as fertiliser. On such a soil (Fig. 2), where an increase in beef cattle production with increasing rates of P fertilisation was related to the P and Ca concentration in the pasture rather than pasture yield or composition, some of the effect of fertilisation might have been achieved by direct supplementation of the cattle (Eng et al. 1978b).

Effects of nutritional factors on pasture quality have been reviewed by Wilson (1982). High P supply may improve herbage palatability and dry matter intake, while Ca and S fertilisation increase dry matter digestibility and intake. These aspects are discussed further by Evans in these proceedings.

Too few grazing experiments involving legume introduction examine the effect of fertilisation, even though it is an expensive maintenace item. Maintenance requirements in grazed pastures are often much less than those estimated in pot experiments or cutting trials (Steel and Humphreys 1974). Continuing appraisal of the nutrient status can result in improved fertiliser economy and also will detect secondary deficiencies such as K (Andrew and Shaw 1979).

The above comments apply to extensive grazing systems. In intensive mixed farming systems, management of fertility constraints should take into consideration all components. The forage component may benefit from and contribute inputs to a cropping system. Thus, higher fertiliser input or soil amelioration for the forage component may be justified by the value of a food crop, which in turn could benefit from N or other nutrient input from the forage or animal manure. This may apply in the use of leucaena as an animal feeding stuff and for soil fertility improvement (Kang et al. 1984; Piggin and Parera 1985) on infertile soils for which adapted leucaena cultivars are not yet available. In intensive systems, insufficient attention has been given to efficient collection, storage and use of animal manures.

Finally, some general principles applying to soil and fertiliser management should not be forgotten. Conservation of organic matter, which contributes substantially to the negative change in oxisols and ultisols, will improve retention of cations (Gillman 1984). Method, timing and form of fertiliser application can also assist to conserve nutrients. Frequent applications of small amounts of soluble N, K and S fertilisers will reduce leaching and volatilisation losses. Medium to highly reactive rock phosphates are a suitable form of P on acid soils for maintenance of perennial crops and also contribute more calcium than acidulated phosphates (Kerridge 1978).

Summary

Future initiatives to remove soil fertility constraints on the production of forages in the Southeast Asia and Pacific region that should be undertaken include the following:

• creation of an awareness of the need for a plant nutrition component in agronomic and animal nutrition research;

• preparation of a manual outlining procedures for recognition of plant nutrient constraints;

• establishment of a register of forage species and lines that are known or found to be tolerant to edaphic constraints.

Research areas which need attention include:

• continued screening of legumes adapted to soils with fertility constraints, with particular attention to shrubby legumes suited for intensive mixed farming systems;

• research on the effects of edaphic constraints on nitrogen fixation, in particular, that of excess Al;

• research on the maintenance fertiliser requirements on improved grassland;

• studies on the recyling of nutrients with the objective of nutrient conservation in intensive systems.

References

Adams, F. 1978. Liming and fertilization of Ultisols and Oxisols. In: Andrew, C.S., and Kamprath, E.J., ed., Mineral Nutrition of Legumes in Tropical and Subtropical Soils. CSIRO, Melbourne, 375–394.

Aguilar, S.A., and Diest, A. van. 1981. Rockphosphate mobilization induced by the alkaline uptake pattern of legumes utilizing symbiotically fixed nitgrogen. Plant and Soil, 61, 27–42.

Andrew, C.S., and Hegarty, M.P. 1969. Comparative response to Mn excess of eight tropical and five temperate pasture legume species. Australian Journal of Agricultural Research, 20, 687–696.

Andrew, C.S., Johnson, A.D., and Sandland, R.L. 1973. Effect of aluminium on the growth and chemical composition of some tropical and temperate pasture legumes. Australian Journal of Agricultural Research, 24, 325–329.

Andrew, C.S., and Jones, R.K. 1978. The phosphorus nutrition of tropical forage legumes. In: Andrew, C.S., and Kamprath, E.J., ed., Mineral Nutrition of Legumes in Tropical and Subtropical Soils. CSIRO, Melbourne, 295–312.

Andrew, C.S., and Norris, D.O. 1961. Comparative responses to calcium of five tropical and four temperate pasture legumes species. Australian Journal of Agricultural Research, 12, 40–55.

Andrew, C.S., and Robins, M.F. 1969. The effect of phosphorus on the growth and chemical composition of some tropical pasture legumes. I. Growth and critical percentages of phosphorus. Australian Journal of Agricultural Research, 20, 665–674.

Andrew, C.S., and Shaw, N.H. 1979. Superphosphate and stocking rate effects on a native pasture oversown with *Stylosanthes humilis* in central coastal Queensland. 4. Phosphate and potassium sufficiency. Australian Journal of Experimental Agriculture and Animal Husbandry, 19, 426–436.

Andrew, C.S., and Thorne, P.M. 1962. Comparative responses to copper of some tropical and temperate pasture legumes. Australian Journal of Agricultural Research, 13, 821–835.

Asher, C.J., and Edwards, D.G. 1978. Relevance of dilute solution culture studies to problems of low fertility tropical soils. In: Andrew, C.S., and Kamprath, E.J., ed., Mineral Nutrition of Legumes in Tropical and Subtropical Soils. CSIRO Melbourne, 131–152.

Begg, J.E. 1963. Comparative responses of indigenous, naturalized and commerical legumes to phosphorus and sulphur. Australian Journal of Experimental Agriculture and Animal Husbandry, 3, 17–19.

Blair, G.J., Panillan, P., and Samosir, S. 1978. The effect of sulphur fertilisation on the yield and botanical composition of pastures in S. Sulawesi Indonesia. Agronomy Journal 70. 559–562.

Blair, G.J., and Till, A.R. ed. 1983. Sulfur in Southeast Asia and South Pacific Agriculture. Research for Development Seminar, Ciawi, Indonesia. ADAB, and the Sulphur Institute. 336 p.

Blamey, F.P.C., Edwards, D.G., and Asher, C.J. 1983. Effects of aluminium, OH:Al and P:Al molar ratios, and ionic strength on soybean root elongation in solution culture. Soil Science, 136, 197–207.

Bouma, D., and Dowling, E.J. 1982. Phosphorus status of subterranean clover: a rapid and simple test. Australian Journal of Experimental Agriculture and Animal Husbandry, 22, 428–436.

Bryan, W.W., and Evans, T.R. 1973. Effects of soils, fertilizers and stocking rates on pastures and beef production on the Wallum of south-east Queensland. 1. Botanical composition and chemical effects on plants and soils. Australian Journal of Experimental Agriculture and Animal Husbandry, 13, 516–529.

Burt, R.L., and Miller, C.P. 1975. *Stylosanthes* — a source of pasture legumes. Tropical Grasslands, 9, 117–123.

Carvalho, M.M. de, Edwards, D.G., Andrew, C.S. and Asher, C.J. 1981. Aluminium toxicity, nodulation and growth of *Stylosanthes* species. Agronomy Journal, 73, 261–265.

Carvalho, M.M. de, Edwards, D.G., Asher, C.J., and Andrew, C.S. 1982. Effects of aluminium on the nodulation of two *Stylosanthes* species grown in nutrient solution. Plant and Soil, 64, 141–152.

Delhaize, E., Loneragan, J.F., and Webb, J. 1982. Enzymic diagnosis of copper deficiency in subterranean clover. II. A simple field text. Australian Journal of Agricultural Research, 33, 981–987.

Dent, F.J. 1980. Major production systems and soil-related constraints in Southeast Asia. In: Soil-related constraints to food production in the tropics. International Rice Research Institute, Los Banos, Philippines, 79–106.

Eng, P.K., Kerridge, P.C., and 't Mannetje, L. 1978a. Effects of phosphorus and stocking rate on pasture and animal production from a guinea grass–legume pasture in Johore, Malaysia. I. Dry matter yeilds, botanical and chemical composition. Tropical Grasslands, 12, 188–197.

Eng, P.K., 't Mannetje, L. and Chen, C.P. 1978b. Effects of phosphorus and stocking rate on pasture and animal production from a guinea grass–legume pasture in Johore, Malaysia. 2. Liveweight Change. Tropical Grasslands, 12, 198–207.

FAO-UNESCO 1979. Soil map of the world. Vol. IX. Southeast Asia. UNESCO, Paris.

Fox, R.L., Hashimoto, R.K., Thompson, J.R., and de la Pena, R.S. 1974. Comparative external phosphorus requirements of plants growing in tropical soils. Tenth International Congress Soil Science (Moscow), 4, 232–239.

Foy, C.D. 1983. The physiology of plant adaptation to mineral stress. Iowa State Journal of Research, 57, 355–391.

Gibson, T.A., and Andrews, A.C. 1978. Pasture Agronomy research in Northern Thai highlands. Proceedings, Australian Society of Animal Production, 12, p.203.

Gillman, G.P. 1984. Nutrient availability in acid soils of the tropics following clearing and cultivation. ACIAR (Australian Centre for International Agricultural Research). Proceedings of the International Workshop on Soils, 1983, Townsville, Queensland, Australia, 39–46.

Gladstones, J.S., and Loneragan, J.F. 1967. Mineral elements in temperate crops and pasture plants. I. Zinc. Australian Journal of Agricultural Research, 18, 427–446.

Grof, B., Schultze-Kraft, R., and Muller, F. 1979. *Stylosanthes capitata* Vog., some agronomic attributes, and resistance to anthracnose (*Colletotrichum gloeosporioides* Penz.). Tropical Grasslands, 13, 28–37.

Gutteridge, R.C., and Steel, R.J.H. 1985. Fertilizer requirements for *Stylosanthes guianensis* ovesown into the grassland foothills of Guadalcanal. Troprical Grasslands, 19, 40–43.

Hacker, J.B. 1982. Selecting and breeding better quality grass. In: Hacker, J.B., ed., Nutritional Limits to Animal Production from Pastures. Commonwealth Agricultural Bureaux, Farnham Royal, U.K., 305–326.

Hall, R.L. 1971. The influence of potassium supply on competition between Nandi setaria and Greenleaf desmodium. Australian Journal of Experimental Agriculture and Animal Husbandry, 11, 415–419.

Hill, G.D. 1970. Studies on the growth of *Leucaena leucocephala*. 2. Effect of lime at sowing on the production from low calcium status soils of the Sogeri Plateau. Papua New Guinea Agriculture Journal, 22, 69–71.

Hutton, E.M. 1983. Breeding *Centrosema pubescens* better adapted to the acid infertile soils of South America. Proceedings, XIV International Grassland Congress, Lexington, Kentucky, USA. Westview Pres., Colorado, 215–218.

Hutton, E.M. 1984. Breeding and selecting leucaena for acid tropical soils. Pesquisa Agropecuaria Brasiliera, 19, 263–274.

IRRI 1980. Priorities for alleviating soil-related constraints to food production in the tropics. International Rice Research Institute, Los Baños, Philippines, 468p.

Ivory, D.A., and Siregar, M.E. 1984. Forage research in Indonesia. Past and Present. In: Asian Pastures. Food and Fertilizer Technology Centre for the Asian and Pacific Region, Taiwan. FFTC Book Series No. 25, 12–29.

Johansen, C., Kerridge, P.C., Luck, P.E., Cook, B.G., Lowe, K.F., and Ostrowski, H. 1977. The residual effect of molybdenum fertilizer on growth of tropical pasture legumes in a sub-tropical environment. Australian Journal of Experimental Agriculture and Animal Husbandry, 17, 961–968.

Jones, R.K. 1974. A study of the phosphorus responses of a wide range of accessions from the genus *Stylosanthes*. Australian Journal of Agricultural Research, 25, 847–862.

Jones, M.B., and Quagliato, J.L. 1970. Respostas de quatro leguminosas tropicais e da alfalfa a vários niveis de enxófre Pesquisa Agropecuaria Brasiliera, 5, 359–363.

Kamprath, E.J. 1984. Crop responses to lime on soils in the tropics. In: Soil Acidity and Liming. Agronomy Monograph No. 12 (2nd ed) ASA-CSSA-SSSA, Madison, 349–368.

Kang, B.T., Wilson, G.F., and Lawson, T.L. 1984. Alley cropping — a stable alternative to shifting cultivation. International Institute for Tropical Agriculture, Ibadan, Nigeria, p. 22.

Keerati-Kasikorn, P. 1984. Soil nutrient deficiencies affecting pasture production in northeast and northern Thailand. In: Asian Pastures. Food and Fertilizer Technology Centre

for the Asian and Pacific Region, Taiwan, FFTC Book Series No. 25, 159–172.

Kerridge, P.C. 1978. Fertilization of acid tropical soils in relation to pasture legumes. In: Andrew, C.S., and Kamprath, E.J., ed., Mineral Nutrition of Legumes in Tropical and Subtropical Soils. CSIRO, Melbourne, 395–415.

Kerridge, P.C., and Ratcliff, D. 1982. Comparative growth of four tropical pasture legumes and guinea grass with different phosphorus sources. Tropical Grasslands, 16, 33–39.

Kerridge, P.C., and Tham, K.C. 1983. Nutrient requirements for establishment of legume grass pastures on inland soils of Peninsular Malaysia. In: Chan, H.Y., ed., Symposium on Classification and Management of Malaysian Soils, Kota Kinabalu, Sabah, Malaysia, Nov. 1974. Malaysian Society of Soil Science, Kuala Lumpur, 236–251.

Little, D.A. 1985. The mineral content of ruminant feeds and the potential for mineral supplementation in Southeast Asia, with particular reference to Indonesia. In: Dickson, R.M. ed., Utilization of Fibrous Agricultural Residues as Animal Feeds. School of Agriculture and Forestry, University of Melbourne (in press).

Loneragan, J.F., and Snowball, K. 1969. Calcium requirements of plants. Australian Journal of Agricultural Research, 20, 465–478.

McIvor, J.G. 1984. Phosphorus requirements and responses of tropical pasture species: native and introduced grasses, and introduced legumes. Australian Journal of Experimental Agriculture and Animal Husbandry, 24, 370–378.

McLean, R.W., Winter, W.H., Mott, J.J., and Little, D.A. 1981. The influence of superphosphate on the legume content of the diet selected by cattle grazing *Stylosanthes*-native grass pastures. Journal of Agricultural Science, Cambridge, 96, 247–249.

't Mannetje, L. Ajit, S.S., and Murugaiah, M. 1976. Cobalt deficiency in cattle in Johore. Liveweight changes and response to treatments. MARDI Research Bulletin, 4, 90–98.

Mosse, B., Hayman, D.S., and Arnold, D.J. 1973. Plant growth response to vesicular-arbuscular mycorrhiza. V. Phosphate uptake by three plant species from P-deficient soils labelled with ^{32}P. New Phytologist, 72, 809–815.

Mosse, B., Powell, C.Li, and Hayman, D.S. 1976. Plant growth responses to vesicular–arbuscular mycorrhiza. IX. Interactions between VA mycorrhiza, rockphosphate and symbiotic nitrogen fixation. New Phytologist, 76, 331–342.

Munns, D.N., and Fox, R.L. 1977. Comparative liming requirements of tropical and temperate pasture legumes. Plant and Soil, 46, 533–548.

Murphy, H.E., Edwards, D.G., and Asher, C.J. 1984. Effects of aluminium on nodulation and early growth of four tropical pasture legumes. Australian Journal of Agricultural Research, 35, 663–673.

Oakes, A.J., and Foy, C.D. 1984. Acid soil tolerance of leucaena species in greenhouse trials. Journal of Plant Nutrition, 7, 1759–1774.

Paramananthan, S., and Eswaran, H. 1984. Problem soils of Malaysia in their characteristics and management. In: Problem Soils in Asia. Food and Fertilizer Technology Centre for Asian and Pacific Region, Taiwan, 1–12.

Partridge, I.J. 1978. Fertiliser response by Siratro (*Macroptilium atropurpureum*) on nigrescent hill soils in S.W. Viti Levu: superphosphate, potassium and molybdenum. Fiji

Agricultural Journal, 40, 81–84.

Piggin, C.M. 1985. Report of results from pasture research trials and developmental sowings. Pasture Section, NTT Livestock Development Project, Kupang, Timor, Indonesia.

Piggin, C.M., and Parera, V. 1985. The use of *Leucaena* in Nusa Tenggara Timur. In: Shrub Legume Research in Indonesia and Australia: ACIAR Proceedings Series No. 3., 19–27.

Probert, M.E. 1980. Growth responses to various calcium sources in a yellow earth with a low calcium status. Australian Journal of Experimental Agriculture and Animal Husbandry, 20, 240–246.

  1984. The mineral nutrition of *Stylosanthes*. In: Stace, H.M., and Edye, L.A., ed., the Biology and Agronomy of Stylosanthes. Academic Press, Australia, 203–225.

Pushparajah, E., and Amin, L.L. 1977. Soils under *Hevea* in Peninsular Malaysia and their management. Rubber Research Institute of Malaysia, Kuala Lumpur, p. 188.

Pushparajah, E., and Shariffudin, H.A. Hamid, ed. 1982. Phosphorus and potassium in the tropics. Malaysian Society of Soil Science, Kuala Lumpur. 590 p.

Russell, J.S. 1975. Comparative salt tolerance of some tropical and temperate legumes and tropical grasses. Australian Journal of Experimental Agriculture and Animal Husbandry, 16, 103–109.

Sanchez, P.A. 1978. Tropical pasture research in acid, infertile soils of Latin America: present status and needs for the future. In: Sanchez, P.A. and Tergas, L.E. ed., Pasture Production in Acid Soils of the Tropics. CIAT, Cali, Colombia, 471–476.

Sanchez, P.A., and Salinas, J.G. 1981. Low-input technology for managing Oxisols and Ultisols in tropical America. Advances in Agronomy, 34, 279–406.

Schaefer, N.L., and Barrs, H.D. 1985. Field test for nitrate uptake up the crop. In: Proceedings, Third Australian Agronomy Conference, Hobart, 30 Jan–1 Feb. 1985 (in press).

Sena, E.M., and Moog, F.A. 1977. Performance evaluation of pasture grasses and legumes under Mindoro conditions. Philippine Journal of Animal Industry, 32, 35–41.

Shelton, H.M., Gutteridge, R.C., Wilaipon, N., Wickham, B., Kratzing, D.C., and Waring, S.A. 1979. Nutrient studies on pasture soils of North-eastern Thailand. Thai Journal Agricultural Science, 12, 235–247.

Smith, F.W. 1983. Availability of soil phosphate to tropical pasture species. In: Proceedings, XIV International Grassland Congress, Lexington, Kentucky, USA, June 1981. Westview Press, Colorado, 282–285.

Spain, J.M. 1979. Pasture establishment and management in Llanos Orientales of Colombia. In: Sanchez, P.A., and Tergas, L.E., ed., Pasture Production in Acid Soils of the Tropics. CIAT. Cali, Colombia, 167–176.

Spencer, K. 1982. Rapid test for determining critical potassium levels in clover tissue. Journal of the Australian Institute of Agricultural Science, 48, 101–103.

Steel, R.J.H., and Humphreys, L.R. 1974. Growth and phosphorus response of some pasture legumes sown under coconuts in Bali. Tropical Grasslands, 8, 171–178.

Sudjadi, M. 1984. Problem soils in Indonesia and their management. In: Problem Soils in Asia. Food and Fertilizer Technology Centre for the Asian and Pacific Region, Taiwan, FFTC Book Series No. 27, 58–73.

Tan, H.T., and Pillai, K.R. 1975. Production of high quality grass in the tropics. In: Conference on Malaysian Food Self-sufficiency, Kuala Lumpur. University of Malaya Agricultural Graduates Alumni, Kuala Lumpur, 127–136.

Tawonmas, D., Panichakul, M., Ratanarat, S. and Masangsul, W. 1984. Problem of lateritic soil for field crop production in Thailand. In: Problem Soils in Asia. Food and Fertilizer Technology Centre for the Asian and Pacific Region, Taiwan, FFTC Book Series No. 27, 50–57.

Tham, K.C., and Kerridge, P.C. 1979. Assessment of the nutrient status of coastal marine sand (BRIS) of Peninsular Malaysia by pot experiment, using *Stylosanthes guianensis*. MARDI Research Bulletin, 7, 43–54.

  1982. Responses to lime, K, Mo and Cu by grass legume pasture on some Ultisols and Oxisols of Peninsular Malaysia. MARDI Research Bulletin, 10, 350–369.

von Uexkull, H.R. 1984. Managing Acrisols in the humid tropics. In: Problem Soils in Asia. Food and Fertilizer Technology Centre for the Asian and Pacific Region, Taiwan, FFTC Book Series No. 27, 382–397.

Wang, S.T. 1984. Management of problem soils in Taiwan, POC. In: Problem Soils in Asia. Food and Fertilizer Technology Centre for the Asian and Pacific Region, Taiwan, FFTC Book Series No. 27, 74–88.

Whelan, B.R., and Edwards, D.G. 1975. Uptake of potassium by *Setaria anceps* and *Macroptilium atropurpureum* from the same standard solution culture. Australian Journal of Agricultural Research, 26, 819–829.

Winter, W.H., McCosker, T.H., Pratchett, D., and Austin, J.D.A. 1985. Intensification of beef production. In: Muchow, R.C., ed., Agro-Research for the Semi-Arid Tropics: Northwest Australia. University of Queensland Press, St. Lucia, 395–418.

Williams, J., and Probert, M.E. 1984. Characterization of the soil-climate restraints for predicting pasture production in the semi-arid tropics. ACIAR Proceedings, International Workshop on Soils, September 1983. Townsville, Queensland, Australia, 61–75.

Wilson, J.R. 1967. Response to salinity in glycine. 3. Dry matter accullation in three Australian species and *G. javanica*. Australian Journal of Experimental Agriculture and Animal Husbandry, 7, 50–56.

  1982. Environmental and nutritional factors affecting herbage quality. In: Hacker, J.B., ed., Nutritional Limits to Animal Production from Pastures. Commonwealth Agricultural Bureaux, Farnham Royal, U.K., 111–131.

Wong, C.C., Chen, C.P., and Ajit, S.S. 1982. Assessment of *Leucaena leucocephala* introductions in Peninsular Malaysia. MARDI Research Bulletin, 10, 159–166.

Seed Production in Tropical Species

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IDEALLY, seed supplies for tropical pasture development should be cheap, reliable, and of good quality. Often they are not, and sometimes their shortcomings are attributable to problems that are amenable to solution through agricultural research. The task here is to enquire into these shortcomings, the prospects for improvement, and the research necessary to bring it about.

There are, of course, other causes of failure. A common one accompanying the recent spread in the need to produce seed is inability to exploit known technology. Slow transfer of experience of lack of resources are frequent hindrances to production. Identification of general research needs demands that attention be directed at the systems least affected by problems such as these, but this must not be interpreted as a denial of their importance. Indeed, transfer and adaptation of technology is at present a more urgent need than research in most countries wanting to produce tropical pasture seeds.

Even so, the countries with the longest experience of seed production and the greatest opportunities to exploit new technology — for example, Australia, Kenya or Brazil — still encounter problems. The most convenient way to introduce them is through identification of the shortcomings in supply.

Shortcomings in Supply

Reliability and Cheapness

Reliability and cheapness are interconnected. Even when expected, unreliable annual production cannot be converted into reliable supply without the costs of carryover and storage of unsold seed. Erratic yields inevitably add to costs.

Absolute reliability of supply is probably unattainable, if for no other reason than that markets for seed are too erratic to sustain stable production. There is, however, commonly room for improvement in reliability of crop yield. This depends on all details of

management, but particularly on the choice of environment in which to grow the crop. Of the environmental factors to take into account, climate is the most critical.

Choice of climate has accordingly received a lot of attention for both grass (Loch 1980) and legume (Hopkinson and Reid 1979) seed production. The combination of experience and research has provided a working rationalisation that is usefully predictive within limits. The problems only begin when very unfamiliar circumstances arise, with the release of an unusual new cultivar or the need to grow crops in a district with an untried combination of climatic characteristics. Then it is necessary to revert to simple trial-and-error. While trial-and-error cannot be eliminated (the risk of the unforeseen is too great), the efficiency of its direction can be greatly increased by an understanding of the behaviour of the species, or the group to which it belongs, in response to environmental variables. Of particular value is an understanding of the control of reproductive processes, and this is one subject where our knowledge is still widely deficient.

The problems are compounded when climatic requirements, even when known, cannot be met. This happens, for example, in small countries needing to produce their own seed but lacking adequate climatic diversity. New tactics are called for. For instance, it is sometimes possible to compensate for lack of day-length change for a short-day plant grown near the equator by use of a cool elevated site (Ison 1982; Ison and Hopkinson 1985). Trial-and-error might eventually discover such an answer, but an approach based on an understanding of the relevant interactions (in this case temperature and photoperiod) is more direct. The need to understand reproductive responses to separate environmental variables must thus be widened to include the interactions between the different ones. These are numerous and as yet poorly understood. They include such things as responses to stress and, in twining legumes, to the disposition of the shoot.

Cheapness depends also on production costs, which, while influenced by a range of economic and managerial factors, are closely linked to yield per unit area of

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crop. Increase in yield is an obvious target in the effort to reduce costs, and a point at which much effort, both private and public, has been directed.

Choice of locality having been made, the grower may seek to increase yield either by raising crop production or improving efficiency of recovery. Efficiency of recovery has generally been so low that the most immediate and substantial gains have stood to be made through attention to it. Most tropical pasture species retain 'wild' reproductive habits, which include wide spread in the time of ripening and ready shedding of ripe seeds. The only exceptions, not surprisingly, are long-domesticated annual field crops like lablab (*L. purpureus*). The majority, however, are expected to persist and spread through regeneration under harsh pastoral conditions, and there has been widespread unwillingness to tamper genetically with habits that might aid this. Consequently other routes than plant breeding and selection have been sought (with only isolated exceptions) to increase efficiency. The exceptions apply to a number of highly variable sexually fertilised grasses, in which selection to condense flowering time into a shorter period has been used (Boonman 1980) and is still advocated (Loch 1985).

The spread in ripening time can also be narrowed by management. This has received a lot of attention (Loch 1980; Humphreys 1979) and much progress has been made. There is a point beyond which it is unwise to go, because the risks of loss through disaster (bad weather, breakdown, etc.) increase with closeness of synchronisation. This point has been reached with many crops, the most conspicuous exceptions being in the groups of highly variable grasses distinguished by Loch (1985).

The most direct and obvious way to improve efficiency is to recover a greater proportion of the standing crop presented for harvest at the time of ripeness. In the highly mechanised systems like that of Australia, improvements in combine harvesters, particularly with respect to intake capacity, have produced progressive yield increases over a long period. The combination of increasing horse power and slower travel (through hydrostatic drive) with the retention of narrow fronts permits the easy handling of crops that were impossible fifteen years ago; and the general upgrading of machine size has greatly increased reliability through speeding up the harvest operation. However, in all respects except minor adaptations, the seed industry is the passive recipient of what is built for the grain industry. The primary tool, the combine harvester, is not and never will be designed specifically to meet the needs of the relatively unimportant seed producer. Improvement will remain to some extent

fortuitous and research will stay within the confines of what is available.

Recognition of ripeness is, of course, a preliminary to efficient recovery. It accordingly receives detailed attention in any new circumstances. This takes the form of simple monitoring, and the result is generally that experience, rather than tangible measurement, is the best guide to recognition. Such experience is readily gained, and its absence is hardly a serious shortcoming.

Efficiency of recovery is potentially improved by prolonging the retention of ripe seed. While this occasionally happens by chance of the weather, its deliberate achievement remains largely a hope for the future. Adhesives have been used experimentally on tropical grasses (Loch and Harvey 1983) following their use with *Phalaris* but as yet without commercial practicability. Retention of some legume seed, notably of siratro (*Macroptilium atropurpureum*), has been improved commercially by the submergence of the pods beneath new growth, which reduces shattering and contributes to yield increase. But this is only possible with certain twining legumes whose balance between vegetative and reproductive development can be readily manipulated (Hopkinson 1983).

It is sometimes possible to bypass the problems of synchronisation and shedding by either a multiple harvest approach or the recovery of shed seed. Multiple harvests can be taken from a number of short, springy grass types by means of non-destructive beating or combing operations. Recovery of fallen seed is very widely practised. Manual sweeping is used to harvest signal grass (*Brachiaria decumbens*) seed in Brazil, Verano stylo (*Stylosanthes hamata*) in Thailand (Hare and Waranyuarat 1980), and fine-stem stylo (*S. guianensis* var. *intermedia*) in Zimbabwe, for instance. Mechanised pneumatic harvesting is used for various legumes in Australia, where also the recovery of fallen seed by combine harvester when it rests in a mat of leaf or litter has been very successful with both siratro (*Macroptilium atropurpureum*) and signal grass. Overall, the attention directed at shed seed has paid big dividends. There are still crops to which it is not applicable, however, notably erect grasses (i.e. the majority) and legumes that drop small naked seeds directly to the ground.

Raising crop productivity, as distinct from efficiency of recovery, requires attention to maintenance of optimum conditions for growth and reproduction, and on the management of the balance between them where requirements conflict. Many of the details of how to do so are quite well understood, thanks to the background of experience and research with pastures as well as with seed crops. Establishment, mineral nutrition,

nodulation of legumes, nitrogen nutrition of grasses, and water use comes into this category. Pest and disease control is usually adequately served by the adaptation of practices developed for other field crops.

On the debit side, control over reproductive behaviour still has deficiencies. It covers a wide range of requirements: to avoid flowering at times when vegetative growth is needed to develop the crop framework; to manage the transition to vigorous and (where needed) well-synchronised flowering; to ensure seed set followed by complete maturation of the seed. The first need is to understand the environmental variables that exert the control and the manipulation practices that can be used to reinforce, replace or combat them.

With the legumes, this largely revolves round control of flowering. The subject has recently been reviewed (Ison and Hopkinson 1985) and need only be summarised. The needs are essentially the same as for choice of locality. There are two outstanding control mechanisms, one photoperiodic, the other operating through stress. They interact with one another and with other variables, and the simple and interactive responses change as the plant passes through the different stages of its life.

The background to photoperiodic control is comparatively well understood, and some of the responses and interactions of some species have been quite thoroughly documented. They are, however, only the tip of the iceberg. Control through stress — that is, the imposition of a slight stress (usually drought) that curbs vegetative growth and stimulates reproductive development — is in an even more primitive state of understanding. Though it is a widespread effect widely exploited, its physiological background is virtually unknown.

With the grasses, stress control seems not to exist, but photoperiodic responses occur in a great variety of forms even within a single species. Knowledge of them is again slight and fragmentary, but often this does not interfere seriously with seed production. Occasionally demonstration of responses has usefully explained behaviour, for example the demonstration of quantitative short-day flowering stimulation of Callide rhodes (*Chloris gayana*) in relation to its seasonal seeding (Loch 1983). Other details of inexplicable behaviour in other grasses could have a photoperiodic origin. It would be often a useful, though seldom an urgent, exercise to elucidate them.

Some grasses are shy — that is, they produce many tillers but few inflorescences (Loch 1985). Narok setaria (*S. sphacelata*) is an example. Others, like *Brachiaria humidicola*, vary in their shyness according to how their sward is managed. Independently of

photoperiodic effects there appear to be interactions between tillers that depend on hierarchy, density, stage of development, etc. that affect their capacity to produce inflorescences. Our management would be more effective if we understood them better.

Many losses to seed production of grasses come about not through failure in inflorescence development but through failure of individual spikelets at or after anthesis. Seed set is highly variable, apparently influenced by various environmental factors (Loch 1985). Failure of caryopsis maturation after successful setting is common, serious, and not at all understood.

A factor drastically affecting both production and recovery is weeds. Weed competition frequently delays establishment to the point of total loss of a first year's production. It continues to interfere with legume (though seldom grass) crop development in later seasons. Even when weed frequency is too low for competitive interference, weed seed contamination raises losses and costs at cleaning. Weed control is, in consequence, a *sine qua non* of seed production.

Great progress has been made in weed control through the adaptation of use of herbicides developed primarily for cereals and grain legumes. But it is an unending battle, a new weed always emerging to occupy a niche left by the control of another.

Quality

Seed quality is best considered in terms of its three conventional components: physical, genetic and vital quality. Shortcomings in physical quality largely revolve round weed seed contamination. They thus arise primarily from failure of weed control, secondarily from inadequacies in cleaning technology. Of these, the former is the critical factor. Cleaning technology, being shared with many other much bigger industries, is advanced, and where problems remain their answer usually lies more realistically in paddock hygiene than in greater sophistication of cleaning.

The issues of genetic quality lie with the user rather than the producer of seed. The seed industry can usually, at a price, produce the quality the client wants. So far, at least in Australia and apparently elsewhere, the client has wanted a guarantee against being cheated through substitution but no more. Perhaps with good reason he has cared little about details of trueness-to-type, variability, and drift. On the whole it has been easy to satisfy such modest expectations, and pedigree certification has only been demanded where substitution risks are high. There is, however, one serious problem that increases with time and threatens the genetic integrity of cultivars of several legume species. This is the persistence of hard seed in the ground, which is a constant problem to

growers trying to keep abreast of changing demands without practising shifting agriculture.

As for vital quality, legume seeds present few problems but grasses suffer from shortcomings that provoke the most intense criticism of the seed industry; and it has to be admitted that the general level of quality of grass seed is extremely low.

The reason for low quality are numerous (Hopkinson 1984). The first is the very immature state of grass seed at harvest, which arises from the combination of poorly synchronised ripening and ready abscission. It applies whereever the whole standing crop is harvested in a single act — that is, to most seed. It means: (1) that a significant proportion of seed is too undeveloped to be ever viable, or to remain viable for long; (2) that seed is often so firmly attached to the head that threshing is necessarily aggressive, hence damaging; (3) that because of continuing metabolic activity, freshly harvested seed is capable of postharvest maturation but vulnerable to overheating, gassing from its own metabolic wastes, and premature drying.

Seed is thus apt to enter storage in a greatly deteriorated state. Then, being grown in the tropics, it is likely to be stored in hot, humid conditions. Finally, if shipped overseas, it may have to experience the interior of a metal container carried as deck cargo and the hazards of an open wharf at its destination.

The causes of low quality have been under investigation for some time in Queesland, and quite a lot of progress, still largely unpublished, has been made. The principles derived to explain the behaviour of orthodox seeds in general (Ellis and Roberts 1981) have been of immense value. We have realised that tropical pasture grass seeds are not physiologically unique, but merely subjected to uniquely extreme mistreatment. It is already possible to see where many of the remedies lie. Fortunately for countries with labour intensive economies, the remedies are mostly easier to apply to manual than to highly mechanised harvest systems. Confidence in the orthodoxy of grass seed and hence the applicability of Ellis and Roberts' viability equation leads to the view that seed storage problems also are within reach of solution. Attention to prevention of damage before entry into storage is the first requisite. Then, particularly in hot, wet climates and conditions where expensive storage facilities cannot be justified, the best policy seems to be to concentrate on thorough seed drying and cheap moisture-proof packaging.

A number of gaps remain. Most effort has gone into seeds of grasses of the Paniceae. Relatively little is known of the behaviour of members of the Chloridae or Andropogoneae which, having very different spikelet structures, are not necessarily similar. Much is still to be done to refine the applicability of the viability equation. Besides attention to storage conditions and packaging, the complementary approach of rejuvenation through periodic imbibition of water (Villiers 1975) has shown promise (R. Borges de Medeiros, unpublished) and could be investigated further. Finally, the measurement of grass seed quality in terms of planting value is still very inadequate. The chief present barrier is our failure to understand dormancy, which differs between field and laboratory and is variable, uncontrollable, and only in a very general sense predictable.

Research

Each shortcoming in supply raises a potential research topic. A list of such topics is an obvious starting point in the planning and structuring of a research program. There are three levels of responsibility to take into account in fitting them into a properly integrated plan.

It is first always necessary to retain a presence in any seed growing region with a watching brief. The continuing stream of new cultivars, the emergence of new diseases, the technological changes that occur, create constantly changing problems and solutions. Fortunately many difficulties can be overcome by versatile husbandry, good communications, and simple adaptive research. To tackle them in this way is the first level of responsibility.

The second level is to conduct the applied research necessary when first level effort is not enough. Some of this research is common to tropical pastures as a whole, or is the province of other specialists (e.g. mineral nutrition, pathology, nodulation). It often needs only first level adaptation to fit it into seed production. The remainder is original research, primarily but not solely agronomic, in its own right. It forms the backbone of what is usually seen as seed production research. Some of its more important targets appear in Table 1. Its planning is generally straightforward, except that it faces one major recurring dilemma. Because of the incessant change that characterises the industry, there is always a high risk that a cultivar or practice will be redundant before the research put into it has paid off. This forces us to seek solutions in broad-based understandings with wide applicability at the same time as reaching quick answers. The state of extreme flux emphasises this need with greater urgency than in many other branches of agriculture. Although much can be learned from a synthesis of agronomic experience, the insights that derive from an understanding of principles are of great importance also.

The necessary principles are often, as has already been pointed out, inadequately understood. This therefore leads to a need for background research, which is the third level of responsibility. In this context it means primarily seed and crop physiology.

All these levels are necessary for any long-term maintenance and improvement of seed production. The first needs no further comment. It is the first priority wherever seed production is a new operation, and in many countries the only one that can initially be justified.

Second level work can be justified once the first level is under control. Appropriate research topics are listed, but their choice depends very much on local priorities and it would be an error to try to formulate an overall policy to tackle them.

The third level, serving everyone equally, is amenable to general planning. It also fits readily into internationally cooperative programs and is thus of immediate present relevance. Although some very useful work has been and continues to be done, the quantity has been inadequate and the continuity generally lacking. If we are to justify its extension, it will be necessary to allocate priorities to the possible areas of investigation. My own view is that the most urgent needs lie with the issues of control of reproductive processes of legumes and seed quality of grasses. The present seminar should serve to expose such opinions to scrutiny and to solicit alternatives.

Prospects

The technology of seed production is already quite advanced, and there is no reason why continuing development and research should not allow it both to progress and to adjust to change. The sensitive situations will always be the new ones, and some of the greatest challenges will be in trying to produce seed in hitherto untried environments.

The technology will, of course, have its limits. Irrespective of other constraints — organisational, economic, etc. — that hamper its exploitation, it will never satisfy all needs. There will be some environments, sometimes covering whole countries, where satisfactory seed production of desired plants will be impossible. The importance of our knowledge here will not be to push the technology to its limits, but to provide for informed decision-making — whether, for

example, to persevere, to import seed, or to seek an alternative species. If knowledge is extended and then used in this way, our prospects of fulfilling the ideals of seed supply will be good.

References

Boonman, J.G. 1980. Seed production of tropical grasses in Kenya. In: Hebblethwaite, P.D., ed., Seed Production. London, Butterworth, 215–227.

Ellis, R.H., and Roberts, E.H. 1981. The quantification of ageing and survival in orthodox seeds. Seed Science and Technology, 9, 373–409.

Hare, M.D., and Waranyuarat, A. 1980. A manual for tropical pasture seed production in northeast Thailand. Department of Livestock Development, University. 60 p.

Hopkinson, J.M. 1983. Controle do desenvolvimento de culturas de leguminosas para semente. In: Medeiros, R.B., Nabinger, C., and de Saibro J.C., ed., Produção e tecnologia de sementes de forrageiros tropicais e subtropicais. Ijuí, Brazil, COTRIJUI, 29–50.

    1984. Environmental effects on quality of tropical pasture seed. Australian Seeds Research Conference, Australian Agricultural Council, September 1984. Queensland Agricultural College, Lawes, Australia, 27–38.

Hopkinson, J.M., and Reid, R. 1979. Significance of climate in tropical pasture legume seed production. In: Sánchez, P.A. and Tergas, L.E., ed., Pasture production in acid soils of the tropics. CIAT, Cali, Colombia, 343–360.

Humphreys, L.R. 1979. Tropical pasture seed production. Rome, FAO, 143 p.

Ison, R.L. 1982. Climatic factors controlling juvenility, flowering and seed production of selections of *Stylosanthes guianensis* var. *guianensis*. Ph.D. thesis, University of Queensland, St. Lucia, Australia.

Ison, R.L., and Hopkinson 1985. Pasture legumes and grasses of warm climate regions. In: Halevy, A.H. ed., CRC Handbook of flowering, Vol. 1. CRC, Boca Raton, Florida, USA, 208–252.

Loch, D.S. 1980. Selection of environment and cropping system for tropical grass seed production. Tropical Grasslands, 14(3), 139–148.

    1983. Constraints on seed production of *Chloris gayana* cultivars. Ph.D. thesis, University of Queensland, St. Lucia, Australia.

    1985. Tiller development in relation to seed production in tropical grasses. Proceedings, XV International Grasslands Congress, Kyoto, Japan (in press).

Loch, D.S., and Harvey, G.L. 1983. Preliminary investigations of adhesive sprays to improve seed retention in tropical grasses. Journal of Applied Seed Production, 1(1), 26–29, Corvallis, Oregon, USA.

Villiers, T.A. 1975. Genetic maintenance of seeds in imbibed storage. In: Frankel, O.H., and Hawkes, J.G., ed., Crop genetic resources for today and tomorrow. Cambridge University Press, 297–316.

Work Group Reports

DELEGATES to the workshop divided into five work groups to consider the types of research required to increase productivity of forages and ensure their more efficient usage. The five areas considered were:
- Collection and evaluation of germplasm
- Fitting forages into farming systems
- Forage management
- Nutrition and rhizobiology
- Animal production

The reports of these groups are summarised.

Collection and Evaluation of Germplasm

Different regions were perceived as having distinct sets of priorities.

The Philippine, Malaysian and the South Pacific delegates gave highest priority to pastures on plantations, while delegates from Papua New Guinea and Eastern Indonesia considered that oversown native pastures deserved first attention. Cut-and-carry system improvement was given highest order of priority in West Indonesia and was also highly rated by the Philippines, Malaysia and Thailand. None of the delegates felt that improvement of communal lands or sowing of fully improved pastures rated early attention.

Collection and evaluation of new material was not deemed as important as evaluation and development of available material, although the need for additions to the shrub collection was acknowledged.

Two regional centres for servicing the humid tropics and dry monsoonal areas would assist in evaluation of new germplasm. This would enable standardised evaluation of germplasm in the region, and enable a coordinated effort which is presently lacking. It was recognised that production systems in the region will continue to require high quality legumes, and shrub legumes in particular.

All delegates endorsed the concept of a regional network to provide seed, information, interaction between workers, access to data bases and training opportunities. Interaction with other humid tropics networks including exchange visits and production of a newsletter were ideas which received enthusiastic support.

Fitting Forages into Farming Systems

A list was prepared of the major farming systems of importance to livestock that may be found in the Southeast Asian and South Pacific regions. The relative importance and prospects for improvement were considered for each system.

Flooded Rice Systems

INTENSIVE MULTIPLE RICE CROP SYSTEMS

Available feed sources for this important system for livestock were rice straw, rice crop weeds, tree leaves, natural herbage on paddy bunds, drainage channels, roadsides and canal banks. These forage resources were considered insufficient, but there was limited scope for improvement for a number of reasons:

(a) rice was the primary crop, and farmers were unlikely to devote any of their time, effort and land resources to growing forages;

(b) in flat paddy areas, the area of land as bund was small and was important for walkways;

(c) there was concern among farmers that forages growing adjacent to rice fields may harbour rats or other weed/insect pests;

(d) livestock numbers in such areas are decreasing because of limited forage and reduced need for animal draught power.

It was decided that future research and development should involve supplementation and chemical treatment of rice straws, as well as the possible limited use of tree and herbaceous legumes on paddy bunds as a protein supplement for rice straw.

SINGLE RICE CROP SYSTEMS (RAINFED)

This system was seen as the most important in terms of livestock numbers supported in countries of Southeast Asia. Feed resources were similar to those in the more intensive rice system, but straws and naturalised grasses in paddy fields were available on a seasonal basis.

The group agreed that there were limitations in terms of feed available and the nutritional status of feeds. However, it was felt that considerable scope existed for fitting various forages into this system to improve feed supply. It was noted that relay cropping of various field crops with rice using residual soil moisture, or with some supplemental irrigation, was common in some areas, such practices increase the amount and quality of crop residues available for livestock. Relay crops included maize, mung bean, soybean and peanuts.

Possible strategies which require further research and developmental attention include:

(a) dual purpose legumes after rice on residual moisture e.g. cowpeas with low harvest index and therefore good forage yields;

(b) fodder legumes after rice grown on stored moisture such as sunnhemp (*Crotalaria juncea*) which has been studied at Khon Kaen, Thailand, and is common farmer practice in parts of India;

(c) herbaceous and tree legumes on paddy bunds.

Upland/Dryland Cropping Systems

The upland or dryland cropping systems were also considered to be of great importance to the livestock industries of Southeast Asia, and in particular Thailand, Indonesia and the Philippines.

Feed sources were seasonal grazing of naturalised species, crop residues, tree leaves, and natural herbage on roadsides, border and pathway areas. Again, it was considered that such feed resources did not consitute a balanced or sufficient diet.

Various improvement strategies and their likely potential for improvement, were discussed:

(a) Crop pasture rotations, though an excellent concept in principle, were not popular with Southeast Asian farmers, probably because the income from a full cropping season was lost during the ley pasture phase. Work in northeast Thailand where leys were utilised as part of a dairy program was discussed. Such schemes have greater viability, as cash flow generated from diary production compensates for inputs into the pasture phase, which of necessity involves application of fertiliser.

(b) Dual purpose grain/fodder legumes were considered to have relevance for improved feeding.

(c) Alley cropping of tree legumes with field crops was considered a priority for research and development. Such systems appear to offer the greatest scope for permanent, sustainable upland agriculture on infertile erodable lands. Potential benefits include nitrogen return for associated crops, high quality feed supplement for livestock and land stabilisation.

(d) Minimal management systems were considered to have a place in upland crop/livestock associations. Such systems would involve sowing of tree or shrubby legumes on marginal land, for use as protein banks for cut-and-carry supplementation purposes.

Plantation Systems

A range of plantation systems were considered (coconuts, rubber, oil palm, cocoa, tea

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and coffee), and it was agreed that only coconut and rubber plantations had significant relevance to livestock production. Young rubber plantations (1–6 years) containing leguminous cover crops were viewed as a largely unexploited source of good quality feed for ruminants. Old rubber plantations may have some potential for sheep production, but it was considered that the very low light intensities in such plantations greatly limit the scope for effective improvement of understorey pasture. It was felt that priority should be given to assessing the productivity and viability of this system.

The group agreed that great potential existed for improving feed supply under old widely spaced coconut plantations, where light transmission was more than 50% and sometimes as high as 80%. Although considerable research has been completed in the Pacific on suitable forage species and liveweight gain potential, no comprehensive and systematic search for productive and nutritious species for shaded environments has ever been conducted. This was considered to be a research priority. Such species should be prostrate to allow collection of nuts, and vigorous to effectively compete with weed species.

Fertiliser use and nutrient cycling were also considered to be research priorites for plantations.

House Garden Systems

The group agreed that house garden systems were ubiquitous and important sources of fodder for livestock. Such areas were small, but of importance because they were adjacent to houses where livestock are corralled.

It was felt that only limited scope existed for improvement of house garden systems, but backyard forage systems have been researched and developed with some success in Thailand. Further research is needed to identify species suitable for fodder, including protein banks and dual purpose trees e.g. fodder/fruit or firewood species. Shade-tolerant species were also required.

Extensive Systems

NATURAL GRASSLANDS

Natural grasslands are extensive in Southeast Asia and the Pacific region. They are currently not widely used for livestock. They are considered to be a potential resource by many, and research has shown that it is possible to sow improved legume species into these systems. However, the meeting considered that the stability of these fire climax systems under grazing is questionable. For this reason, they were not considered a high priority for development unless more grazing-tolerant grasses were also oversown. The likelihood of undesirable weed invasion is high, and has already occurred at many sites.

INTENSIVE IMPROVED PASTURES

Fully improved grass/legume pastures have been developed in Malaysia and in some countries of the South Pacific. The Malaysian experience was not successful and there are no plans for further development of these pastures. However, in the Pacific, productive improved pastures have been developed and form the basis of the main productive system for the government and expatriate ranches in those countries. Because of the importance of large-scale development to the short-term future of their beef industries, further research and development in this sector is warranted.

Slash-and-burn System

There was discussion on the slash-and-burn system used in Timor, which involved rotation of upland crops (maize and upland rice) with a leucaena thicket fallow phase. It was agreed that this system was of great relevance to other slash-and-burn systems in the region as a means to reduce the length of the forest fallow phase while still maintaining

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soil fertility and stability on steep slopes. A further advantage is the availability of forage for associated livestock.

Approach to Fitting Forages into Farming Systems

The participants agreed on the need to look closely at the various farming systems available and to explore ways to make better use of available resources. They set priorities for research and development based on the significance of the system to livestock, the opportunity for fitting forages into that system, and the interest and motivation of farmers towards feeding of their livestock.

It was felt that researchers should take new strategies directly to the on-farm testing stage, in order to assess the suitability of the technique to local farming systems and to understand the process involved in adoption. It was agreed that research and development of forages should be concentrated on 'best bet' strategies in an attempt to improve levels of adoption.

Forage Management

Forage management should aim at maximising the production of high quality of forages over as long a period as possible. Such management may require a combination of factors such as pre-sowing land preparation, establishment technology, post-establishment management to enhance persistence, cutting and/or grazing management, animal supplementation and the use of fertilisers, weed control measures, etc. to maintain the species.

Seed Production

Two options were considered: a) grow only species that are capable of setting viable seed within a given environment; b) developing techniques to encourage flowering and seed set. The first option does not require new research institutes but rather an extension of evaluation programs. Better characterisation of the climatic/soil environment would assist. The second requires support research in plant physiology to understand the role of factors such as day length and stress on floral initiation. An understanding of the basis for uneven ripening would contribute significantly to increasing the supply of high quality seed.

Technology is available to maintain the postharvest viability of seed but this information has not been extended to governments and consumers.

Establishment

Establishment prospects would be enhanced if high quality seed was available. The selection of species (particularly grasses) that are capable of vegetative propagation was considered an important criterion to be considered in evaluation programs. Similarly, studies of ways of establishing shrub legumes from cuttings would be beneficial (e.g. leucaena).

Establishment procedures should ideally be low cost and robust. In this regard the use of low cost herbicides should be evaluated and the development of systems to encourage early germination and seedling growth should be developed. Such studies might include the development of low cost, small scale sowing equipment, development of seed coating techniques to be able to package nutrients, rhizobia, herbicides, insecticides, etc. on the seed at a regional centre for use by farmers.

Utilisation of Forages

The species used should be capable of producing under the prevailing management conditions, and should be capable of providing full forage or strategic supplementation at key times throughout the year.

In communal grazing areas, research should concentrate on trees that can be managed more easily than herbaceous species.

Research is also required on the effect of cut-and-carry removal on the nutrient requirements of the area. This should be included as part of an overall conceptual model of the cut-and-carry systems, which should be developed to examine constraints in the system and to define areas of research.

Weed Control

Research is required into weed ingress into sown and natural pastures. Attention in plant introduction programs should emphasise competitiveness of sown species in addition to yield.

General

Because of the dominance of rice producing systems in Southeast Asia, and the high ruminant density generally associated with them, research is required on the introduction and management of forage species into the rice crop to be used as a source of fodder (e.g. sesbania), human food (e.g. cowpea), or as a green manure.

Nutrition and Rhizobiology

Highest priorities for research and investigation in these fields were assigned to the following topics:

● the characterisation of sites by soil type and forage species present, and standardisation of methods used to characterise and determine soil properties. These data are necessary for a complete picture of nutrient supply and plant growth potential. Associated work on *Rhizobium* populations will enable assessment of the need for inoculation of seed.

● diagnosis of nutrient deficiencies, approached through foliar and soil testing, and the need for a manual to aid diagnosis of specific deficiencies.

● the study of nutrient, environmental and management factors affecting and enhancing N fixation by legumes.

● the interchange of information on climatic and edaphic conditions through a register and a newsletter. A current scarcity of expertise emphasised the need for more trained personnel to increase awareness of nutrient constraints to production.

● the search for legumes with good agronomic characteristics which can adapt to a wide range of conditions. The use of non-specific legumes was advocated, but it was noted that further research was required to enable good forage plants such as leucaena and centro to be grown on acid soils. This may require selection of rhizobia for the particular constraints of acid soils.

● a study of management of acid soils through use of adapted species and soil amendments. Shrub legumes are of particular importance because of their use as forage and fuel wood and their role as soil stablisers and nitrogen suppliers in upland agriculture.

Lower priority for action was assigned to integrated nutrient management for proper utilisation and conservation of resources. Nutrient sources such as animal and other wastes, fertilisers and crop residues need to be analysed for major elements and trace elements. Research on the specific requirements of alkaline soils under coconut plantations was indicated.

Other problems requiring investigation but assigned less importance were the need for effective rehabilitation of degraded land using composite fertiliser pellets at the time of seeding, or seedcoating. There was also a need to study the physical aspects of soil in forage-based systems in relation to erosion and water conservation.

Animal Production

Ways of systematically assessing research priorities for increasing production of meat and milk and improving draught power were explored from a farming systems perspective. Participants identified four major feeding systems, and, after assessing production possibilities for each, they assigned priority to those areas where production increases were feasible. The following are the research priorities indentified in each of the major feeding systems.

Cut-and-carry

● identification of desirable and undesirable forage species, and of their effects on animal production. Special attention should be paid to possible teratogenic, hepatotoxic, anti-nutrient and other chronic effects.

● investigation of ways to balance supply and demand in the cut-and-carry feeding system, by studying the potential role of fertilisers, legumes, catalytic supplements and minerals.

● exploration of methods to conserve feed for the dry season, with particular emphasis on provision of feed for draught animals immediately prior to commencement ·of cultivation for wet season crops.

Mixed Crop/Livestock Systems

● identification of methods that give improvements in quality or quantity of feed (e.g. legume banks, alley cropping, growing leguminous forages on bunds etc.) that could be sustained over a long period of time under cutting and/or grazing regimes.

● introduction of multipurpose tree species into farming systems without compromising existing production. Special emphasis should be given to expansion of agroforestry.

Communal Grazing Systems

● research on stocking rates and times taken to utilise grazing reserves. Possible improvements of reserves through legume introductions need to be investigated.

● management of communal grazing. The problems of land tenure and responsibility will continue to limit effective implementation of developments arising from research.

Open Grazing (Privately Owned)

● research on pasture management and improvement;
● introduction of legume species.

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