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Forages on Red Soils in China

Proceedings of a workshop, Lengshuitan, Hunan Province, Peoples' Republic of China, 22–25 April 1991

Editors: P.M. Horne, D.A. MacLeod and J.M. Scott

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Foreword

As China's population is now predicted to exceed 1.2 billion before the year 2000 there has been renewed interest from national and international organisations in increasing food production from under-utilised and waste lands. While China will continue to rely heavily on grains and will have to continue to increase production in this area, there is a rapidly increasing demand for animal products. Present indications are that this increasing demand cannot be met from further intensification of existing animal production systems.

The red soils region of south central China has been the focus of recent research as it encompasses large areas of under-utilised and waste lands that could be developed for both upland cropping and animal enterprises. However, the region presents some difficult and unique problems in relation to soils, climate, land tenure, transportation and marketing. This workshop has been the first major forum bringing together scientists from within China and overseas to discuss these particular problems and suggest directions for future research.

The co-sponsors of the workshop were the Chinese and Fujian Academies of Agricultural Sciences and ACIAR. As collaborators with the University of New England (UNE) on ACIAR Project 8925 'Forage development of the red soils of south central China', they are carrying out research to overcome some of the physical limitations to forage development on these soils.

The sixty workshop participants were drawn from more than thirteen Chinese agencies and represented expertise in the areas of soil science, forage agronomy, climatology, animal husbandry, forestry, sociology and agricultural economics.

While the papers presented in the proceedings generally represent each discrete discipline, much of the discussion focussed on integration of this knowledge into the development of sustainable agricultural systems for these upland areas.

One of the difficulties faced by the organisers was the communication barrier between the overseas and Chinese scientists. Although most presentations were in Chinese, the presence of interpreters for question and answer sessions and the use of slides and overheads in both Chinese and English enhanced the exchange of ideas. These proceedings are being translated into standard Chinese and published by the Chinese Academy of Agricultural Sciences.

ACIAR wishes to thank Zhang Shixian and Wu Chaolin from the Ministry of Agriculture, Vice-President Liang Keyong, Professor Liu Gengling and Madame Huang Jizhang from the Chinese Academy of Agricultural Sciences (CAAS) and Professor Liu Chung Chu from the Fujian Academy of Agricultural Sciences for their assistance. Thanks are also due to Professor Zhang Maxiang (CAAS) as head of the organising committee who ensured that all papers were submitted and translated to English. Mr. Peter Lynch from ACIAR has devoted much time to the technical editing of these proceedings. Finally, the staff of ACIAR Project 8925 at UNE deserve thanks for initiating and ensuring the smooth running of the workshop.

Associate Professor Graeme J. Blair
Forage Program Co-ordinator ACIAR

Keynote Address

CHINA has passed new milestones in socialist modernisation and as a consequence has attracted worldwide attention for its rural economic reforms. The Third Plenary Session of the 11th Central Committee of the Communist Party of China recognised that China's rural economy had entered a new stage: social productivity had been raised and national economic strength had been markedly improved. The recently concluded 7th National People's Congress announced that the last decade of this century is a critical period in the history of the country's modernisation.

The further improvement of agriculture and an all-round development of the rural economy are the primary tasks for social and economic development during the 8th Five-Year Plan. China has a population of 1.1 billion people and a great economic potential. China has fed 22% of the world's population with 7% of the total cultivated land. Farmers have achieved considerable improvement in their standard of living.

During the past 10 years grain production has increased from 305 million t to 407 million t. Cotton production increased from 2.16 million t in 1978 to 4.15 million t in 1988 and oil bearing crops from 5.22 million t to 13.2 million t. These trends have continued through to the present.

In 1990 the performance across the rural sector was particularly strong. This achievement was due to a number of factors: the Government has strengthened rural policies, extension services have been increased, emphasis has been placed on introducing new technologies, and seasonal conditions through this particular year were extremely favourable.

Nonetheless there are factors which will continue to dampen progress in the agricultural sector. These include the loss of farmland due to increasing population and an accelerated growth in consumption which is happening too quickly for new technologies to keep pace. The technical service sector in agriculture is still incomplete.

Worldwide land systems are being degraded. This is the result of a plundering-type land management. The world population is expected to reach six billion by the year 2000 with a major part of the growth occuring in developing countries. This ever-increasing population will place more and more pressure on the land.

In China and elesewhere the creation of truly sustainable agricultural systems has become a challenge of great urgency. At this conference it is an appropriate time for us all to make an appeal to the world to recognise that there is only one globe.

For the current generation the challenge is to get rid of poverty, malnutrition and disease, we have to cherish every inch of land, prevent water quality decline and soils eroding. The Chinese government has recognised that the red soils region are extensive in the subtropical and tropical zones with great potential for feeding an increasing population. This region is therefore the focus of much urgent attention.

Tropical and subtropical areas in China amount to around 2.17 million square kilometres with the dominant soils being 'red'. The soils can be further subdivided into lateritic soils, red soils, yellow soils and purple clay soil. Their collective distribution extends from the Yangtze River to the Nanhai islands and from hilly areas to the south of the Yangtze River to the foothills of the Hengduan Mountains. This area embraces 14 provinces and autonomous regions with 28 million ha being arable. Of this, 11 million ha is dryland farming land. A further 47 million ha is hilly and mountainous. The dryland farming area is important for crop, forest and animal production. It is an important production base for grains, oil seeds, fruits, medicinal herbs, timbers and grass-fed animal production.

The recorded history of Chinese agriculture stretches back 2000 years. These records show that with appropriate methods the red soils can be productive. Despite this by 1949 large areas had become seriously degraded: soil erosion was widespread and water loss from these landscapes was extensive. The people were poverty-stricken.

However, since the emergence of new China and the adoption of agricultural development measures the decline has been halted and large areas have been brought back into production.

In an agricultural–animal production system the principles of ecology are extremely important. Elements of the various resources involved are necessarily mutually linked, limited and must be balanced. China has a variety of soil types some of which are properly utlised and highly productive. Large areas though are not so well utilised and some are degraded. Despite these latter soils being potentially less productive because of the overall shortage of land it is imperative that they be brought into production. And in the development process equal stress needs to be placed on productivity and protection.

Attention also needs to be given to intellectual development. There is a need for more research and education programs based on the results of that research. Already a great amount of planning has been done. Plans for land development have been developed and major works are underway to enhance water and soil conservation. Attention is being given to breeding and evaluating grasses for the various agro-climatic zones of the red soils region to increase capacity for grazing. A committee of examination and approval is to be established to guarantee supply and certify quality of grass seeds and a major agricultural survey is to be conducted as a precursor to an agricultural modernisation project.

Principles for agricultural resource development have been established by the Chinese government. These include recognition of the importance of integrated management, adherence to ecological principles, the need for development to combine biological measures with engineering means and recognition of the balance required between current benefit and future benefit.

In our efforts to bring the expansive, upland, red soil areas back into sustainable production we look forward to being part of the sharing of wisdom. We look forward to increasing cooperation within the international community and we look forward to the challenge of preserving the productive capacity of our precious soil resources.

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Potential and Problems for Forage Development and Animal Production in the Red Soils Region of Southern China

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THE most difficult challenge facing China today is that of feeding an expanding population (predicted to surpass 1.2 billion before the year 2000) with a limited supply of arable land (<10% of the total land area) (Zhao 1989). The enormity of this problem has focused national attention on the redevelopment of wastelands for agricultural use. Of particular concern, because of the large areas of barren land it encompasses, is the red soils region of southern China.

This region covers an area of more than 2.6 million km^2 in the tropical and subtropical climatic zones totalling 14 provinces with a population of 600 million people. Of this area, 0.64 million km^2 is arable land and 0.58 million km^2 is grassland (Table 1). Of the 1.06 million km^2 of hilly and mountainous land, 0.48 million km^2 (18% of the total region) has become eroded wasteland as a result of inappropriate land utilisation and excessive deforestation particularly in the past 40 years (Li, M. 1986; Li, C.K. 1986; State Statistical Bureau 1989). Soil erosion is a serious and growing problem in the region. In Jiangxi Province, the area subject to soil erosion damage has expanded from 1.07 million ha in the 1950s to 3.46 million ha in 1985; equivalent to 21% of the total land area of the province. In Szechuan Province, it is estimated that between 25 and 30% of the land is in need of urgent soil erosion control measures (Xu 1991).

The potential of the eroded hills for growing forages has not been recognised until recently and ruminant animal production has remained low. Pig production is still the major animal industry in China (accounting for 85% of meat production in 1986) and the large majority of this was produced in the red soils region (Ren 1991). Pigs are the dominant livestock in the region (74% of the total), followed by cattle (16%), goats (8%) and sheep (2%) (Table 2). Pork production from the region in 1989 was 14.4 million t (96% of the total output of animal products) (Table 3). The raising of pigs is dependent on grain supplies that could be used directly for human food (Huang 1990). Forage development on the barren hills and mountains would create a source of feed for ruminant animals in areas that are currently poorly utilised.

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The potential for forage development

Developing forages on these barren lands which are characterised by acid, infertile soils, depends largely on the availability of species adapted to the soils and climate. Most of the region is classified as tropical or sub-tropical with an annual mean daily temperature of 17–20 °C and an active accumulated temperate (>10 °C) of 5400 to 6000 degree-days. However, in many areas north of Guangdong and Guizhou Provinces, mean daily temperatures in January and February are as low as 5 °C and in July as high as 30 °C. The mean annual duration of sunshine is 1500–1900 hours and mean annual solar irradiance is 420–460 MJ/m^2. Annual rainfall ranges from 1300 to 1700 mm with a distinct peak in spring and early summer followed by a late summer drought (Domros and Peng 1986, EOCWB 1986). For forage species with the ability to persist through the cold winter and the hot, late-summer drought, the potential productive growing season could be as long as 8 to 10 months.

More than 5000 plant species have been identified in the region as having some value as forages (Shu 1989). Recent evaluations have identified many promising introduced legume and grass species including cocksfoot (*Dactylis glomerata*), phalaris (*Phalaris aquatica*), tall fescue (*Festuca arundinacea*), perennial ryegrass (*Lolium perenne*), white clover (*Trifolium repens*), green panic (*Panicum maximum*), rhodes grass (*Chloris gayana*), setaria

Table 1. Land resources ('000 ha) in the red soils region of southern China. (Source: NRCSC 1989)

Provinces	Total land	Arable land	Forestry	Grassland
Jiangsu	10505	6131	273	331
Zhejiang	10498	2955	4897	1084
Anhui	14017	6771	3334	755
Fujian	12229	2081	7451	1819
Jiangxi	16695	4442	9553	1211
Hubei	18595	6614	6881	2529
Hunan	21183	4703	10756	2879
Guangdong	21303	5410	9200	3923
Guangxi	23641	3714	9709	6038
Szechuan	56547	13066	1948	17713
Guizhou	17622	3033	6425	6493
Yunnan	38361	4716	17516	13060
Total	261197	63678	10593	57969

Table 2. Livestock numbers ('0000) in the red soils region of southern China. (Source: State Statistical Bureau, 1989)

Provinces	Cattle*	Pigs	Goats	Sheep
Jiangsu	38.8	1780.6	684.9	52.4
Zhejiang	71.7	1311.3	76.2	103.8
Anhua	482.6	1219.6	398.5	17.8
Fujian	124.6	890.3	58.6	—
Jiangxi	295.5	1454.5	12.9	—
Hubei	343.7	1965.7	181.2	3.7
Hunan	383.8	2694.4	62.9	0.9
Guangdong	566.0	2213.6	44.1	—
Guangxi	648.0	1527.2	68.8	—
Szechuan	984.5	6381.7	570.8	340.1
Guizhou	552.0	1294.0	127.0	41.0
Yunnan	766.4	1930.8	548.2	167.9
Total	5287.0	24663.7	2798.3	727.6

* including buffalo

(*Setaria sphacelata*), elephant grass (*Pennisetum purpureum*), finger grass (*Digitaria smutsii*), maku lotus (*Lotus pedunculatus*), wynn cassia (*Cassia rotundifolia*), siratro (*Macroptilium atropurpureum*) and lablab (*Lablab purpureus*). The features of these species include high seasonal yields, good drought, heat, cold and acid tolerance and, for some, strong persistence. Amelioration of soil acidity and low fertility (especially P) is essential to achieve successful long-term persistence of these species. The use of such improved species in combination with soil amelioration can result in forage yields 3 to 5 times higher and growing seasons 3 to 5 months longer than native species (Yang 1989). At Nanshan in Chengbu county, Hunan Province, for example, the fresh weight of forage harvested from improved pastures has reached 37.5 t/ha/year.

The potential market for ruminant animal products is large, both within China and in the nearby trading region of Hong Kong. The average annual consumption of meat per person in China (22.6 kg in 1988) is much less than in the developed countries (for example, 73 kg in the United States). An increase in the annual consumption to 35 kg per person in China by the end of the year 2000 would require an increase in total meat production from the 1986 level of 21.1 million t to 42 million t (Ren 1991). This would have to be achieved without a reduction in the average annual consumption of grain of 400 kg per person. Since it is unlikely that there will be an increase in the availability of grain supplies for livestock production (pigs and poultry) such an increase in meat production would have to come from the ruminant livestock sector.

Problems Limiting Forage Development

Fragmented grazing lands

Although the total area of grassland in the region is very large, (Table 1), only a small proportion of this exists in plots of land sizeable enough for extensive grazing. In Guangdong Province, for example, the total area of grassland is 4 million ha of which only 0.4 million ha is in tracts greater than 300 ha (Zhou et al. 1990). Two methods of pasture management will need to be used: grazing for the large tracts of land and cut-and-carry for forages on smaller areas or in association with cropping. This fragmented distribution of grasslands will make the transportation and marketing of animal products a primary limitation to the development of the ruminant livestock sector (see Sturgeon, these Proceedings).

Table 3. Animal products ('000 t) in the red soils region of southern China (Source: State Statistical Bureau 1989)

Provinces	Total meat	Pork	Beef	Mutton	Dairy
Jiangsu	1486	1420	13	53	94
Zhejiang	811	798	5	8	122
Anhui	870	774	71	25	26
Fujian	562	551	6	5	51
Jiangxi	905	889	15	1	23
Hubei	1236	1217	9	10	46
Hunan	1787	1769	14	4	10
Guangdong	1386	1351	32	3	51
Guangxi	939	713	24	2	8
Szechuan	3771	3679	59	33	254
Guizhou	660	630	20	10	10
Yunnan	646	608	27	11	66
Total	14859	14399	295	165	761

Low levels of utilisation and improvement of forages

Of the 0.58 million km^2 of grassland in the region, more than 99% is covered by native grasses characterised by low productivity and poor forage quality and only 1% is improved pasture. Approximately 45% of the grassland is currently used as pasture for grazing animals in Hunan and Hubei Provinces, 35% in Jiangxi and 40% in Jiangxu, Zhejiang, Fujian, Guangdong and Guangxi. In the red soils region as a whole, it is estimated that 0.20–0.23 million km^2 of potential forage resources have not been utilised (NRCSC 1989). There is a need for the parallel development of a ruminant animal husbandry industry and improved forages for upgrading the forage resources and utilisation of the native grasslands.

Competing demands for forages, fuel and food

Shortages of forage and fuel for cooking and heating are part of the reason for the continuing denudation of the barren hills. An indication of the magnitude of problem was provided by ESMAP (1989b) which estimated that of the total fuel requirements of rural households in Hengnan county in the red soils region of southern Hunan, 32% (302 kg/person/year) was met by fuelwood, 13% (128 kg/person/year) by straw, 10% (107 kg/person/year) by grass and 45% by coal and kerosene. Of the total annual fuelwood consumption in the county only 28% came from sustainable supplies leaving a deficit of 72% (210 000 t) to be met by burning crop residues and material collected from hillside areas. ESMAP (1989a) found that about 45% of total rural household fuel was used to cook feed for pigs.

The shortage of grain for human and pig consumption has resulted in an expansion of the land area planted. In Guangxi and Guizhou provinces, for example, the average available arable land per person is less than 0.04 ha (NRCSC 1989). As a result, many red soil hills, which are more suitable for forages than crops, have been cultivated for grain production. Grain yields from these lands are very low and in many cases soil erosion has increased.

Socio-economic problems

Perhaps the most difficult limitations to forage development in the region are shortages of investment capital, poorly developed marketing infrastructures for animal products and the social and economic problems associated with forage management, animal husbandry and land tenure. To overcome these limitations, provincial and local governments must act to provide positive incentives for forage and animal husbandry developments in the form of development capital, expertise, marketing and guaranteed tenure to land.

Integrated farming systems

A possible solution to the problems of soil erosion and the competing demands for forages, fuel and food is the integration of fuelwood and fruit trees with rotations of forage and grain crops. One possible model is the planting of tree hedges along the contours of the hills with strips of forage and grain crops in the intervening spaces. Similar integrated farming systems have been used in eroded upland areas of the tropics, successfully stabilising the soil, increasing levels of soil organic matter, improving water infiltration and diversifying agricultural production. Experiments will soon commence in Hunan, under the supervision of the Chinese Academy of Agricultural Sciences and the Australian Centre for International Agricultural

Research, to examine the effects of various similar integrated farming systems on soil erosion control.

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Agroclimatic Resources and Forage Adaptability in the Red Soils Region of South Central China

Leng Shilin, Lu Xuedu, Li Yue and Yin Yanfang*

THE red soil region of south central China extends north to the Yangtze river, south to the Nanling mountains, west to the Guizhou plateau and east to the coastal provinces of Fujian and Zhejiang. It is a region dominated by hills and plains. The region has a climate characterised by four distinct seasons; unevenly distributed rainfall with a spring peak; frequent drought in late summer and autumn; a short cold period in winter and a long hot period in summer. There are sufficient thermal resources, rainfall and solar radiation for the production of many crops and forages. However, the potential is limited by occasional very low temperatures, overcast winter days, drought, waterlogging, strong wind and hail.

Agroclimate Characterisitics

The characteristics of the region's agroclimate are described here from data collected at 10 sites within the region and 6 sites outside but adjacent to the region. These 16 sites are identified in Figure 1.

Sunshine hours, solar radiation and potential photosynthetic productivity

The mean annual duration of sunshine in this region is 1500–1900 hours, with the mean percentage of sunshine (% of daylight hours in which there is direct sunshine) being 35–40% (Table 1). From west to east, the duration of sunshine increases, from 1500–1700 hours in Hunan to 1700–1900 hours in Jiangxi, Fujian and Zhejiang. The duration of sunshine is shortest in late winter and spring because of frequent cold fronts that bring cold, overcast weather to the region.

The mean annual solar radiation ranges from 4200–4600 MJ/m^2, which is lower than in north-east China (4600–5000 MJ/m^2), north China (5400–5800 MJ/m^2) and north-west China (6300 MJ/m^2) but greater than in the Sichuan basin and Guiyang region (less than 3400 MJ/m^2). Highest levels of solar radiation (600–670 MJ/m^2/month) are received in summer as a result of the long daylength, high sun angle, and absence of cloud. The lowest levels occur in January and February (200–250 MJ/m^2/month). The distribution of PAR (photosynthetically active radiation; solar radiation in the frequency band 380–710 nm) is the same as for total solar radiation, with the annual mean ranging from 1900–2100 MJ/m^2.

As a result of the high summer solar radiation levels, the region has a high potential photosynthetic productivity (PPP); defined as the highest potential crop yields based on solar radiation levels under optimum temperature and moisture conditions. PPP can be calculated as:

$$\text{PPP(kg/ha)} = 146.4 \times Q_p$$

where Q_p is PAR (MJ/m^2/unit time) (Xu Xuegong 1990). The annual PPP is 90 000–100 000 kg/ha (Table 2). In the east of the region, PPP is 7500 kg/ha more than in the west. Summer crops (such as rice, cotton, sweet potato and sugar cane) grow from April to October when the PPP is 75 000 kg/ha and the maximum attainable yield is 31 500 kg/ha. This is higher than in Sichuan and Guizhou, similar to Jiangsu and Hubei and lower than in Guangdong and Guangxi.

Mean and accumulated active temperatures

Temperature is a major index for the evaluation of the region's agroclimatic resources. High temperatures in summer are ideal for many crops but yields can be reduced by cold periods in spring and autumn. In this region, the mean annual temperature is 17–20 °C and accumulated active temperature (AAT; accumulated degree days above 10 °C) is 5400–6000 degree-days. The frost-free period is 270-300 days, which is up to 70 days longer than in Nanjing and Wuhan. Compared with Nanjing and Wuhan, the mean annual temperature is 2–3 °C higher and the period of temperatures above 10 °C

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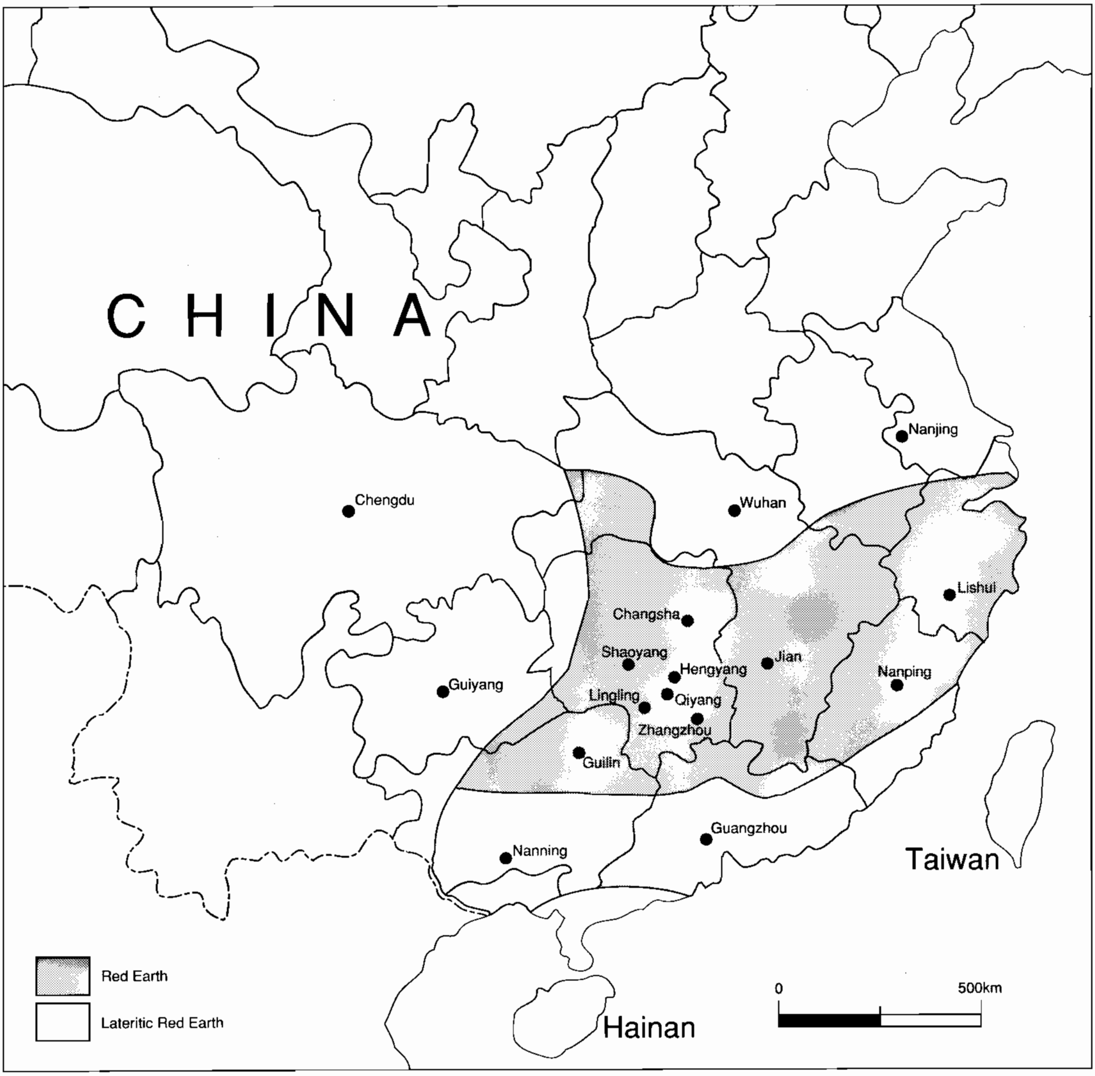

Figure 1. The location of collection sites for agroclimatic data.

is 10–20 days longer, resulting in summer-growing crops beginning to grow 5–10 days earlier. In comparison with Chengu and Guiyang, the mean annual temperature is 2–3 °C higher, the AAT is 400–800 degree-days longer and the summer-growing crops begin to grow about the same time. In comparison with Nanning and Guangzhou, the mean annual temperature is 3–4 °C lower, summer-growing crops begin to grow up to 40 days later, the duration of the period of temperatures above 10 °C is 80 days shorter and the AAT is 1600–2000 degree-days shorter.

The values of AAT are higher in the east (5700–6100 degree-days in Zhejiang, Jiangxi and Fujian Provinces) than in the west (5400–6100 degree-days in Hunan Province). The AAT values (both above 0 °C and above 10 °C) are important measures for determining the potential distribution of crops and cropping systems. In this region, the high AAT values indicate that after double-cropping rice, a third crop (such as cauliflower, barley, wheat or forage) is possible.

Mean daily temperatures rise above 10 °C from the last 10 days of March and above 15 °C from the last 10 days of April. In spring, however, regular cold fronts every 7–10 days bring low temperatures, strong winds, rain and snow. Frequent but less severe cold fronts occur in mid to late autumn.

Table 1. Duration of sunshine (h) and solar radiation ($MJ/m^2/month$) in the region (Weather Bureau of Hunan Province, 1981).

Place	Sunshine (h)					Radiation ($MJ/m^2/month$)				
	Jan.	Apr.	Jul.	Oct.	Ann.	Jan.	Apr.	Jul.	Oct.	Ann.
Changsha	72	100	240	131	1520	209	347	638	356	4400
Hengyang	79	99	273	144	1664	203	335	666	351	4430
Shaoyang	88	107	260	147	1677	193	334	607	333	4180
Lingling	76	98	261	144	1623	202	335	643	354	4390
Zhangzhou	79	101	273	140	1614	209	336	665	350	4380
Qiyang	73	100	264	138	1613	196	335	651	346	4370
Guilin	84	83	228	173	1663	215	309	581	409	4440
Lishui	119	134	256	162	1813	244	393	631	376	4580
Nanping	105	116	243	162	1710	239	362	613	385	4480
Jian	95	109	278	170	1814	223	348	674	394	4650
Nanjing	148	171	228	193	2155	274	451	580	414	5040
Wuhan	125	147	257	175	2058	242	409	633	383	4900
Chengdu	73	114	163	66	1228	176	350	467	222	3610
Guiyang	55	132	191	95	1371	175	396	516	280	3980
Nanning	93	107	223	192	1827	242	352	576	446	4790
Guangzhou	139	89	231	211	1909	301	325	592	479	4880

Table 2. Photosynthetic potential productivity (PPP) of the region.

Place	Ann. PPP t/ha	Period ⩾ 10 °C	Radiation (⩾ 10 °C) MJ/m^2	PPP t/ha *
Changsha	97.6	23/3–21/11	349.0	77.5
Hengyang	98.3	22/3–23/11	355.8	79.1
Shaoyang	137.9	26/3–21/11	329.8	73.3
Lingling	97.4	24/3–25/11	351.6	78.1
Zhangzhou	97.3	23/3–22/11	347.1	77.2
Qiyang	97.0	20/3–26/11	355.7	79.0
Guilin	98.6	15/3– 2/12	367.4	81.6
Lishui	101.7	18/3–25/11	361.9	80.4
Nanping	99.5	6/3– 6/12	376.9	83.7
Jian	103.2	19/3–26/11	376.1	83.5
Nanjing	112.0	1/4–11/11	363.3	80.7
Wuhan	108.7	26/3–16/11	375.4	83.3
Chengdu	80.1	16/3–22/11	288.7	64.1
Guiyang	88.5	26/3–16/11	307.8	68.4
Nanning	106.4	13/2– 5/1	448.9	99.7
Guangzhou	108.5	10/2– 9/1	458.9	101.9

* Ideal yield = 0.04 × PPP, where 0.4 is the maximum coefficient for grain yield of crops

Table 3. Thermal resources of the region.

Place	Mean temp.			Extreme temp.		Period and AAT (>10 °C)		Frost-free period
	Jan.	Jul.	Ann.	Ext. H	Ext. L	Days	AAT	Days
Changsha	4.7	29.7	17.2	40.6	−11.3	243	5457	275
Hengyang	5.6	29.8	17.9	40.8	−7.9	248	5672	293
Shaoyang	5.1	28.5	17.1	39.5	−10.5	241	5350	277
Lingling	5.8	29.1	17.8	43.7	−7.0	247	5584	311
Zhangzhou	5.8	29.2	17.8	41.3	−9.0	245	5563	290
Qiyang	6.1	29.6	18.1	40.0	−8.4	252	5759	292
Guilin	7.9	28.3	18.8	39.4	−4.9	263	5941	309
Lishui	6.3	29.4	18.1	41.5	−7.7	252	5705	256
Nanping	9.1	28.5	19.3	41.0	−5.8	276	6165	301
Jian	6.2	29.5	18.3	40.2	−8.0	253	5802	281
Nanjing	2.0	28.0	15.3	40.7	−14.0	225	4889	224
Wuhan	3.0	28.8	16.3	39.4	−18.0	236	5233	238
Chengdu	4.9	24.0	15.3	37.5	−7.8	235	4638	271
Guiyang	5.5	25.6	16.2	37.3	−5.9	253	5107	278
Nanning	12.8	28.3	21.6	40.4	−2.1	330	7483	342
Guangzhou	13.3	28.4	21.8	38.7	0.0	338	7661	345

Rainfall

If solar radiation and temperature are ideal for plant growth, precipitation is the decisive factor controlling yields. This region has abundant rainfall, both in terms of the annual mean of 1300–1700mm and the distribution (Table 4). The annual rainfall of the region is higher than in Jiangsu, Hubei, Sichuan and Guizhou Provinces and similar to that of Guangdong and Guangxi Provinces. During the main growing season, from April to September, rainfall averages 850–1200mm (65–70% of the annual total). December and January have the lowest monthly totals, averaging 50–60mm/month. Between 600–800mm falls in May and June (45–50% of annual total), mostly in heavy storms. However, from July to September, there is a drought with an average of 250–400mm (less than 25% of the annual total). The surplus of rainfall in spring and the deficit in late summer emphasise the need for measures to store water as well as measures to control flooding and waterlogging.

The annual relative variability of rainfall (RVR), which ranges from 15–20%, has a clear seasonal pattern. The RVR is greater in months where rainfall is low and vice versa. In April–June, the RVR averages 30–45% whereas in August–September it averages 60–90%.

Forage adaption to the agroclimate of the region

Solar radiation. Most annual and perennial forages are light-demanding, growing vigorously in conditions of greater than 14 hours of sunshine per day (Beijing Agricultural University 1982). In this region, only the low radiation levels caused by cloudy weather in spring and early summer will affect the growth of autumn or spring sown forages.

Temperature. The optimum temperatures for photosynthesis are 20–25 °C and the maximum should be below 35 °C. When temperatures are below 10 °C photosynthesis is severely inhibited and below −20 °C, photosynthesis ceases. The optimum temperatures for respiration are between 30–40 °C. The mean temperatures of the hottest and coldest months in this region are 28–30 °C and 5–9 °C respectively, which are not prohibitive for growth of forages. However, the recorded extremes of 43 °C and −12 °C would damage forages.

Forages with a growth period of 100–120 days need AAT (>5 °C) of about 2400 degree days. The thermal resources of the agroclimate of the region can meet the requirements of these forages (Table 5). The AAT (>5 °C) for autumn-sown forages is 3000 degree-days, compared with 2850 for spring-sown forages.

Table 4. Rainfall patterns of the region.

Place	Rainfall (mm)						RVR (%)*		
	Jan.	May	Apr.-Sep.	Apr.-Jun.	Jul.-Sep.	Ann.	Apr.-Jun.	Jul.-Sep.	Ann.
Changsha	59.1	230.8	913.4	621.3	292.1	1389.8	28-37	59-73	16
Hengyang	60.9	213.2	834.7	587.4	247.3	1337.4	29-69	61-93	16
Shaoyang	51.8	235.4	882.7	605.1	277.6	1327.5	36-51	54-90	15
Lingling	65.7	234.1	916.7	625.4	329.6	1411.9	39-43	53-92	18
Zhangzhou	65.8	210.0	952.7	617.6	335.1	1469.8	42-47	65-70	22
Qiyang	54.4	212.3	839.3	573.6	265.7	1275.6	30-50	54-71	15
Guilin	56.9	353.8	1413	947.8	465.2	1900.3	34-38	42-55	14
Lishui	51.9	229.5	1019	643.0	375.8	1427.0	30-44	51-77	17
Nanping	57.1	300.4	1195	811.2	383.8	1663.9	42-46	47-67	16
Jian	54.8	268.3	992.8	691.0	301.8	1457.5	33-51	68-74	18
Nanjing	30.9	100.2	754.1	356.4	392.8	1031.3	35-50	52-56	17
Wuhan	34.9	161.9	863.2	511.4	351.8	1204.5	30-48	59-86	19
Chengdu	5.9	88.6	838.2	250.6	587.6	947.0	27-41	39-47	12
Guiyang	19.2	194.3	927.7	528.2	399.5	1174.7	38-47	29-41	15
Nanning	38.0	186.8	1038	508.7	529.5	1300.6	37-63	42-60	15
Guangzhou	36.9	293.8	1391	756.6	634.5	1694.1	29-45	39-58	17

* RVR = Relative variability of rainfall $= \frac{1}{\bar{x}} \times \frac{1}{n} \times \Sigma|x_i - \bar{x}| \times 100\%$

$\bar{x}$ = mean for all years   n = number of years

x_i = value for year i

Table 5. AAT (>5 °C) during the growth period at selected sites in the region.

Location		Growth period (days)
Early spring-sown	1/4-31/7	122
Hengyang	2898.9	
Qiyang	2912.3	
Lingling	2865.7	
Late spring-sown	11/5-20/8	102
Hengyang	2785.1	
Qiyang	2808.3	
Lingling	2708.1	
Autumn-sown	11/10-10/6	243
Hengyang	2985.3	
Qiyang	3059.9	
Lingling	2922.4	

Precipitation. Most forages adapted to this region are mesophytes (requiring moderate amounts of water, such as many clover species (*Trifolium* spp.), cocksfoot (*Dactylis glomerate* L.) and ryegrass (*Lolium* spp.)) or xerophytes (water-stress tolerant such as *Roegneria* spp, meadowgrass (*Poapratensis*), lucerne (*Medicago sativa*) and bush clover (*Lespedeza* spp.)). For all these species 1000-1500 mm of annual rainfall is sufficient. Whilst the annual average for this region is greater than this, drought in late summer and early autumn may be disadvantageous to forage growth.

Evaluation of several adapted forage species. Some drought tolerant grasses and shrubs already exist on the hilly, red-yellow soils, of which the most common species are *Imperata cylindrica*, *Arundinella hirta* and *Paspalum thunbergii* (Anon, 1980). The main sown forage species in this region are perennial, winter-growing grasses and legumes (such as ryegrass, cocksfoot, white clover and red clover) and annual heat-tolerant species (such as sudangrass, pearl millet and common vetch) (Su Jiakai 1983).

Perennial ryegrass (*Lolium perenne*) is the dominant grass species planted in the temperate parts of the region and grows well in the hilly areas of the Yangtze Valley. There is a large area of sown pastures based on perennial ryegrass at Nanshan, Hunan Province. It is adapted to wetter areas with warm winters and will not survive temperatures lower than −15 °C or higher than 35 °C. It is well suited to the hilly, higher altitude areas where temperatures are less extreme.

Red clover (*Trifolium pratense*) is planted in large areas of Yunnan, Guizhou and Hubei Provinces (Chen Shaoping 1989). It is intolerant of the high temperatures and heavy rainfall that occur in summer on the plains and low hills and is susceptible to frost.

White clover (*Trifolium repens*) is the most important leguminous forage for mountain pasture in the region because of its high nutritive value and persistence. It grows well in areas with more than 1000 mm rainfall and will survive winter temperatures as low as −15 °C.

Sudangrass (*Sorghum sudanensis*) is an annual that grows well in both southern and northern China. It is intolerant of cold (optimum temperature for growth is 20–30 °C) and will not germinate at temperatures below 8–10 °C. Seedlings are sensitive to temperatures below 2–3 °C but mature plants have a degree of cold hardiness. An extensive root system means that it will grow in areas that receive less than 250 mm rainfall. This capacity for drought resistance means that it can be sown in early May to avoid late cold weather.

Climatic potential productivity (CPP) of forages

The CPP of forage is defined as the highest potential yield of forages based only on climatic factors. The four main factors to consider are solar radiation, temperature, precipitation and CO_2. Generally, CO_2 is abundant and well distributed. So, CPP can be divided into three levels: photosynthetic potential productivity (PPP), photosynthetic-temperature potential productivity (PTPP) and a preciptation function (f(w)).

PPP was defined earlier in this paper as the highest potential crop yields based on solar radiation levels under optimum temperature and moisture conditions. PTPP is the highest potential crop yields based on both solar radiation and temperature under optimum moisture conditions. PTPP (kg/ha) can be calculated as:

$$PTPP = PPP \times f(T_i) \times f(G_i)$$

where $f(T_i)$ is a temperature function to account for the effects of temperature on PPP and $f(G_i)$ is a leaf area index function to account for the effects of leaf area on PPP (Xu Xuegong 1990). $f(T_i)$ can be calculated as:

$$f(T_i) = \begin{cases} 0 & T \leqslant T_1 \text{ or } T \geqslant T_2 \\ (T_i - T_1)/(T_2 - T_1) & T_1 < T < T_2 \end{cases}$$

where T_i is the monthly mean temperature and T_1 and T_2 are the lowest and highest temperatures for photosynthesis. $f(G_i)$ can be calculated as:

$$f(G_i) = 1 - \exp(-kL)$$

where k is a coefficient of solar radiation intercepted by leaves and L is the leaf area index. Based on climatic records from 10 stations, the PTPP of spring-sown forages (growth period of six months) is about 82 500 kg/ha, which is 86% of PPP for that growth period. The PTPP autumn-sown forages is about 90 000 kg/ha, which is 76% of PPP for that growth period.

There is a significant difference between harvested yield and PTPP because of the effects of moisture availability, especially in this region where rainfall is very unevenly distributed throughout the year. The CPP, defined earlier as the highest potential yield of forages based only on climatic factors, can be calculated as:

$$CPP = PTPP \times f(w)$$

where f(w) is a moisture function to account for the effects of rainfall on PTPP and is calculated as:

$$f(w) = \begin{cases} W/E_0 & W \leqslant E_0 \\ 1 - (W - E_0)/3E_0 & E_0 < W < 4E_0 \\ 0 & W \geqslant 4E_0 \end{cases}$$

where W is monthly rainfall and E_0 is potential evapotranspiration (Xu Xuegong 1990).

The CPP of spring-sown forages is about 60 750 kg/ha; 67% of PTPP and 52% of PPP (Table 6). Based on the climatic records from the 10 stations, the CPP of autumn-sown forages is about 7500 kg/ha higher than for spring-sown forages in this region. In Hunan, however, the CPP of spring-sown forages is 2250 kg/ha higher than for autumn-sown forages. The CPP in Guilin for either spring-sown or autumn-sown forages is 10 500–22 500 kg/ha lower than other regions because of the effects of excess rainfall.

Table 6. Climatic potential productivity (CPP, t/ha) in the region.

Place	PTPP Autumn-sown	PTPP Spring-sown	CPP Autumn-sown	CPP Spring-sown
Changsha	86.4	79.8	60.7	60.6
Hengyang	89.6	83.5	56.8	56.7
Shaoyang	82.2	85.1	56.7	64.9
Lingling	88.4	86.5	60.9	65.4
Zhangzhou	87.7	84.7	62.3	63.7
Qiyang	89.2	82.6	61.1	60.1
Guilin	92.6	81.6	49.6	45.8
Lishui	93.9	80.2	72.8	61.1
Nanping	94.2	80.6	65.9	57.5
Jian	98.0	86.0	61.1	56.3

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A Simple Agro-climatic Model for Forage Production on the Red Soils of South Central China

P.M. Horne*

ONE of the problems facing forage development in a new area such as the red soils region of south-central China is identifying the major limiting features of the land resources and developing strategies to overcome those limitations. Such strategies may include modifying the prevailing conditions to alleviate the limitations (e.g. through the addition of lime and fertilizers) and selecting species that can tolerate the limiting conditions (for example, acid-tolerant forage species such as *Cassia rotundifolia* cv Wynn). A similar approach can be applied to the climatic resources of the region. Climatic factors (such as temperature, rainfall and light) will be the primary determinants of the success or otherwise of forage production in the red soils region.

Establishment and persistence are the two main stages of forage production. Of the two, establishment is the more sensitive to variations in climatic factors. Establishment failure often occurs during the stages of early seedling growth and survival, primarily as a result of moisture stress (Campbell et al. 1987). Unlike other environmental factors (such as soil type, topography and drainage), climatic factors such as rainfall are largely beyond modification by human intervention and have a very large inherent variability. Therefore, selection of the most reliable times of year for sowing becomes essential to ensure the success of forage establishment.

For two main reasons, a reassessment of the climate for forage production in the red soils region was necessary. Firstly, of the two most important climatic variables for forage establishment (soil moisture and temperature), soil moisture is the most variable. As the variation of rainfall between years can be high, field experiments to select the best sowing times may take many years to produce reliable results. Secondly, the prevailing climatic classification system in China defines the climate of the red soils region as sub-tropical mainly on the basis of heat sums above 10°C, also known as active accumulated temperatures (Leng Shilin et al. these proceedings; Domros and Peng 1988). Whilst this classification may be appropriate for irrigated summer crops and annual dryland crops, perennial forages must survive the whole year. Therefore, low winter temperatures and drought stress are also important factors to consider in selecting species for the region.

Computer modelling, combining the analysis of long-term climatic data (rainfall, evaporation, temperature and irradiance) with the specific requirements of forage species, enables the calculation of risks associated with different sowing times and the severity of stress periods through which perennial species would have to persist. This paper presents the results of one such simple model used to predict the climatic limitations to forage establishment production in the red soils region.

Materials and Methods

A soil water budget model was used to calculate soil moisture contents for individual soil layers and the whole profile using long-term (30 years) precipitation and evaporation data from two sites within the red soils region (Jianyang in Fujian Province and Hengyang in Hunan Province) (Fig. 1). The model is based on another developed by McCaskill (1987) and consists basically of a layered 'bucket model' of soil moisture. The model requires the soil parameters θ_{LL} (soil moisture at the lower limit, defined as the moisture content at a suction of -1500 kPa; $cm^3\ cm^{-3}$), θ_{UL} (soil moisture at the upper limit, defined as the moisture content at a suction of -30 kPa; $cm^3\ cm^{-3}$) and θ_{SAT} (saturated soil moisture; $cm^3\ cm^{-3}$) for each predefined layer of the soil. For the purposes of this model, the profile (0–60 cm) was sub-divided into layers 5 cm deep.

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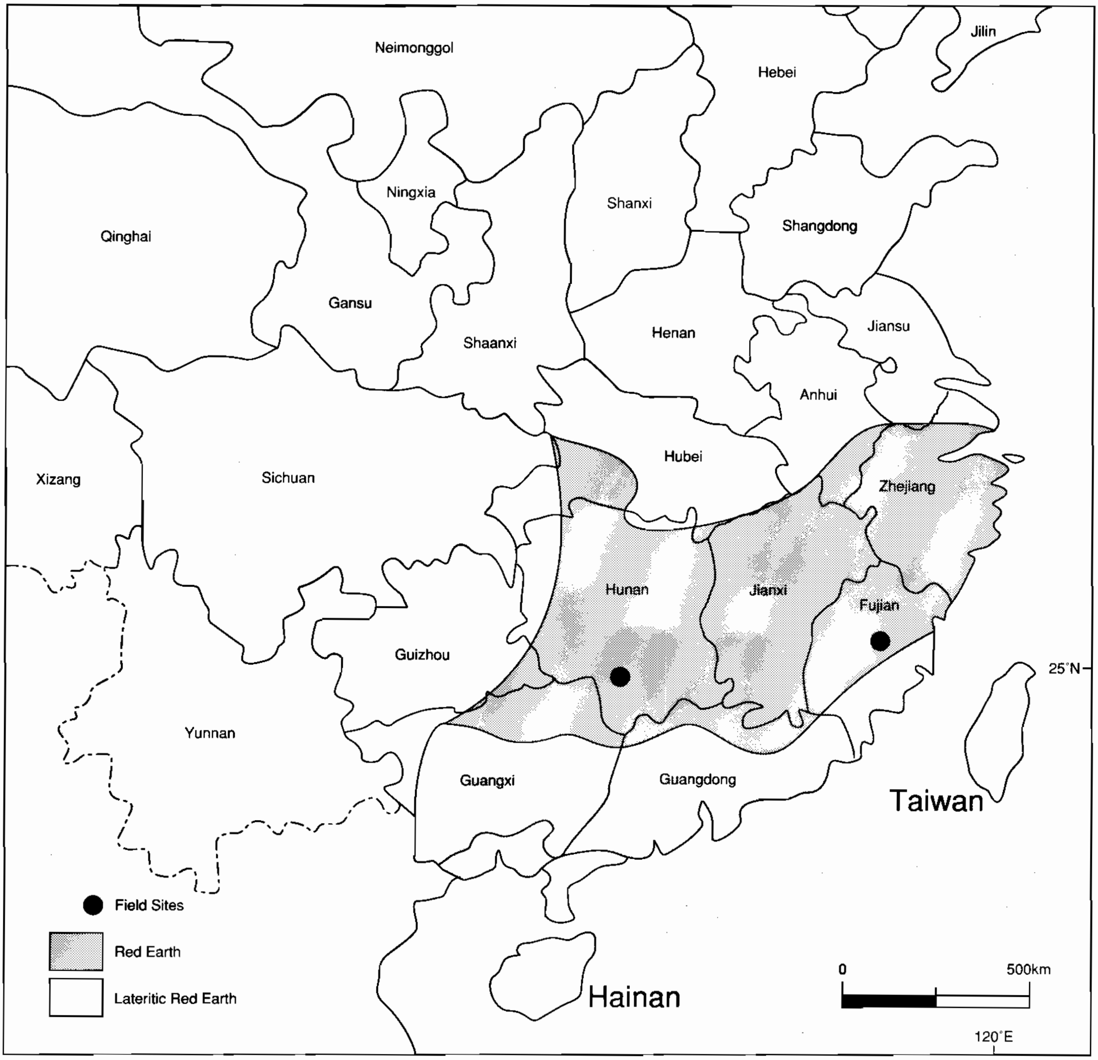


Figure 1. Map of southern China showing the section of the red soils region described in these Proceedings.

For each timestep of the model (10 days), rainfall is distributed down through the soil profile, filling the top layer first. If the inward flux is larger than the holding capacity of the layer ($\theta_{SAT} - \theta_{LL}$), the actual soil water in the layer (θ_i, $cm^3\ cm^{-3}$) is increased to θ_{SAT} minus drainage (assumed to occur at 3% per day between θ_{SAT} and θ_{UL}). The flux entering the next layer then becomes the flux entering the current layer minus the proportion retained plus drainage from the current layer. If the flux into a layer is less than the excess water holding capacity ($(\theta_{SAT} - \theta_{LL}) - \theta_i$), the flux is added to θ_i and flux to the next layer becomes zero, if the new θ_i is still less than θ_{UL}. If the new θ_i is between θ_{SAT} and θ_{UL}, drainage occurs to the next layer and the actual soil water content of the current layer equals θ_i plus flux into the layer minus drainage.

After precipitation in a particular timestep is budgeted into all layers of the soil, the evaporative demand is also distributed between layers. Pan (or potential) evaporation (E_{PAN}) is converted to actual evapotranspiration (E_T) using the empirically derived relationship of Smith and Johns (1975) which reduces pan evaporation in proportion to the profile soil moisture content (θ_p, $cm^3\ cm^{-3}$):

$$\frac{E_T}{E_{PAN}} = 0.2 + 0.8 \min \left\{ 1, \frac{F_\theta}{0.88} \right\}$$

where

$$F_{\theta,t} = \left\{ \frac{\theta_i - \theta_{LL}}{\theta_{UL} - \theta_{LL}} \right\}$$

This two-stage linear function shows that the first 12% of available water is freely available. Below this point, E_T as a percentage of E_{PAN} declines to a minimum of 20% at θ_{LL}.

The distribution of E_T between the layers is then a function of the existing moisture content of each layer and the depth of each layer:

$$\theta_i = \theta_i - E_i$$

where E_i is the evaporative loss factor for layer i and is calculated as:

$$E_i = (F_{\theta,i})^2 \times (D_i)^2 \times E_T \times \left\{ \frac{E_T}{\Sigma E_i} \right\}$$

where D_i is a unitless depth factor describing the reduction in evaporative loss as a function of the depth of layer i and $F_{\theta,i}$ is the actual soil moisture content of layer i ($cm^3\ cm^{-3}$). The sum of the E_i for all layers (ΣE_i) is always less than or equal to E_T since both D_i and $F_{\theta,i}$ are constrained to lie between 0 and 1.

Once these final θ_i have been calculated for a single timestep of the model, they are used to produce a soil moisture index (SMI) for the whole profile which indicates the relative availability of soil water for plant growth in the profile. The SMI is calculated as:

$$SMI = \min(1, 1.15\ F_\theta)$$

This relationship is based on a common model for the availability of soil moisture (Hanks and Ashcroft, 1986) which indicates that between θ_{UL} and $0.87(\theta_{UL} - \theta_{LL})$, soil moisture is freely available for plant growth. Below this point, there is a linear decline in availability to zero availability at θ_{LL}. SMI therefore varies from a value of 1, indicating that soil moisture is freely available for plant growth down to a minimum of zero, indicating that soil moisture is completely unavailable for plant growth.

A temperature index (TI) was developed for temperate forage species using a relationship similar to that first suggested by FitzPatrick and Nix (1970). The relationship is illustrated in Figure 2. The optimum temperature for germination and early growth of this general relationship is 22 °C. Mean daily temperatures for each ten-day period were converted to a temperature index using linear interpolation between the values shown in Figure 2. The relationship in Figure 5 is unlikely to apply to mature plants which are known to have broader optimum temperatures for growth (7 to 30 °C) than seedlings (McCaskill 1987).

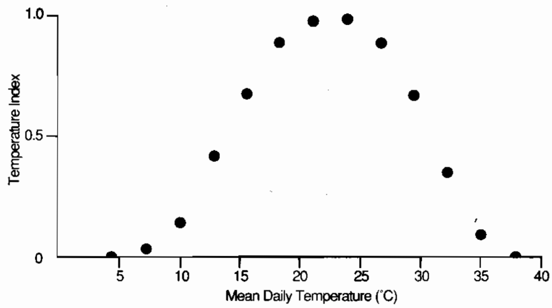


Figure 2. Relationship between mean daily temperature and temperature index.

A light index (LI) was also calculated using the relationship illustrated in Figure 3. Whilst there are marked differences between species in the response of photosynthesis to irradiance, this relationship was found to be a useful approximation for light intensities up to full daylight.

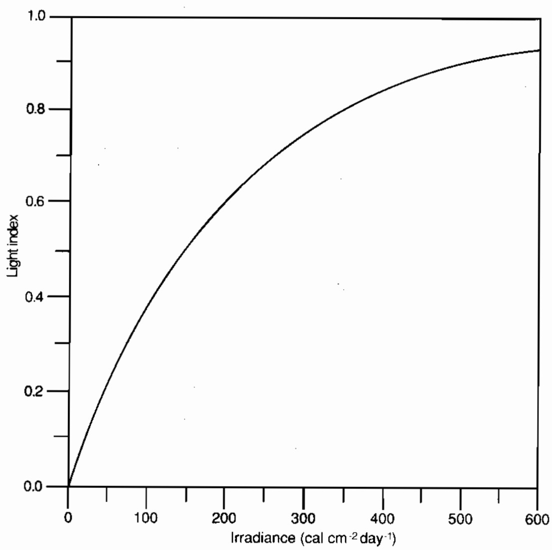


Figure 3. Relationship between irradiance and light index.

The three indices were then combined into a 'growth index' (GI) that indicates the degree of restriction placed on establishment by sub-optimal mean-temperatures, light intensities and soil moisture conditions:

$$GI = SMI \times TI \times LI$$

GI can range from 0 (climatically-induced establishment failure) to 1 (no limitations to establishment success from mean-temperature or soil moisture conditions). It does not account for climatic extremes (such as daily minimum temperature) which can have a significant impact on establishment success.

Results and Discussion

Mean monthly rainfall and pan evaporation (Class A) data for the two locations show that the Hunan site has a more continental climate than the Fujian site, with spring and summer dominant rainfall followed by a late summer drought (Fig. 4). The Fujian site receives significantly more spring rainfall as the result of typhoons and the late summer drought is less severe than in Hunan. Rainfall intensities and, hence erosivity, are greatest during the period of spring and early summer rainfall, especially in Fujian where intensities can reach 120 mm/hour.

The temperature indices reflect the continental influences on the climate in Hunan (Fig. 5). Mean daily temperatures range from 5 °C in January to

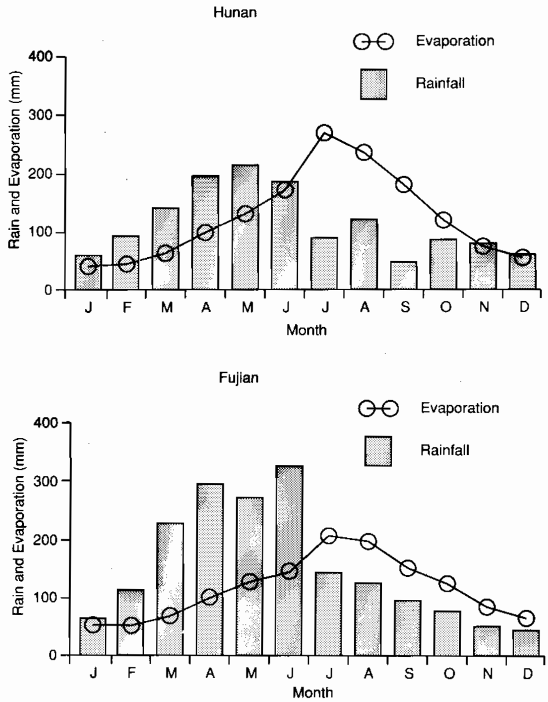


Figure 4. Mean monthly rainfall and evaporation data for the sites in Hunan (a) and Fujian (b) provinces.

30 °C in July, compared with 7 °C and 28 °C respectively in Fujian. Both the mid-summer and winter depression of temperate forage growth due to temperatures outside the optimal range are more severe in Hunan than Fujian. The frost free period per year in Fujian is greater than in Hunan (300 versus 248 days respectively).

Light rarely limits forage establishment except in conditions of extreme competition. However, low light levels can limit subsequent production. The data in Figure 5 indicate that light limitations will occur during the period from November to March and, although not severe, the yield depression will be greater in Hunan (mean irradiance in February of 150 cal/cm^2/day) than Fujian (mean irradiance in February of 175 cal/cm^2/day).

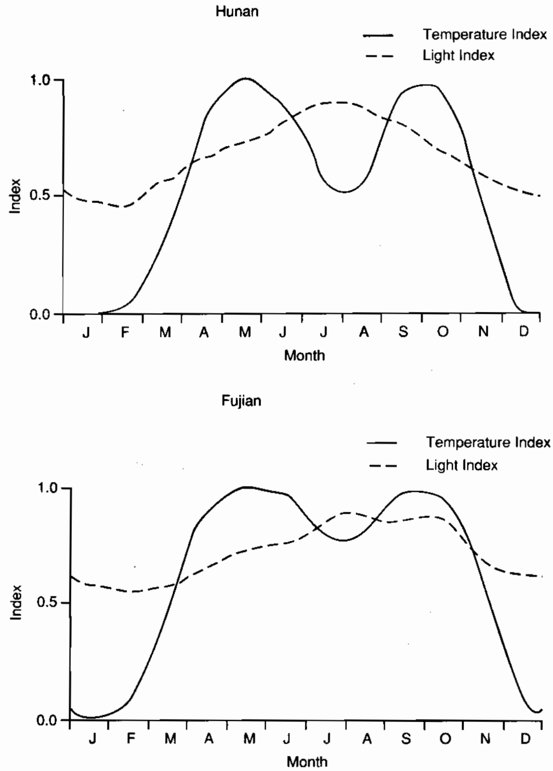


Figure 5. Temperature and light indexes for Hunan (a) and Fujian (b) provinces.

Annual (between years) and seasonal (between seasons) variations in rainfall and evaporation result in annual and seasonal variability in the profile SMI. This variability can be described using the median SMI and upper and lower quartiles (Fig. 6). The median gives a more accurate indication of the most frequent soil moisture conditions at any time of the year than the mean because rainfall events (and hence soil moisture) are rarely symmetrically distributed. Fluctuations in the curves in Figure 6 result from the use of monthly evaporation data with ten daily rainfall data. In Fujian, the median SMI are high for most of the autumn, winter and spring, only dropping to levels that will significantly inhibit establishment and growth of forages in mid-summer. In Hunan, however, the late-summer drought (July–October) is longer and much more severe (due to very high rates of evaporation) and forages susceptible to moisture stress are unlikely to survive.

In addition to this seasonal variation in SMI, there is significant annual variation, as indicated by the quartiles in Figure 6. At both sites, variability around the median SMI in spring is low, indicating that not only are soil moisture conditions ideal for forage establishment and growth, but that these conditions are very reliable. In autumn and early winter, however, the variability around the median is high, indicating that while the median SMI is high, some years will be very dry. In Fujian, in particular, 25% of years in autumn (that is, those years below the lower quartile) will be significantly drier than in summer.

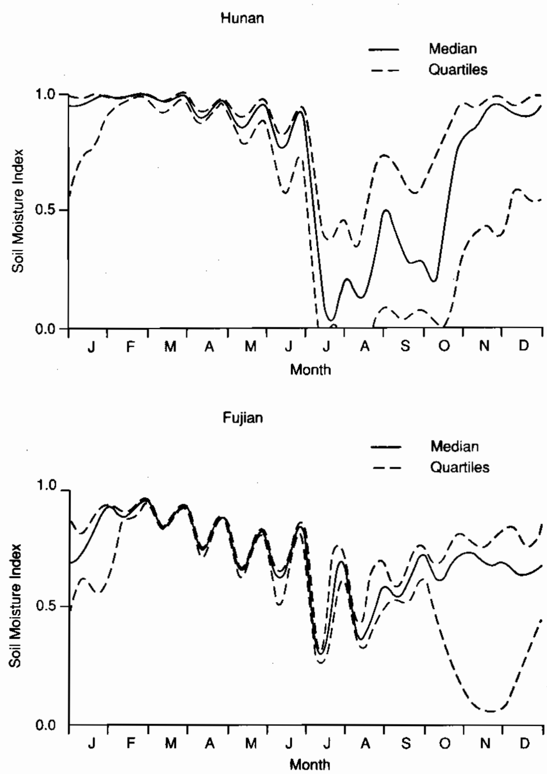


Figure 6. Soil moisture indexes and quartiles for Hunan (a) and Fujian (b) provinces.

This difference in variability of SMI between spring and autumn is clearly illustrated in Figure 7.

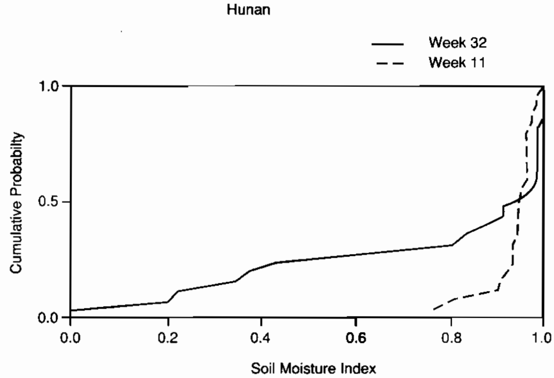


Figure 7. Cumulative probability distributions of SMI for a 'week' in spring and a 'week' in autumn ('week' 32) in Hunan Province.

The cumulative probabilities of occurrence of SMI are plotted for two 'weeks' (10 day periods) in Hunan that had the same median SMI (SMI = 0.92; one in April ('week' 11) and one in November ('week' 32)). The curves give the probability of SMI being less than a particular value. Thus, for example, Pr(SMI < 0.6) is 0 for 'week' 11 but 0.25 for 'week' 32. This figure shows that sowing forages in spring could be described as a strategic activity (that is, it can be reliably carried out each year), since Pr(SMI < 0.8) in spring is 0 compared with 0.3 for autumn.

For temperate forages, it is important to consider the reliability of SMI for autumn sowings since there will be a longer period of moderate temperature conditions to aid establishment prior to the onset of the summer drought. In Figure 8, the cumulative probabilities of SMI are plotted for both sites for the first week in October (being a likely time for autumn sowings). The median SMI (as indicated by a probability of 0.5) at Hunan is 0.15 compared with 0.6 for Fujian. There is also a large difference between the two sites in the probabilities of occurrence of low soil moisture conditions. For example, the Pr(SMI < 0.4) is 0.55 in Hunan but only 0.20 in Fujian. These figures clearly indicate that autumn sowing conditions are mostly more favourable in Fujian than Hunan. However, the curves also show that Pr (SMI > 0.8) is 0 in Fujian but 0.20 in Hunan. That is, in 20% of years, the SMI is greater than 0.8 in Hunan. This indicates that autumn sowings in Hunan might be carried out successfully as a tactical activity (one that can be carried out in particular years). If seed of temperate forage species is sown in autumn when soil moisture conditions are adequate, then establishment is likely to be more successful than from sowings in the subsequent spring. This has been verified from experiments in Hunan.

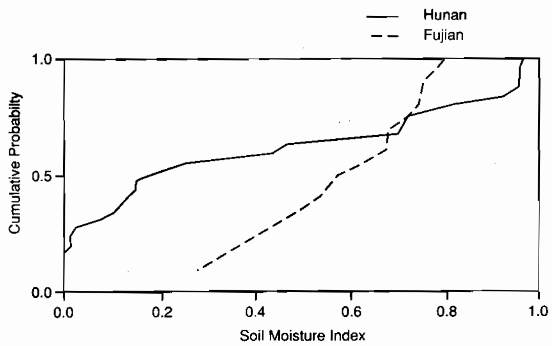
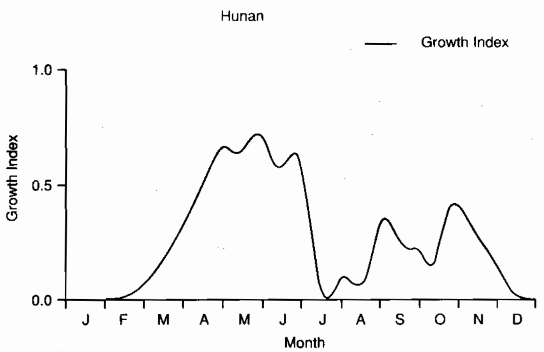


Figure 8. Cumulative probability distributions of SMI for the first week in October in Hunan and Fujian provinces.

The growth index represents the combined effects of temperature, soil moisture and light on the growth of forages at these two sites (Fig. 9). At both sites, growth is limited from December to February by low temperatures. In Fujian, apart from a moderate summer depression of growth (July–August) due to the combined effects of high temperature and low soil moisture, growth conditions from March to November are satisfactory. In Hunan, conditions for growth from April to June are ideal but the summer depression in growth is longer and more severe than



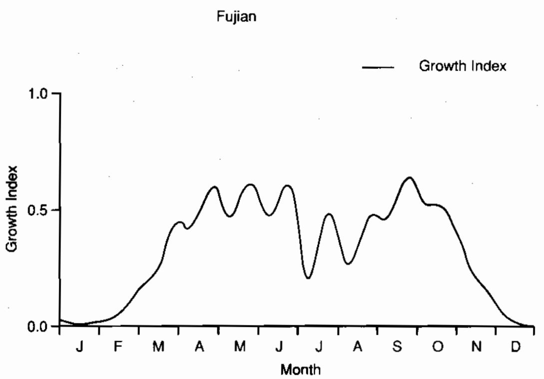


Figure 9. Growth indices for Hunan (a) and Fujian (b) provinces.

in Fujian. Growth conditions in autumn are also not as favourable as in Fujian.

Conclusions

The use of this computer modelling approach has allowed the calculation of probabilities of favourable conditions for establishment and growth of forages in the red soils region. The main conclusions are:

1. Temperate forages may be successfully established in February and March every year at both locations. However, they must be species that can both establish quickly and tolerate moisture stress if they are to survive the late summer drought, especially in Hunan. Growth during summer is likely to be severely limited.
2. Establishment of September and October-sown temperate forages will only be successful if sown in those years when ideal temperature and soil moisture conditions coincide. In those years, subsequent establishment and persistence through the summer may well be more successful than forages sown in the following spring (especially in Hunan).
3. Tropical forages may be successfully established in April and May to produce high yields throughout the summer, but will require a degree of cold tolerance to persist. The relatively low frequency of severe frosts (especially in Fujian) may assist persistence of the tropical species.
4. The results have highlighted the large variations in climatic conditions for establishment and persistence that occur across the red soils region. Forage technologies for one location may not be suitable for another.

Further developments are required in this modelling approach:

1. Forage seedling survival and subsequent establishment are a function of soil moisture conditions at planting and the duration of subsequent dry periods (Frasier et al. 1984). The occurrence of high median SMI throughout spring may hide the fact that in some years good soil moisture conditions at sowing are followed by moisture stress. Ideal conditions of SMI (both level and duration) need to be defined so that the probability distribution of these conditions can be calculated.
2. The SMI were calculated using ten daily data for a 60 cm deep soil profile. Of much greater importance for forage establishment will be for the model to calculate the SMI in the top 5 cm using daily data.
3. Forage species vary markedly in their ability to tolerate moisture stress. The model will be run to incorporate these differences in response to soil moisture tension rather than volumetric moisture content.

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Classification of Environments of Southern China and Species Performance in Southern China

Wu Xieen*

CULTIVATED perennial forage grasses are the basis for developing animal husbandry, establishing favourable agricultural ecological environments and controlling water and soil erosion.

There are many species of cultivated perennial forages which are potentially suited to the range of environments in the red soil area of China. However, the nature of the soil and climate conditions in the area restricts the range for some species. The development of a system of classification of the main cultivated perennial forage species has therefore been important as it allows the selection of the best species.

Through a national grasses divisions program of cultivated perennial forages a grouping has been achieved of introduced and natural forage species for South China. This has been achieved through a series of replicated trials carried out in various areas of southern China and the results of these trials subjected to assessment by the author.

Assessment process

The national grasses divisions program was conducted in four provinces and one autonomous region — Fujian, Guangdong, Guangxi, Hainan and in the southern part of Yannan. The annual average temperature at the sites ranged from 16 °C in the north to 26 °C in the south. The average temperature in the coldest month (January) ranged from 7 to 21 °C with temperatures higher in the south. The average temperature of the hottest month (July) ranged from 28 to 29 °C. The annual accumulated temperature $\geqslant$ 10 °C ranged from 5500 to 6500 °C in the north and more than 6500 °C in the south. Annual rainfall ranged from 1100 to 2200mm. Because of high altitude and the nature of the topography light frosts and freezing occurs during the winter in the north. In the mountainous areas (> 600–800 m above sea-level) in the north and north-west of the study areas heavy frosts and snow occur.

The soils vary from mountainous red loam in the north to red lateritic loam in the south. Soil pH is in the range from 4.5–5.5 and all soils are low in nitrogen, phosphorus and organic matter.

Evaluation of species

Temperature, sunshine, rainfall and soil structure are the main factors determining the growth of forages. The study found that temperate grasses did not persist because of high summer temperatures. The characteristics of forages which are adapted to South China are:

(i) ability to withstand high temperatures (37–41 °C) and dry conditions during the summer and early autumn,
(ii) ability to withstand light frosts and freezing (−5– −7 °C) during the winter,
(iii) adaptation to the acid nature of the red soils,
(iv) tolerance of high rainfall and short dry spells, and
(v) ability to absorb phosphorus from soils of low P status.

Desirable characteristics are an ability to produce large amounts of quality forage on soils low in available N with minimal applications of applied N, ease of establishment and good palatability.

The evaluations showed that only tropical and subtropical forages were able to maintain high productivity and persistency. Temperate forages adapted readily to the mountainous areas (>600–800 m a.s.l.) in the north and north-west parts of South China.

After evaluation five heat resistant grasses and legumes — broadleaf paspalum, *Kazungula setaria*, siratro, *Leucaena leucocephala* and *Stylosanthes guianensis* were selected as the most suitable perennial forages. Species suited to intensive utilisation systems such as dairying included the more frost-resistant tropical species *Paspalum urvillei*, *Desmodium intortum*, *D. uncinatum*, the high yielding *Pennisetum purpureum* and the temperate perennial ryegrass.

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Establishment trial

An area of 80 ha was selected to establish planted forages in Fuching County during 1986–88. Fuching is located in the central part of Fujian Province at an altitude of 260–320 m a.s.l.. The annual average temperature is 19.7 °C (range 39 °C– – 1 °C) and the annual rainfall is 1000–1100 mm. The soil is a red lateritic loam with a pH of 5–5.5 and an organic matter content of less than 1%.

The land was ploughed and legume-grass mixtures sown. These mixtures consisted of siratro and broadleaf paspalum or *Kazangula setaria* sown into alternating rows 30–40 cm apart. The sown swards were fertilised with manure and the native pasture left unfertilised. In the second year one year old, 2 m high, leucaena trees were transplanted at 3m × 3m spacings into the sward. The pasture was fenced into six pasture plots and a rotational grazing system with native yellow cattle imposed one year after the leucaena trees were transplanted. The grazing was continuous for three years and the productivity (economics) of the system compared with native hilly pasture.

The results of the experiment were:

1. There was no significant difference in the productivity of siratro–leucaena–paspalum or siratro–leucaena–setaria pastures.

2. The time that forages remained dormant during winter was reduced from 4.5–5.5 months for the native pasture to 2–2.5 months for the sown pasture. Total fresh yields were 9.5 t/ha/yr from native pasture and 76.6 to 86.9 t/ha/yr from sown pasture.

3. The inclusion of legumes in the mixture increased the palatability and crude protein content of the herbage. Crude protein content was increased from 6.06% in the native pasture to 15.6% in the sown pasture and the crude fibre reduced from 35.7% in native to 27.6% in the sown pasture.

4. Stocking rate on the improved pasture was 0.77 ha/cow compared to 3.3–4.0 ha/cow on the native pasture. In addition to an increase in stocking rate average daily gain over the 38 day grazing period increased from 0.29 kg on the native pasture to 0.57 kg on the sown pasture.

5. The soil N content increased from 69.75 kg/ha under the native pasture to 244.2 kg/ha under the sown pasture and soil cover increased from 60–70% on the native to 90% on the sown pasture resulting in better soil protection in the latter.

Discussion

Temperature and water are the basic factors determining grassland establishment and productivity. The survival and productivity of forages are particularly influenced by maximum and minimum temperatures.

The climatic zones of South China can be broadly divided into tropical, south sub-tropical and central sub-tropical zones. The characteristics of each of these zones and the types of forage species suited to each is as follows:

(i) ⩾10 °C, annual accumulated temperature ⩾6500, highest annual temperature ⩾ 36 °C, lowest temperature > – 1 °C, annual rainfall >800 mm. Species adapted to this zone were high yielding tropical grasses with drought tolerance.

(ii) ⩾10 °C, annual accumulated temperature between 5500 °C and 6500 °C, highest yearly temperature above 36 °C, lowest temperature > – 7 °C, annual rainfall >1200 mm. Species adapted to this zone include winter-tolerant tropical and sub-tropical types.

(iii) ⩾10 °C, annual accumulated temperature <5500 °C, highest yearly temperature <34 °C, lowest yearly temperature > – 15 °C, annual rainfall >1800 mm. The temperate forages are suited to this zone.

When topography is superimposed onto these subdivisions by climate it is possible to establish four main forage suitability zones:

Zone 1. The hilly and plains areas of southern parts of Fujian, Guangdong, Guangxi and the whole of Hainan constitute this zone. The species most suited to the zone are siratro, *Leucaena leucocephala*, *Stylosanthes guianensis*, setaria, broadleaf paspalum and elephant grass.

Zone 2. This zone includes the hilly and mountainous areas in northern parts of Fujian, Guangdong and Guangxi provinces. Species suited to this zone include *Desmodium intortum*, *D. uncinatum*, *Leucaena leucocephala*, broadleaf paspalum and *Paspalum urvillei*.

Zone 3. This zone includes the mountainous area >600–800 m a.s.l. of the north and northwest parts of Fujian, Guangdong and Guangxi provinces. White clover, perennial ryegrass and orchardgrass are suited to this zone.

Zone 4. The hilly and mountainous areas of southern Yunnan constitute this zone. Siratro, stylosanthes, broadleaf paspalum and elephant grass are adapted to this region.

Soil Erosion and Revegetation in the Hilly Area of South China

Lu Xixi and Shi Deming*

THE hilly area of south China, located in the tropics and subtropics with favourable climatic conditions, is one of the important bases of agriculture, forestry and animal husbandry in China. However, owing to a number of environmental and historical factors, soil erosion has developed over several decades and, as a result, the area has become one of the most seriously degraded areas in China. Severe erosion has resulted in a sharp decrease, even total loss, of soil productivity leading to large areas of waste land. Examples are the 'red desert' on Quaternary red clay, 'white sand hills' on granite and 'bare stone hills' on red sandstone and limestone areas. The objective of this study was to evaluate the characteristics of eroded soils and their effects on plant re-establishment in order to devise measures of revegetation for different degrees of erosion.

Characteristics of Soil Erosion

Extent of erosion

The hilly area of south China is bordered by Dabian mountain in the north, Ba and Wu mountains in the west, the Yungui Plateau in the southwest and by the sea in the southeast. It includes Hunan, Hubei, Jiangxi, Anhui, Jianshu, Zhejiang, Fujian, Guangxi, Guangdong and Hainan provinces. Erosion is particularly serious in Jianxi (34 000 sq km of eroded land, amounting to 21% of total area), Fujian (140 000 sq km) and Guandong (17 000 sq km).

Types of erosion

The hilly area of south China has a variety of erosion forms and degrees of erosion intensity. Erosion forms can be related to soil parent material.

Granite. Eroded granite soils occur mainly in Jianxi, Guandong, Fujian and Hunan provinces. They have a total area of 197 200 sq km and account for 84.4% of the total area of eroded soil in south China. With 76.4% of this area being classified as having greater than moderate erosion the region is the most severely affected. It has been estimated that the annual average soil loss is 8000 to 15 000 t/sq km.

The regolith developed on granite has five layers (Fig.1): soil layer, red clay layer, white sand layer, weathering rock fragment layer and spherical weathering layer.

The red clay layer has a higher clay content than both the white sand and weathering rock fragment layers. As soon as the soil and red clay layers are eroded away, gully and landslide erosion readily

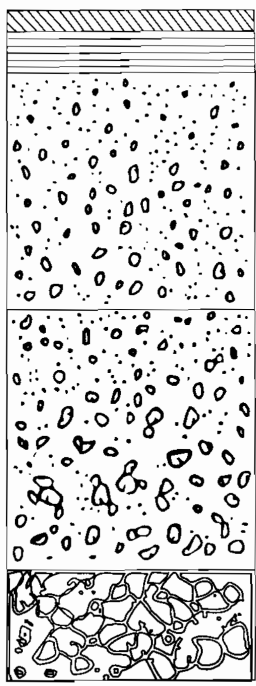

Figure 1. Profile of soil and weathering crust developed on granite.

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develops. These forms of erosion are characteristic of highly weathered granite. On non-agricultural land sheet erosion due to deforestation and intensive rainfall is more common.

Purple shale. These soils are widely distributed in Hunan, Jiangxi, Guangdong and Fujian provinces. They are very shallow. Consequently the low water-holding capacity of the profile and the proximity of slowly permeable rock near the surface result in serious runoff and soil erosion. The purple shale breaks down readily because of its heavy texture and high expansion and contraction coefficient. Therefore soil erosion is followed by a phase of dominantly mechanical weathering and incipient soil formation, but erosion prevents the development of a mature profile. The main forms of erosion found are sheet and gully, the latter having a characteristic criss-cross pattern.

Quaternary red clay. This occurs on alluvial terraces and low-lying areas mainly in Jiangxi, Zhejiang and Hunan provinces. The weathering zone can be divided into four layers (Fig 2): yellow-brown soil layer, red clay soil layer, plinthitic layer and Tertiary residuum or gravel layer. The red clay is believed to be mainly of alluvial origin. Because of their higher clay content, the soil and weathering crust have higher erosion resistance than in the case of granite. However, surface flow is large and erosion is very serious because of the poor soil permeability. Erosion forms include sheet, rill, and gully. Gullies deepen very quickly on the red clay soil layer, but slowly on the plinthitic layer. The annual average erosion is 5000–10 000 t/sq km/yr, which is lower than that of granite and purple shale areas.

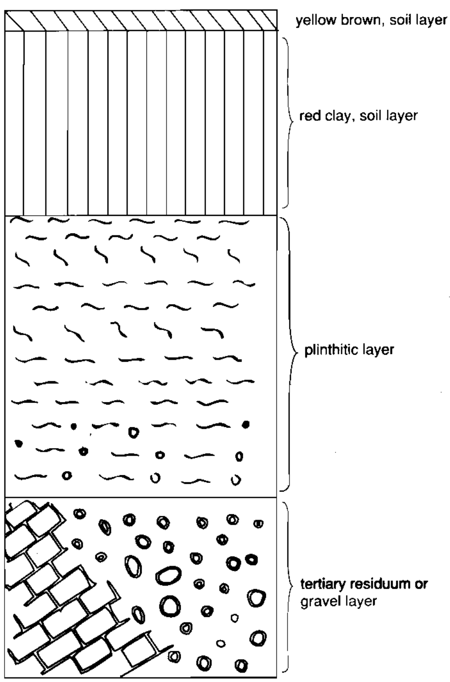

Figure 2. Profile of soil and weathering crust developed on Quaternary red clay.

Limestone. This formation is mainly distributed in Guangxi, Guangdong, Fujian and Anhui provinces. The main weathering process is chemical corrosion of carbonate minerals. Carbonate is removed in solution leaving behind a small amount of insoluble residue for soil formation. Limestone soils are thus shallow and have low water-holding capacity. Large amounts of runoff are generated and these are highly erosive. It has been estimated that the rate of erosion is ten to several hundred times the rate of soil formation.

Other parent materials. These include red sandstone, gravel stone, basalt, metamorphic rock and Xiashu loess.

Eroded Soil Properties

Organic matter and nutrient content

Erosion has exposed the B and even C horizons. Their organic matter (O.M.) and nutrient contents respectively are generally much lower than the eroded topsoil. For example the O.M. content of the B horizon of red soil developed on granite is between 0.5 and 1.0%; that of the underlying white sand and weathered rock fragment layers decreases to 0.3–0.5% or less than 0.3%. In Quaternary red clay the O.M. content of A horizon topsoil, soil and plinthitic layer is more than 1.00, 0.4 and less than 0.3% respectively. Total P and K contents are greatly affected by parent material. For instance, total P content is 0.1% in purple soil, but about 0.04% in soil derived from other parent materials.

R_2O_3 content and SiO_2:R_2O_3 ratio

Exposed white sand and weathering rock fragment layers have higher SiO_2 and lower Al_2O_3 contents than exposed red clay in the granite area. Therefore the SiO_2:R_2O_3 ratio of the former two layers is much higher than that of the latter one. On the other hand, on the Quaternary red clay Fe_2O_3 and Al_2O_3 in exposed soil increase and SiO_2 decreases as erosion becomes more severe. The reason for this is that in red clay profiles A_2O_3 increases and SiO_2 decreases with depth. Erosion has thus led to the surface soil of the eroded landscapes, the so-called 'red desert', having SiO_2:R_2O_3 ratios characteristic of old land surfaces. pH decreases with depth so that as erosion progresses the pH of exposed soil decreases. Typical pH values for slightly, moderately and severely eroded soils are 5.1, 4.7 and 4.5 respectively.

Soil texture

Easily eroded fine silt and clay are washed away when runoff occurs, as in sheet erosion. Sand and gravel are left behind so that soil texture becomes coarser. As erosion becomes more severe, different layers of the weathering profile are removed and the texture of material exposed at the surface varies accordingly. In the Quaternary red clay area, the clay (<0.002 mm) contents of exposed AB, B and C horizon are 40, 50 and 55% respectively.

In the granite area the clay content of the red clay soil layer is about 30% whereas that of the white sand and weathering rock fragment layers is less than 5%. In comparison with granite soils the higher contents of clay and Fe_2O_3 and Al_2O_3, which act as bindings agents, of the Quaternary red clay increase the formation of water-stable aggregates and hence resistance to erosion. In granite weathering zones the thick white sand layer has poor aggregate stability and erosion resistance so that once it is exposed erosion progresses rapidly.

Soil permeability

Soil permeability has a direct effect on runoff. In Quaternary red clay the saturation permeability coefficients (saturated hydraulic conductivity) of the slightly eroded soil is 7.4 cm/hour but that of the severely eroded soil is only about 0.3 cm/hour which is less than one-twentieth of the former. Therefore, erosion of Quaternary red clay increases surface runoff, which increases the potential for further erosion. Water infiltration is decreased markedly and vegetation is prone to drought. Erosion of granite soil may expose a substratum having high permeability and infiltration with relatively little runoff occurring. This leads to strong leaching which depletes the already low amount of available nutrients present. When saturated, the white sand layer has low mechanical strength and is prone to collapse to form landslides.

In shallow eroded red sandstone soils percolating water encounters bedrock and underground channels form which lead to tunnel erosion and landslides.

Available water capacity

Generally, the water held by the soil at tension between ⅓ and 15 bar is called available water capacity and can be used by vegetation. Erosion exposes material with poorer structure and lower perosity than the topsoil so that available water capacity is diminished. It has been found that in Quartenary red clay the available water capacity of an exposed B layer was 8% (gravimetric) while that of an exposed C layer was 4%. Some studies distinguish readily available water. This is arbitrarily determined on the moisture release curve as that occurring above a specific water volume of 10^{-2} ml/bar/g.

In severely eroded Quaternary red clay this critical value occurs at a tension of ⅓ bar, i.e. at field capacity. In other words virtually none of the available water is classified as readily available.

Aeration status

The aeration status of eroded soil becomes progressively poorer with continued soil loss. In Quaternary red clay slightly eroded topsoil was found to have 27% air-filled perosity (pores 0.3 mm), but severely eroded topsoil had only 10% air-filled perosity.

Revegetation Measures

According to the degree of erosion and the properties of eroded soil, different revegetation measures should be taken.

Areas without apparent erosion

In that prevention is better than cure, areas not showing signs of erosion at present should be managed so as to avoid erosion occurring in the future. In forested areas tree felling should be combined with replanting to maintain the protective tree cover. Overfelling should be prohibited in areas where the erosion hazard is high. More attention has to be paid to national land utilisation to eliminate practices conducive to erosion.

Slight to moderate erosion areas

Slightly eroded areas can often be revegetated simply by closing them off to prevent over-grazing and tree felling thus allowing trees and grass to grow under the favourable hydrothermal conditions in the hill land of south China. Moderately eroded areas have to be re-afforested in addition to closing them off. In these areas techniques such as fish scale pits, contour banks and contour trenches should be adopted to encourage tree and grass growth.

Three kinds of hill closure exist at present: 1) Total closure whereby land is closed off for a long time. This form of exclusion is used for moderately eroded areas and is particularly important in water catchment areas. 2) Seasonal closure, whereby land is closed off for part of the year, usually from spring to autumn. This strategy is particularly suited to slightly eroded areas where favourable hydrothermal conditions prevail. 3) Rotational closure, in which land is closed for periods of 3 to 5 years, is used in areas where vegetation can easily be established but where there is a shortage of fuel.

Severe to very severe erosion areas

In these areas poor growth conditions seriously restrict vegetation establishment and growth. Hill closure and low cost afforestation are insufficient on their own. Seven-year-old Masson pine planted in severely eroded soil derived from Quaternary red clay, for example, was only 60–70 cm high after a number of years and the survival rate of oil tea shrubs was less than 50% because of inadequate moisture. The roots of two-year-old *Lespedeza* were observed to form a dense mass near the surface and were unable to extract water and nutrients from depth so that growth was severely restricted. In 'white sand hill' areas on granite, tree growth is poor unless mechanical conservation measures, such as contour terraces and trenches, are undertaken.

Contour terraces, with sediment and water-holding ditches to increase their efficiency, are constructed on moderate, uniform slopes; while contour trenches are used on steep slopes where terraces are difficult to build. After engineering measures have been installed, a small amount of phosphorus fertilizer should be applied and where possible soil texture should be improved before planting trees in combination with shrubs and grass. For the control of gully erosion more comprehensive measures have to be adopted. Runoff at the head of the gully has to be diverted, the mouth of the gully dammed, and trees planted on outside slopes with crops on inside slopes. In the densely gullied area found on purple shale areas the readily weathered shale can be used for building check dams.

Where terraces have been constructed crops can be grown on the terraces with trees and grass used to stabilise the terrace faces. Where the soil cover is thin explosives have had to be used to build the terraces.

Having adequate supplies of potassium and phosphorus the purple shale soils stabilised by contouring have been used for intensive cropping. The less fertile Quaternary red clay soils should be planted to trees and grass using contour trenches and fish scale pits dug into the exposed B layer or horizon. Where the C horizon layer has been exposed, pits (30–50 cm deep × 15 cm diameter) are dug, organic manure added to create localised areas of high fertility and trees and grass planted. As in the granite areas, gully erosion in the Quaternary red clay has to be controlled by check dams combined with planting of trees and shrubs within gullies.

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Soil Water Regime and its Modification of Upland Red Soil in Southern Hunan

Zhang Maxiang*, Liu Rongle*,†, Shen Fulin*, Jiang Huadou* and Xie Liangshang*

THE hilly red soil area in southern Hunan is in the subtropical zone, with broad leaved evergreen forests and a humid monsoon climate. The dominant soils are red, most of which are derived from Quaternary red clay and granite, paddy and purple soil. Abundant rainfall and solar radiation offer great potential to develop agricultural production in the area. However, rich natural resources cannot fulfill their potential for agricultural production unless they are utilised adequately and properly.

Although annual precipitation is more than 1200 mm there are critical dry spells in autumn (July, August, September, even October). These periods of water stress often lead to agricultural production losses. The objectives of this study were therefore to determine the soil moisture regimes of the upland soils so as to minimise the problems induced by water stress.

Materials and Methods

The experimental site

Experiments were carried out at the Red Soil Experimental Station (Lat. 26°45′42″N, Long. 111°52′32″E) of CAAS in Qiyang county, Hunan Province. The altitude ranges from 150 m to 170 m. At the Station the annual average temperature is 17.8 °C and the annual average rainfall is about 1275 mm with the maximum in May and the minimum in December. Maximum monthly evaporation occurs in July. The soil studied was a deep clay red soil developed from Quaternary red clay.

General measurements

Soil samples from 0–20 cm were collected at the experimental site for determining, by pipette method, particle size distribution and amount of micro-aggregates. Infiltration rate was measured on disturbed soil samples by double-ring infiltrometer. A pressure membrane apparatus was used to prepare soil water characteristic curves.

Soil moisture regime experiment

Soil moisture regime was monitored on the north slope of the experimental revegetation hill at the Station. The experiment was initiated in 1985. Three treatments were compared.

1. A bare soil plot (BS), in which the soil was bare and undisturbed.
2. A revegetated soil plot (VS), in which the soil was undisturbed and with a vegetation cover consisting of a mix of grasses and shrubs which had been established for more than two years.
3. A ditch-pit plot (DPS), in which terraces (2.5 m wide × 0.3 m high) were built with ditch-pits on the inner sides of the terraces. The vegetation cover was similar to VS. The pits (0.3 m wide × 0.2 m long × 0.4 m deep) were at 3 m intervals and connected with ditches (0.3 m wide × 0.2 m deep).

Soil moisture of each treatment was monitored daily with gypsum blocks at soil depths of 10, 30, 50, 70 and 100 cm.

Soil erosion experiment

The experiment was carried out in runoff plots (5 m wide × 13 m long) in the tea plantation of the Experimental Station in 1985. Four unreplicated treatments were compared:

(i) control (bare soil between rows of tea planted along contours),
(ii) grass strip (four strips of grass 1.2 m wide planted between contoured rows of tea trees),
(iii) ditch-pit (four ditches 0.25 m wide × 0.15 m deep made at equal intervals on contours; pits

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0.3 m wide × 0.6 m long × 0.5 m deep were dug in each ditch at a 2 m intervals), and
(iv) terrace (four contoured terraces 2.8 m wide and 0.5 m high).

Modification of soil moisture in upper profile

In 1990 an experiment was conducted to evaluate the influence of soil moisture on the growth of sweet potato at Menggongshan, which is 25 km southwest of Qiyang. The treatments were:
(i) control (no mulching),
(ii) ridging (ridges 20 cm high, 30 cm wide),
(iii) straw mulching,
(iv) plastic film mulching, and
(v) addition of burnt lime.

Each plot was 3.6 × 6.0 m. Soil samples from 0–15 cm were collected weekly to measure moisture content. Gravimetric moisture was determined by drying samples in a ventilated oven at 105 °C for eight hours.

Results and Discussion

Texture, infiltration and water retention

The texture of the experimental soil is classified as clay according to the USDA system, with the proportions of clay, silt and sand being 40.0%, 49.2% and 10.8% respectively (Fig. 1). The same figure also shows that this soil had a high microaggregate content and a high structure index (95%).

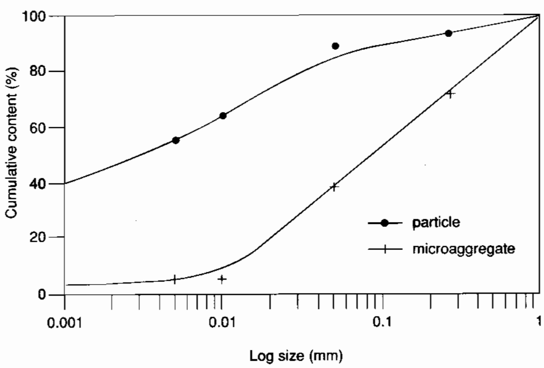

Figure 1. Size distribution of primary particles and microaggregates in red soil.

The large amount of microaggregates would account in part for the high infiltration rate shown in Figure 2. It has to be remembered however that infiltration was not measured in situ but on a disturbed and repacked sample. The relationship between cumulative infiltration and time is best described by the equation of Kostiakov and Philip (Fig. 2).

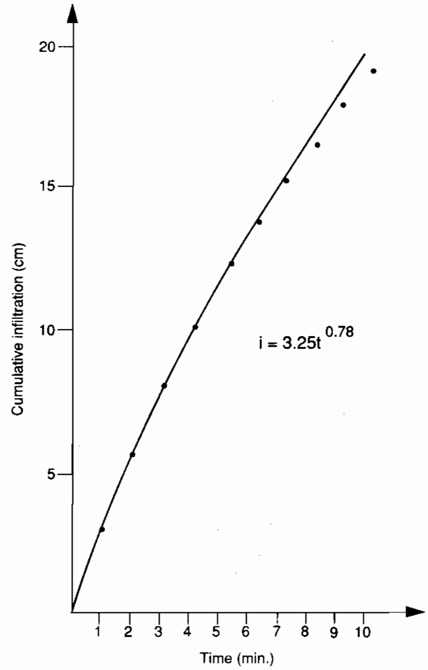

Figure 2. The cumulative infiltration of the red soil.

The cumulative infiltration of the experimental soil developed on a Quaternary clay was found to be considerably higher than that of a granite soil which contained a large amount of sand but low microaggregate content. This suggests that structure manifested as microaggregation is more important than texture in determining infiltration rate.

Soil moisture characteristic curves for three soil depths are shown in Figure 3. For a given suction, water retention increased with depth. The specific water capacity, which expresses the change in

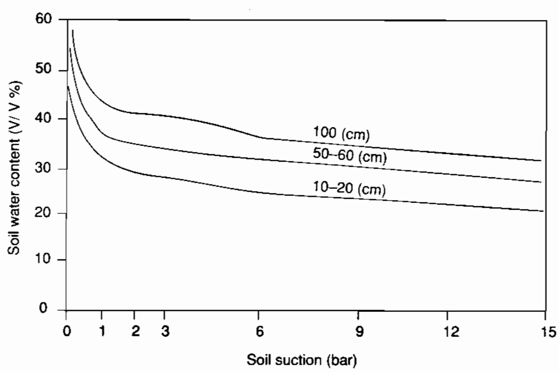

Figure 3. Soil moisture characteristic curve for three depths of a red soil profile.

moisture content with suction, decreased sharply when suction increased (Fig. 4). This indicates that the rate of water release decreased quickly as moisture content fell below field capacity. Most of the water readily available to plants was released within the 0–2.0 bar suction range.

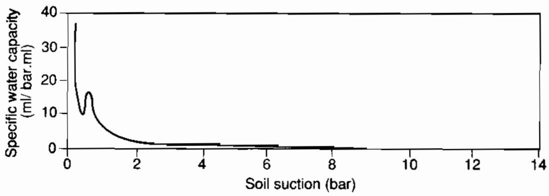

Figure 4. Water release curve of the 10–20 cm red soil layer.

Soil moisture regime

The annual soil water regime in BS is shown in Figure 5. Based on the mean moisture content of the five sampling depths, the regime can be divided into four periods — wet, depletive, dry, and restorative. Beginning and ending dates of each period are shown in Table 1. During the wet period covering late spring and early summer in 1985, soil water content was high and fluctuated around field capacity. The depletive period, which began in early summer, was short lasting only fifty days and indicating that the water stored in the soil profile was depleted quickly. The dry spell lasted from midsummer to the first half of autumn and was characterised by a low soil water content which did not change much. Observations at the same site from 1982 to 1986 had shown that dry spells in summer and autumn were distinct each year. In 1985 the dry spell lasted 140 days. In the restorative periods from late autumn to winter, precipitation increased and air temperature decreased, so that soil-moisture content increased.

Because the surface soil was affected directly by rainfall and evaporation, its water content changed considerably and rapidly in each soil water period. In the 10–30 cm soil layer, the influence of rainfall and evaporation on soil water content decreased and moisture contents were higher than in the surface soil. Four distinct periods of soil moisture could be recognised. Water content was greatest in the deepest layer (70–100 cm) and in this layer fluctuations were least noticeable to the extent that distinct periods could not be identified.

Comparing the seasonal changes in soil water content with those of atmospheric evaporation potential and crop requirements in the growing season we conclude that seasonal changes in soil moisture were not compatible with crop needs in southern Hunan, e.g. many crops require large amounts of soil water for their vigorous growth during the period of soil water shortage, which seriously hinders the growth of crops. Therefore, it is very important to modify the soil moisture regime for dryland agriculture production in the area. Although irrigation is the obvious means of overcoming moisture shortage, other measures need to be explored because of a lack of irrigation and water-harvesting works and the limited proportion of irrigated upland agricultural fields in southern Hunan.

Effects of vegetation and ditch-pits on soil moisture

Soil moisture regimes of VS and DPS had similar annual patterns of variation and mean profile soil moisture contents (Fig. 5). There were, however, significant differences between treatments and in soil-water change during the soil moisture periods, identified in Table 1. During the depletive period, with a high initial soil water content in the profile, soil moisture in VS decreased more rapidly than in BS and a little slower than in DPS. Increase in soil water content as a result of rainfall was most pronounced in the VS treatment and the least in BS, with DPS being intermediate. During the dry period in BS the soil moisture content of layers below 50 cm, which were much higher than those of upper layers, had similar values and pattern of change with a minimum

Table 1. Soil moisture periods of upland red soil in southern Hunan for 1985–86.

Soil moisture period	Beginning-ending dates[1]	Duration (days)	Average water content in the profile (gravimetric %)[2]
Wet	????–10/5	n.a.	>27.0
Depletive	11/5–30/6	50	27.0–23.5
Dry	1/7–20/11	140	23.5–21.0
Restorative	21/11– 2/3	100	21.0–27.0

[1] As the wet period had already begun when measurements commenced it is not possible to specify precisely the start of the wet period
[2] Weighted average of values obtained for 10, 30, 50, 70 and 100 cm depths

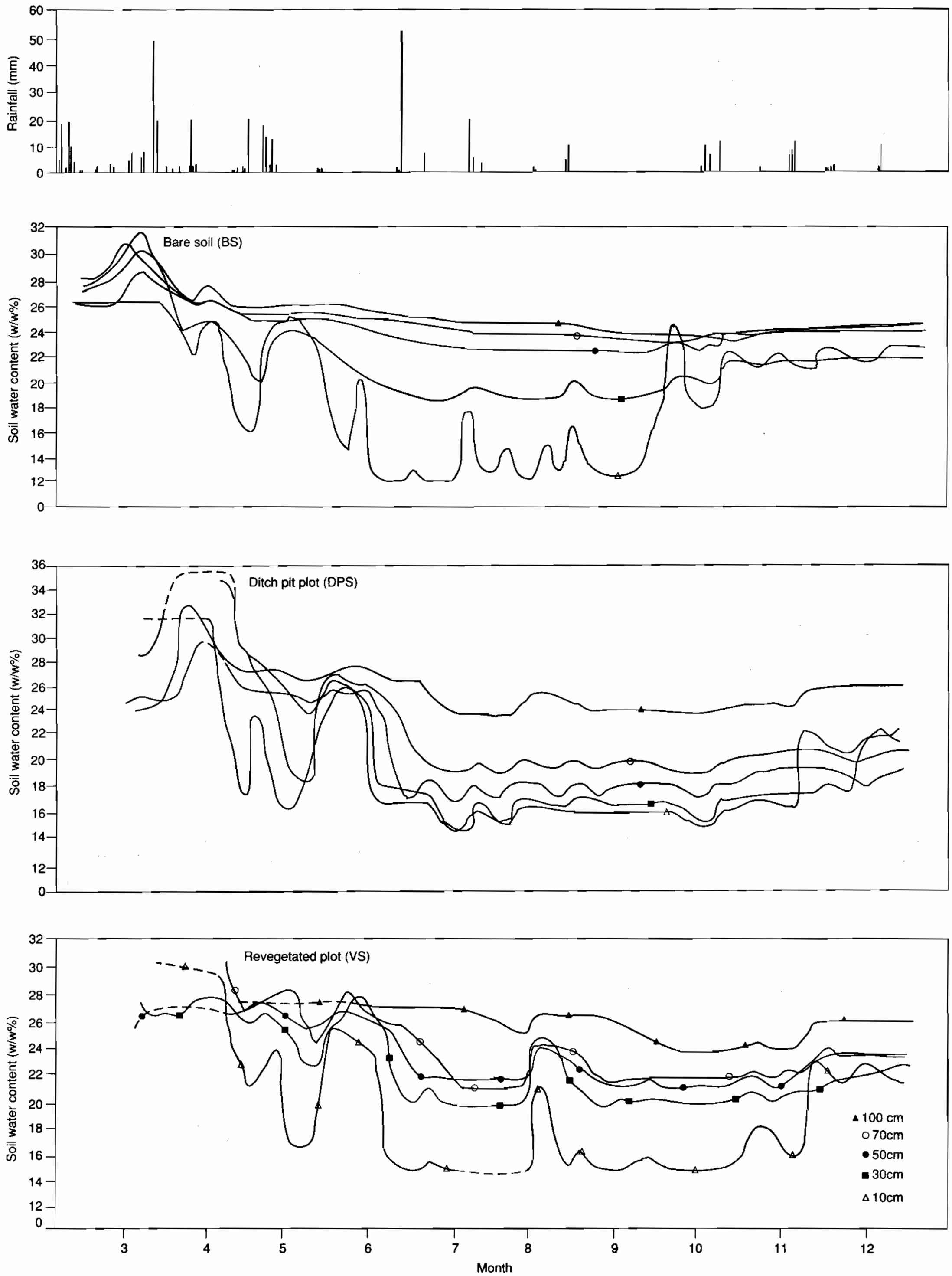

Figure 5. Soil water regimes in BS, DPS and VS treatments.

content of 22.5–23.5% (Table 2). In VS, the moisture content of layers from 50 cm to 70 cm was lower than in BS because of water absorption by plants. The minimum water contents of these layers in the dry period were 20.6–21.3%; these were much higher than those in the uppermost layers. In DPS, the fluctuation pattern in moisture was similar for layers from 0 to 70 cm; moisture content at 100 cm was significantly higher.

Table 2. Commencement dates and average water content for the dry period for different depths for each treatment.

Depth (cm)	Commencement date (day/month)			Minimum water content for dry period (gravimetric %)		
	BS	VS	DPS	BS	VS	DPS
10	10/7	20/6	20/6	12.5	14.0	16.5
30	20/7	10/7	20/6	18.8	19.5	17.0
50	10/8	10/7	1/7	22.5	21.3	18.0
70	1/10	20/7	10/7	23.0	20.6	20.0
100	n.a.	5/10	15/7	23.5	23.5	24.0

Water contents in the soil layers from 30 to 100 cm in VS and DPS fluctuated more than in BS due to extraction of moisture by plants from depth. The reverse was true in upper layers (0–30 cm) as a result of the mulching effect of vegetation. Differences in beginning dates of dry periods of each layer were marked between VS, DPS and BS treatments (Table 2).

Because of the extraction of water by plant roots, beginning dates of the dry spell in VS and DPS were earlier than those in BS at any soil depth from 0 cm to 100 cm. The deeper the soil layers, the earlier the dry period began in VS and DPS compared with BS.

Soil erosion

Soil erosion by water causes severe and widespread soil degradation on the upland red soils of southern Hunan. It reduces the depth of topsoil, degrades structure and permeability, which in turn affect the moisture regime of the soil profile.

The effects on erosion and runoff of terraces, grass strips and ditch-pits are presented in Table 3. It is seen that runoff and soil loss were reduced significantly by all three treatments when compared with the control. The terrace had the minimum water runoff (6.63% of control) and the grass strip had the minimum soil loss (2.54% of control). It is concluded that the use of terraces, grass strips and ditch-pits benefit the soil moisture regime in the upland red soil profile by allowing more water to penetrate into the soil profile.

Table 3. Effect of treatments on runoff and soil loss in 1985.

Treatment	Runoff (mm/plot/year)	Soil loss (kg/plot/year)
Control	226.3	308.0
Grass strip	24.7	7.8
Ditch-pit	48.1	20.3
Terrace	15.0	17.5

Effects of management practices on soil moisture

In comparison with the control, soil-moisture content in the surface 0–15 cm was maintained at higher levels throughout the 12 week measurement period by mulching with straw and plastic film (Fig. 6). The effects of mulching would result from maintaining infiltration at higher rates for longer periods and decreasing evaporation.

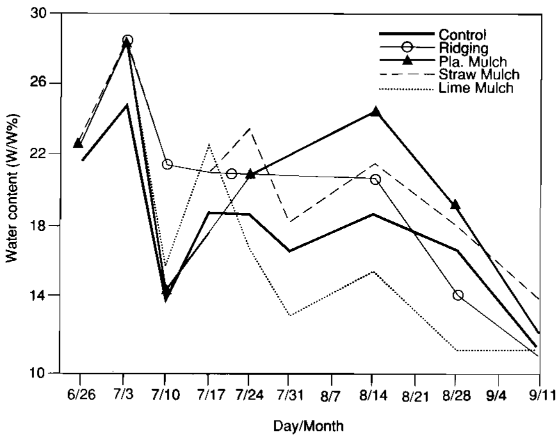

Figure 6. Effect of different treatments on the water content of 0–15 cm layer of red soil at Menggongshan.

The surface application of burnt lime resulted in higher moisture contents in comparison with the control during the first four weeks; thereafter, however, values were lower. Initially the lime may have aided water infiltration by stabilising structure against raindrop impact. Later on it was observed that the surface soil had become harder to penetrate. This may possibly have been due to a chemical reaction between the lime and clay minerals which made the soil become compact and subsequently decreased the infiltration of rainfall. Ridging loosened the soil and aided rainfall acceptance. However, during the dry season soil water was shed so readily that the moisture content for this treatment was lower than that of the control in the last four weeks. Therefore mulching with straw and plastic film seems to be the most effective means of maintaining soil water in the upper soil.

Physical Properties of Red Soils and Their Effect on Availability of Water

Xu Xiuyun and Yao Xianliang*

It is generally believed that the red soil region of south China has a favourable moisture regime for agricultural and forestry production. In actual fact, the distribution of rain, which is influenced by the monsoon from the southeast Pacific, is extremely uneven.

The rainy season usually extends from April through to October, and the dry season from November to March (Yao 1989). However, within the rainy season the rainfall for July, August and September constitutes one tenth of the total annual rainfall. At this time temperatures are high and the demand for water by plants is greatest. Consequently, severe droughts are frequently experienced during summer and autumn in the red soil area of central China.

The problem of drought arising from uneven rainfall distribution is exacerbated by certain physical properties of the red soils that affect moisture supply to plants. In this paper the effects of these properties on the availability of water to plants are discussed.

The Structure of Red Soils

It is well known that soil structure controls porosity and pore size distribution. These in turn determine water infiltration and movement within the profile and its availability to plants. They also affect soil aeration, tilth, the extension of plant roots and resistance to erosion. Experiments have conclusively shown that good structure has to be maintained in order to make full rational use of the red soils.

The physical properties of cultivated and uncultivated topsoils developed on three of the main parent materials of the red soils are summarised in Table 1. Clay content varies with parent material, being highest on basalt and lowest on granite (Yao and Yu 1982). Amorphous sesquioxides (Fe_2O_3 and Al_2O_3) vary with parent material and climate. The highest amount is found in the latosols of the tropical region where it may exceed 10%. As the climate becomes more subtropical, weathering becomes less severe and amorphous sesquioxide content decreases markedly. In the red earths developed on Quaternary red clay in the sub-tropical zone it is less than 1%.

The main clay mineral is kaolinite which is characterised by low shrinkage and swelling properties. Consequently the activity of the clay (plastic index/clay content) is low.

Structural stability

The dominance of the low-activity clay and the bonding effect of the sesquioxides lead to the formation of stable structural aggregates. The structure is fine with a high proportion of water-stable aggregates in the 1.0–0.01 mm size range (Table 2). The structual coefficients in Table 1 indicate the percentage of the total clay content present as water-stable micro-aggregates. These very stable aggregates are referred to as 'pseudo-sand' as they decrease the effective surface area of the clay particles so that the physical behaviour of the red soils is in many respects akin to that of sandy soils. As a result, the saturated hydraulic conductivity (K_{sat}) of well structured cultivated topsoil is as high as 11.5 cm/hour (Yao and Yu 1966). This value is much higher than the range of 0.78 to 1.08 cm/hour shown by soils of similar clay content from the temperate North Plain of China (Institute of Soil and Water Conservation 1961).

Cultivation of red soils leads to a decrease in organic matter and hence structural stability. Table 1 shows large decreases in the amount of water-stable aggregates in cultivated topsoils which often have lower clay and sesquioxide contents compared to corresponding uncultivated soils. The decrease is attributed to differential removal of fine particles by erosion processes such as surface scouring. As structural stability decreases, fine particles may also be eluviated down the profile.

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Table 1. Physical properties of topsoils.

Soil type	Utilisation	Clay (<0.001 mm) %	Amorphous $Fe_2Al_2O_3$ %	>0.25 mm water-stable aggregates %	Structural stability coefficient %	Aeration porosity[1] %	Activity of clay[2]
Latosol	Uncultivated	56.5	10.4	90.8	93.1	30.3	0.26
(Basalt)	Cultivated	50.8	3.2	70.4	84.6	27.9	0.26
Lateritic red soil	Uncultivated	17.5	—	70.0	95.5	2.4	0.31
(Granite)	Cultivated	21.5	3.1	40.0	73.3	9.0	0.47
Red earth (Quarternary	Uncultivated	39.9	0.74	73.6	88.4	20.5	0.31
red clay)	Cultivated	30.7	0.52	28.4	70.0	10.9	0.63

[1] Air-filled porosity at −10 kPa
[2] Plastic index ÷ clay content

Table 2. Percent water-stable aggregates (1–0.01 mm) of red soils.

Soil	Number of samples	Microaggregate
Red soil	65	94.1 ± 6.9
Latosol	5	85.0 ± 8.0

The above data emphasise the importance of adopting management practices that conserve organic matter in order to maintain structural stability and resistance to erosion. Soils depleted in organic matter become difficult to manage. They tend to become compact and to harden on drying. After rain they become sticky and, where structure has broken down, puddle at the surface. Yao and Yu (1966) have shown that K_{sat} of poorly structured red soil can decrease from 11.5 to 2.9 cm/hour. Reduced water infiltration and root extension are some of the main reasons for low yields on red soils in south China.

Development of Surface Crust

One aspect of structural degradation that has a large adverse effect on moisture-supplying capacity is the development of a crust at the soil surface. Surface aggregates in cultivated red soils are prone to breakdown when exposed to raindrop action. This is most likely to occur in spring when soils are bare. Furthermore, rainfall, particularly in the tropical region, often has intensity exceeding 10 cm/hour and kinetic energy of 10^5Pa (Greenland 1977). Crusting is most serious in red soils derived from Quaternary red clay with lower contents of binding sesquioxides which make them less resistant to raindrop impact. The kinetic energy of intensive rainfall causes fine particles to become detached from aggregates and block pores. When surface soil dries a hard crust forms. The strength of the crust may impair seed emergence.

Table 3 shows that the physical condition of the crust is much less favourable than that of the underlying soil. Due to blocking of pores bulk

Table 3. Physical properties of surface crust (0–2 cm) in comparison with subsoil (20–40 cm).

Depth (cm)	Bulk density (t/m^3)	Total porosity (%)	>50 μm porosity (%)	<50 μm porosity (%)	K_{sat}[1] (cm/hour)
0–2	1.38 ± 0.06 (n = 6)	42.2 ± 3.2 (n = 6)	6.3 ± 1.5 (n = 6)	38.5 ± 2.4 (n = 6)	4.1 ± 1.3 (n = 5)
20–40	1.27 ± 0.09 (n = 8)	48.8 ± 2.3 (n = 8)	11.6 ± 3.4 (n = 6)	37.9 ± 1.8 (n = 6)	11.6 ± 3.0 (n = 4)

[1] K_{sat} = saturated hydraulic conductivity measured at 10°C

density is higher; porosity and aeration porosity (pores >50 μm) are significantly lower. K_{sat} is only one third of the subsoil. As a result, water infiltration is greatly reduced and less water is stored in the profile for plant use. This is particularly serious in a region where intense rainstorms and steeply sloping topography are conducive to the generation of erosive run-off.

Erosion risk can be reduced by protecting the bare soil surface with a mulch of crop residue to provide protection against raindrop impact. Residues would also conserve soil organic matter.

Water Availability

The large amount of micro-aggregates in red soils determines their water retention characteristics. Figure 1 shows that the gravimetric moisture content at a matric potential of − 10 kPa is 40% or more. As matric potential decreases to −30 kPa moisture content falls sharply. Moisture contents at this potential, which are regarded as equivalent to field capacity, are 38.3% and 32.7% for the latosol and red earth shown in Figure 1.

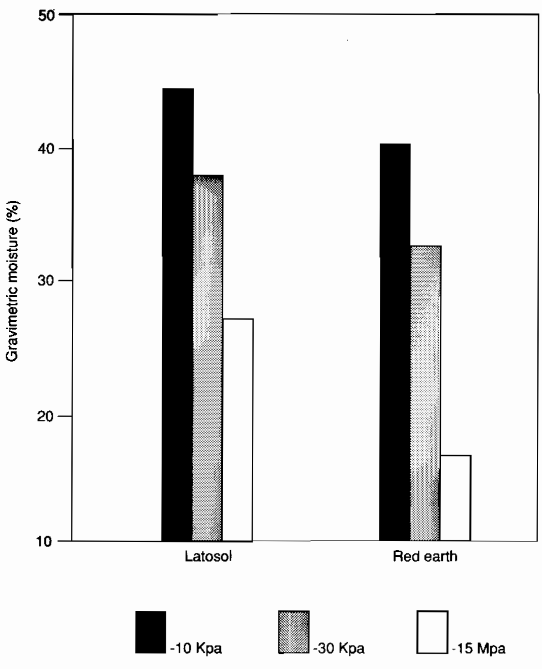

Figure 1. Gravimetric moisture content of red soils at three matric potentials.

At wilting point (− 1.5 MPa) moisture contents for these soils are 27% and 17% respectively. The latosol has an available water capacity of about 11%, and the red earth 15%. This means that for the latosol only about one-third of the field capacity is available for plants, and one half in the case of the red earth.

The shape of the moisture characteristic curve can be related to the texture and structure of red soils. The micro-aggregates behave as sand particles so that initially moisture content falls sharply as inter-aggregate pores are emptied with decreasing matric potential. Within aggregates, however, water is strongly adsorbed on clay surfaces and is not available for plants. Because the soils are rich in clay the moisture content at wilting point is high.

It is generally considered that water is not uniformly available over the moisture range from field capacity to wilting point. Water availability is assessed from the slope of the moisture characteristic curve, dQ/ds, referred to as the specific water capacity. Due to the abundance of micro-aggregates behaving as sand, moisture content declines exponentially as matric potential decreases (Fig. 2).

A critical value of 10^{-2} ml/100 kPa/g is often used for specific water capacity. Below this value water is not readily available so that uptake by roots cannot meet the plant's transpiration demand. Figure 2 indicates that the critical value is reached at a matric potential of around −50 kPa. At this potential moisture content is still high (36.4% for the latosol, 30.4% for the red earth). This means that at times of strong transpiration demand in summer and early autumn plants are subject to stress at relatively high moisture contents.

Conclusions

Due to uneven distribution of rainfall the red soil areas are subject to drought in summer and autumn. The problem is made worse in poorly managed soils in which structural breakdown, particularly crusting, leads to reduced infiltration and storage of moisture in the profile. The combination of large contents of micro-aggregates and clay leads to a relatively low available water capacity and poor water-supplying ability.

These adverse soil physical conditions must be counteracted by creating good soil structure to increase rainfall infiltration and storage, and to improve moisture-supplying capacity. This entails building up organic matter in the soil to increase structural stability. To increase crop production on red soils consideration has to be given to augmenting rainfall with irrigation.

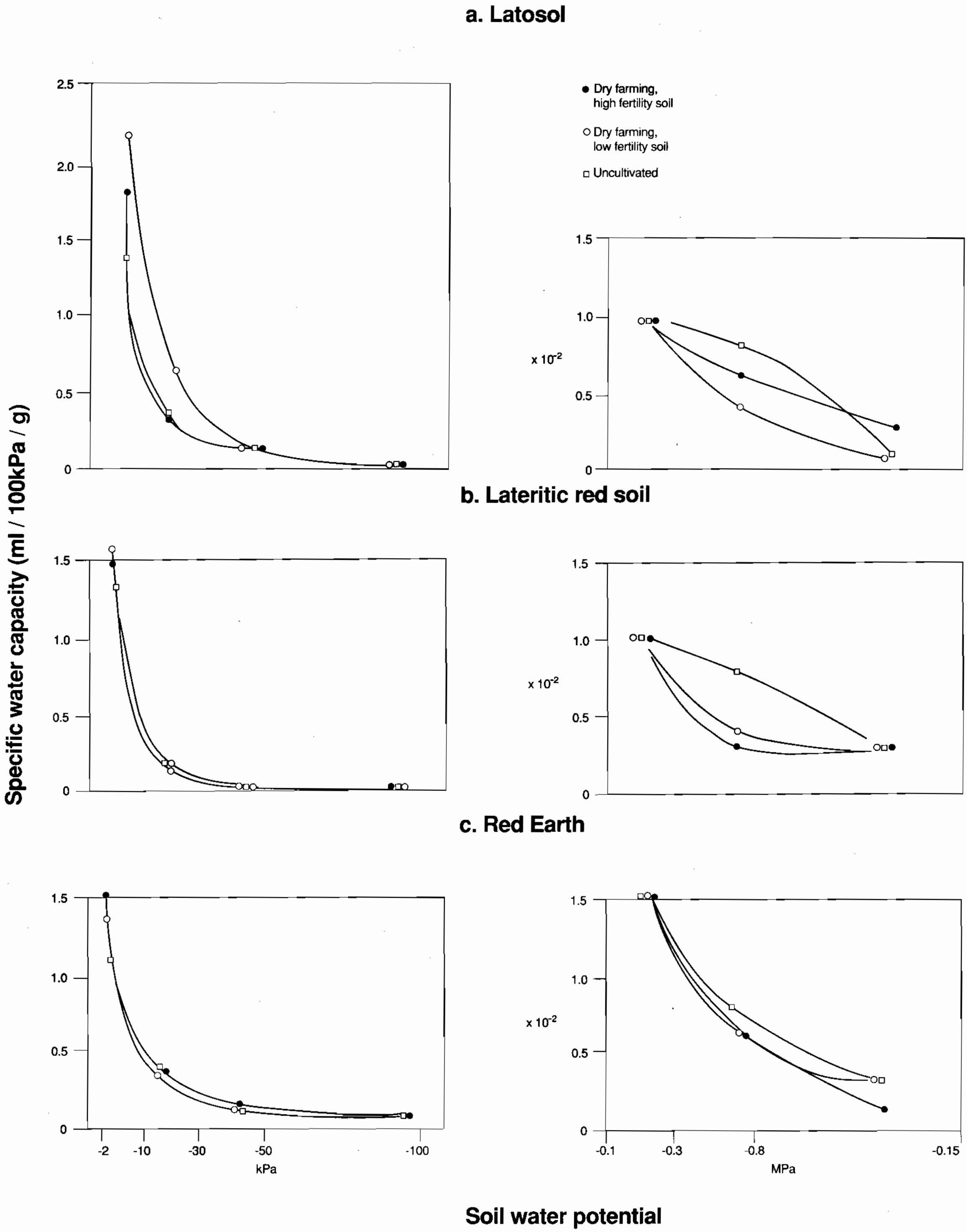

Figure 2. Specific water capacity of soils.

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Amphoteric Properties of Red Soils and Significance for Fertility

X.N. Zhang and G.Y. Zhang*

THE red soils of China are classified as variable charge soils. As such these soils have a surface chemistry characterised by amphoteric properties and thus differ from constant charge soils. The amphoteric properties are associated with high contents of iron and aluminium oxides and affect the charge, ion adsorbtion and acidity characteristics of the red soils. Consequently amphoteric properties have an important bearing on the fertility status and management of these soils.

Charge characteristics

The amphoteric character of the colloids in red soils means that they carry positive and negative electrical charges simultaneously. Compared to soils of the temperate regions the quantity of permanent negative charge is lower and the proportion of variable negative charge is relatively higher in red soils. As a consequence negative charge varies markedly with pH. This characteristic is of great importance for the nutrient retaining capacity of the soil. For instance, a latosol was found to have 3.7 $cmol_c$ and 7.4 $cmol_c$ of negative charge per kilogram of clay at pH 4 and pH 7 respectively (Fig. 1). This means that the cation retaining capacity can be doubled if the soil pH is raised to neutral from its natural pH.

The contribution of organic matter to the negative charge of this kind of soil deserves special attention. As shown in Fig. 1 the removal of organic matter from the clay fraction of the latosol resulted in a decrease in net negative charge within the pH range commonly encountered, thus leading to an increase in the zero point of net charge (ZPNC) to about pH 4.5 from the original value of pH 4.0. This means organic matter can contribute considerably to the nutrient retaining capacity of this soil type.

Iron oxides are the chief carrier of positive charge. However, the relationships between electrical charge and iron oxide content of red soils are quite complicated. The removal of free iron oxides from the clay fraction of the red soils results in an increase of negative charge density and a decrease in ZPNC (Fig. 2).

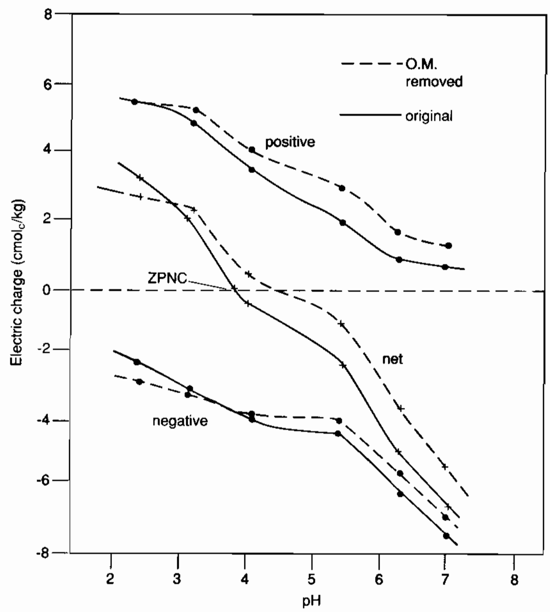

Figure 1. Electric charge-pH curve of a latosol (clay fraction).

The electrokinetic properties of red soils affect soil structure through the dispersion and flocculation of soil colloids. Figure 3 shows that the zeta potential of red soil colloids changes with pH and is influenced by free iron oxides and humus content. The effect of adsorbtion of specific anions and cations on the electrokinetic properties is marked (Fig. 4).

Ion adsorbtion characteristics

The red soils carrying positive and negative charge can adsorb anions and cations simultaneously.

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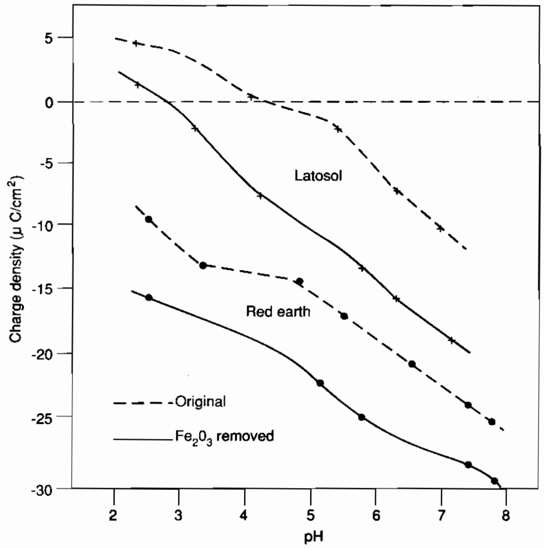

Figure 2. Change in the charge density of red soils (clay fraction) upon removal of Fe_2O_3.

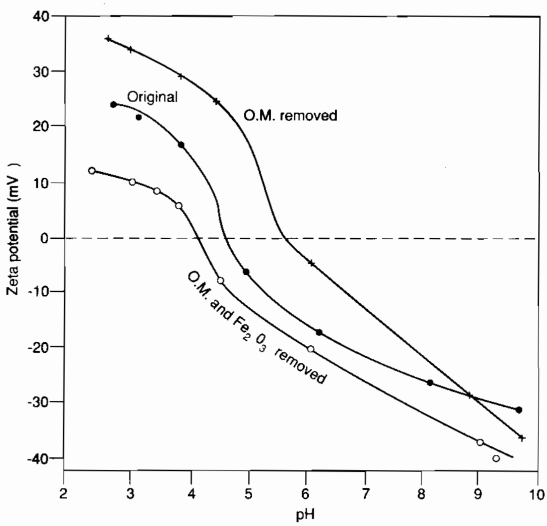

Figure 3. Change in the zeta potential of a latosol (clay fraction).

Adsorbtion is controlled by the quantity of electric charge carried by the soil, the nature of the ion species and experimental conditions, especially pH. It would seem from Figure 5 that the iso-ionic point (P_i) for the red earth and latosol are pH 3.7 and pH 4.5 respectively; negative adsorbtion of Cl^- can occur when the pH exceeds a certain value. P_i is also strongly affected by the type of electrolyte. For instance, the adsorbtion of sulfate from solution far exceeds that of chloride leading to an increase in P_i in sulfate solution. The removal of iron oxides from red soils leads to the lowering of P_i (Zhang et al. 1979).

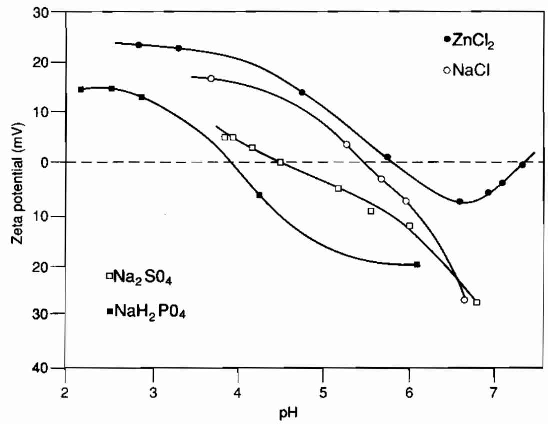

Figure 4. Effect of adsorbtion of specific anions and cations on zeta potential.

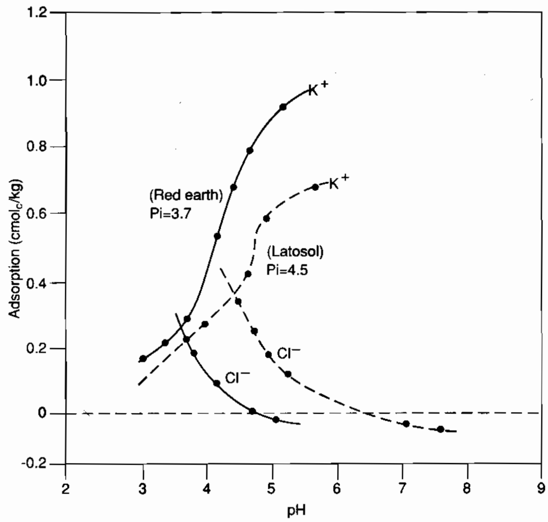

Figure 5. Ion adsorbtion in relation to pH of the soil (P_i = iso-ionic point).

It is noticeable that the bonding energy of red soils with cations is relatively low compared to yellow-brown earth due to the low-charge density on the surface of clay particles (Fig. 6). This will lead to a high degree of dissociation of adsorbed cations from red soils (Zhang and Zhao 1984). The bonding energy of cations increases with increasing pH due to increase in negative charge with pH (Zhang and Zhao 1984).

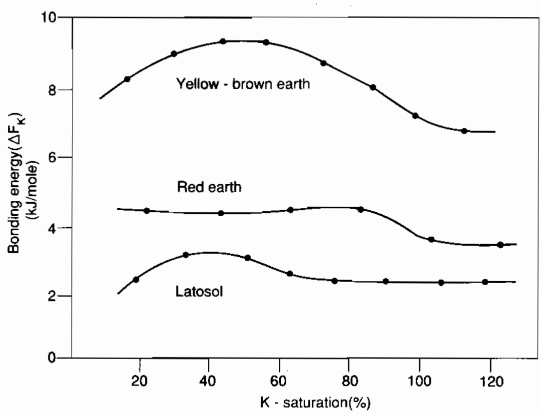

Figure 6. Bonding energy of K^+ with soils.

Red soils can adsorb phosphate and sulfate by the mechanism of ligand exchange, replacing OH^- and/or OH_2 from soil particle surfaces. As a result, the charge properties of the soil are also changed (Zhang and Zhao 1988). The amount of negative charge increased and that of positive charge decreased with the amount of phosphate or sulfate added. Figure 7 shows that the net negative charge increased by 1.9 cmolc/kg after the addition of 5 $cmol_c$ $H_2PO_4^-$/kg at pH 4.8, when the soil carried only a small amount of net negative charge. The change in surface charge of this soil after the adsorbtion of sulfate was similar to that after phosphate adsorbtion.

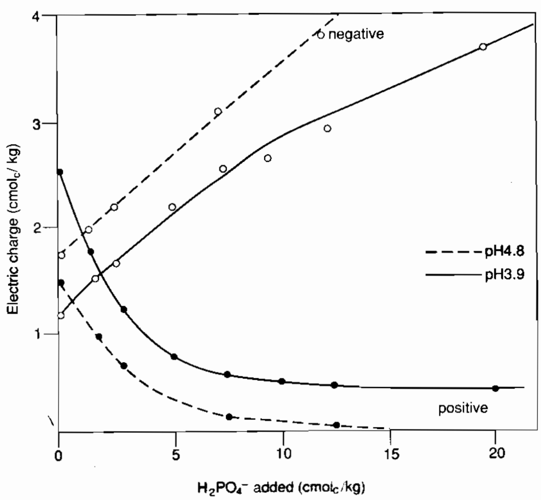

Figure 7. Change in the surface charge of a latosol after the adsorbtion of phosphate.

The practical significance of the ion adsorbtion characteristics of red soils is twofold. The leaching loss of some nutrients such as nitrate may not be as serious as in predominantly constant-charge soils due to the presence of positively charged sites. On the other hand, because ions are easily dissociated from clay particle surfaces into the soil solution, the leaching loss in percolating water may be large. However, the rise in pH and the application of phosphate or sulfate can decrease the leaching loss of nutrient cations.

Acidity characteristics

The amphoteric properties of red soils mean that they can possess exchangeable acidity and exchangeable alkalinity simultaneously. The exchangeable acidity is caused principally by replacement of exchangeable aluminium ions. Under natural conditions this strong replacement power of aluminium will enhance the leaching loss of nutrient cations. Above pH 5.5 the amount of exchangeable aluminium is low. The exchangeable aluminium content of a soil depends on the pH value and its CEC when the pH is lower than 5.5.

Exchangeable alkalinity can arise from ligand exchange between specific anions, such as sulfate and fluoride, and hydroxyl groups on the soil particle surfaces. The released OH^- can neutralise soil acidity and raise soil pH (Zhang et al. 1990). Figure 8 shows that the amount of OH^- released from latosol and red earth increased with the increase of sulfate adsorbed. Figure 9 shows that the release of OH^-

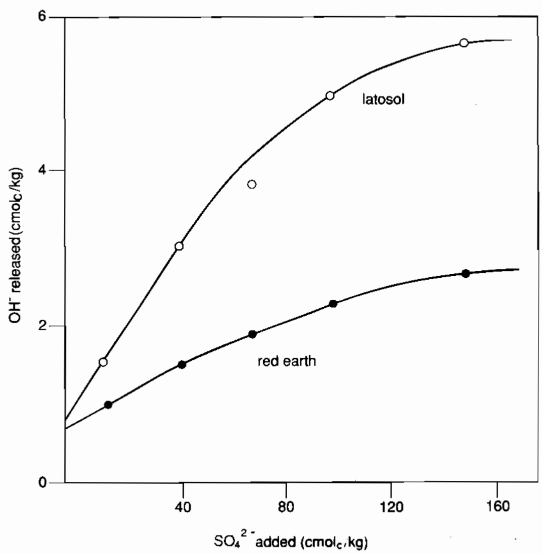

Figure 8. Release of OH^- from red soils at pH 5.0 as a function of SO_4^{2-} added.

increased as soil pH declined. A comparison of Figures 8 and 9 shows that fluoride is more strongly adsorbed and displaces more OH^- than sulfate.

A simple method for the simultaneous determination of exchangeable acidity and alkalinity of soils and which can distinguish between Na-exchangeable and Ba-exchangeable acidity and between SO_4 exchangeable and F-exchangeable alkalinity has been proposed by the authors (Zhang et al. 1990). Data obtained from this method show that the amount of Ba-exchangeable acidity is larger than that of Na-exchangeable acidity, and the amount of F-exchangeable alkalinity is larger than that of SO_4^- exhangeable alkalinity (Table 1). The amounts of exchangeable acidity and exchangeable alkalinity of red soils derived from acid parent materials are higher than those of soils derived from basic rocks.

Figure 10 shows that the amounts of exchangeable acidity and alkalinity increase with the concentration of equilibrating neutral salt solution up to 0.1 mol_c/l and then approach a constant value.

From the foregoing sections it is clear that soil pH has a strong influence on the surface properties of red soils. By adjusting the pH through management practices, such as liming, these properties such as CEC can be manipulated to improve soil fertility.

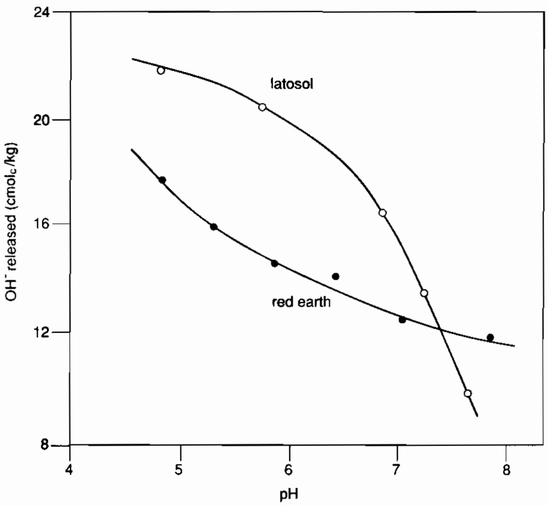

Figure 9. Release of OH^- in relation to pH of soil (F^- added: 35 $cmol_c/kg$).

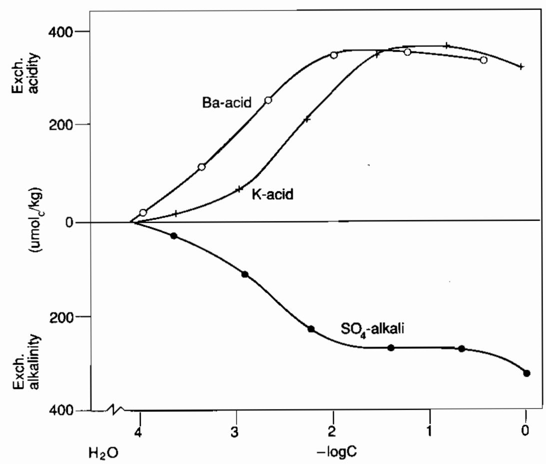

Figure 10. Exchangeable acidity and exchangeable alkalinity of a lateritic red earth (C, conc. of salts in mol_c/l).

Table 1. The exchangeable acidity and exchangeable alkalinity of red soils ($\mu mol_c/kg$).

Parent material	Depth (cm)	Na-exch. acidity	Ba-exch. acidity	SO_4-exch. alkalinity	F-exch. alkalinity
Tuff	0–10	12	30	9	16
(Guangdong)	20–30	16	42	8	19
	50–60	20	49	15	23
	80–100	28	66	15	31
Shale	0–10	127	193	66	146
(Guangxi)	20–30	87	143	54	101
	50–60	68	122	38	73
	100–120	44	62	30	46

Conclusion

Red soils possess amphoteric characteristics when compared to permanent charge soils. Management practices for regulating the fertility of red soils are therefore quite different from those required by soils of temperate regions in which permanent change is dominant. The inherent fertility of red soils is low in so far as nutrient-retaining capacity and soil acidity are concerned. On the other hand, these properties can be changed more readily than in soils of temperate regions. Further research is needed on how the properties of red soils can best be manipulated to improve fertility.

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Physiological Factors Influencing the Management of Forages on Upland Red Soils of South Central China

Graeme J. Blair*

THERE are two major factors that control the quantity and quality of forage produced on the red soils area of South Central China.

Firstly, adverse soil conditions of low pH, high soil solution Al levels, low P status, deficiencies of other nutrients such as K and Mg limit overall productivity and must be ameliorated if production levels are to be increased and erosion controlled. These subjects are dealt with elsewhere in these proceedings. Secondly adverse climate conditions of cold winters and dry and high temperature conditions during summer impose added constraints on production. These are also dealt with elsewhere in these proceedings.

An ideal forage production system is one which produces a constant supply of high quality material throughout the year. Clearly this is not possible in such an environment as Hunan.

Understanding the physiology of forage species, particularly in their response to defoliation, can be a major aid to devising better management strategies to enhance both productivity and persistance.

Timing of Defoliation

Because of changes in the stored carbohydrate levels and the height of the growing species throughout the life cycle of forage plants timing of defoliation can affect both productivity and persistence. Smith and Nelson (1985) reported that the total non-structural carbohydrate level in the stem bases of timothy (*Phleum pratense*) was lowest at the stem elongation stage and increased until seed maturity (Fig. 1).

In an experiment reported by Kneival et al. (1971) a decrease in production from both timothy and smooth bromegrass (*Bromus inermis*) occurred when cut between the period of stem elongation and early heading. During this time carbohydrate levels would be expected to be low and the growing species would be above cutting height. This means that new tillers had to be initiated from carbohydrate reserves in the roots and stem bases, hence regrowth was slow and production reduced.

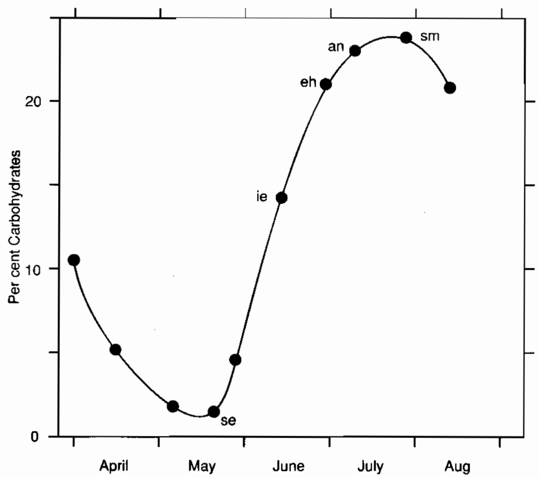

Figure 1. Total non-structural carbohydrate (%) in the stem base of timothy during development: se = stem elongation, ie = inflorescence emergence, eh = early heading, an = antheses and sm = seed maturity (Smith and Nelson 1985).

In most grass genera basal tiller development is suppressed because of apical dominance of existing tillers up until anthesis. If the plants are cut or grazed before stem elongation only leaf blades are removed and the intact shoot can elongate satisfactorily. Cutting or grazing after anthesis is also satisfactory because the basal ancillary buds are no longer suppressed by apical dominance and can quickly develop into new tillers if environmental conditions are favourable.

In perennial legumes, such as white clover (*Trifolium repens)* and pasture peanut (*Arachis pintoii*), which root at the nodes of the stems growing on or under the soil surface, in stoloniferous

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grasses such as *Digitaria decumbens*, in rhizomateous plants such as kikuyu (*Pennisetum clandistinum* and some buffel grasses (*Cenchrus ciliaris*) time of defoliation is less important for both production and survival because of the many auxillary buds present that can initiate new growth.

In annual legumes such as subterranean clover (*Trifolium subterraneum*) defoliation near flowering results in reduced seed production and this, in turn, may result in a decrease in the persistence of the legume.

Maximum vegetative yields are generally obtained when the sward is allowed to grow to a leaf area index (LAI) of between 3 and 5. Beyond this LAI respiration losses from shaded leaves in the base of the canopy results in a loss in weight at a rate similar to that accumulated by new growth at the top of the canopy. Because of this it is important to think carefully about the defoliation regime used in forage evaluation programs. Ideally each entry in the evaluation should be allowed to reach a ceiling LAI before it is cut. If a rapidly growing entry is not cut until the slower growing ones have reached their ceiling LAI then overall production data will be distorted (Fig. 2) to the disadvantage of the rapid grower.

Farmers are often faced with the dilemma of quantity vs quality of forages and this is related to the timing of utilisation (Fig. 3).

The decline in quality (% digestible dry matter, % digestible energy and % crude protein) is associated with a change in leaf:stem ratio and to lignification of tissue. Although application of

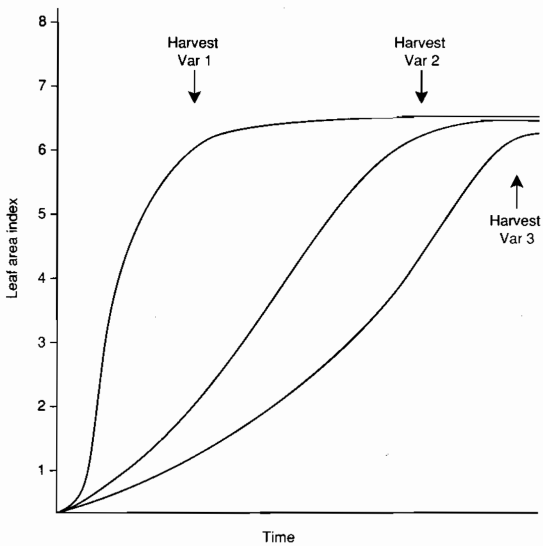

Figure 2. The effect of varying cutting time in relation to LAI in three species.

nitrogen can change the nutritive value of the forage it has little effect on the rate of decline in quality with age (Table 1).

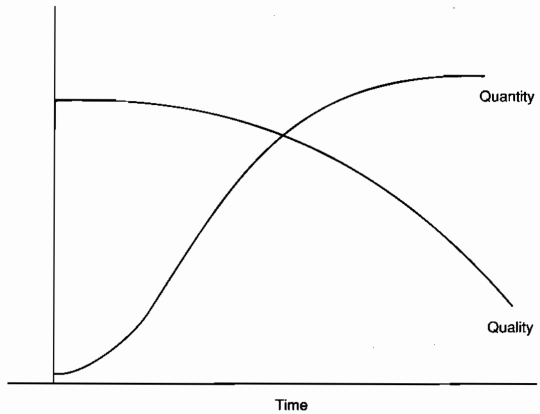

Figure 3. Change in the quantity and quality of forages over time.

Table 1. The effects of maturity and nitrogen application on the digestible crude protein (%) and digestible dry matter (%) of smooth bromegrass in New Hampshire, USA (Colovos et al. 1961 cited by Lechtenberg and Hemken 1985).

Date of cutting	Digestible crude protein Low N	High N	Digestible dry matter Low N	High N
May 29	68.1	75.6	70.8	71.6
June 9	59.7	69.0	64.6	63.1
June 20	54.5	61.7	56.9	57.3

Timing of cutting or grazing can affect the botanical composition of mixed swards, particularly in those with differing growth habits or flowering times such as in mixtures of temperate (C3) and tropical (C4) grasses such as may be developed on the red soils of South Central China.

This problem may be accentuated when the species in the mixture have different soil fertility requirements. In an experiment conducted on the Northern Tablelands of NSW, Australia, Cook et al. (1978) found that there was a strong interaction between grazing management and fertilizer application on the botanical composition of a mixed ryegrass (*Lolium perenne*), a cool temperate C3 grass and redgrass (*Bothriochloa macra*), a tropical C4 grass (Table 2). In all grazing-management treatments the percentage of ground covered by redgrass declined when superphosphate was applied and the amount covered by ryegrass increased. When no fertilizer was applied there was an increase in redgrass and a decrease in ryegrass irrespective of grazing management.

Table 2. The effect of grazing management and fertilizer on the botanical composition (% ground cover) of a ryegrass (*Lolium perenne*)-redgrass (*Bothriochloa macra*) pasture on the northern tablelands of New South Wales (Cook et al. 1978).

Grazing management	Superphosphate (kg/ha)	Redgrass 6	Redgrass 18	Redgrass Change	Ryegrass 6	Ryegrass 18	Ryegrass Change
		% ground cover					
Light throughout	0	29	33	+4	8	2	−6
	500	7	7	0	29	34	+5
Hard throughout	0	13	17	+4	8	2	−6
	500	7	9	+2	20	9	−11
Spelled Aug-Oct	0	15	16	+1	12	5	−7
	500	9	3	−6	28	36	+8
Hard Aug-Oct	0	27	31	+4	10	3	−7
	500	15	19	+4	18	13	−5

(Time since grazing commenced (months))

In the presence of fertilizer, spelling the pasture in the August to October period, when ryegrass commences growth after winter dormancy, resulted in an increase in ryegrass density which in turn reduced redgrass density. By contrast, when the pasture was hard grazed in the same period ryegrass density declined and redgrass density increased.

Timing of defoliation can also affect the weed content of pastures. If defoliation occurs at a time when the weed species is germinating and becoming established the ground area is opened up and this reduces the competition to the developing weed seedling.

This is clearly demonstrated by the data on thistle invasion into a subterranean clover–perennial ryegrass–bromegrass pasture in Tasmania, Australia in Table 3 . Where the pasture was grazed in autumn thistle populations remained high in spring and when it was not grazed in autumn the population was low. Spring grazing had little effect on thistle density.

Table 3. The effect of timing of grazing on slender thistle (*Carduus pycnocephalus*) density (plants/sq m) (Bendall 1973).

Grazing time Autumn	Grazing time Winter	Grazing time Spring	Thistle density Autumn	Thistle density Spring
			plants/sq m	
yes	yes	yes	15.5	22.6
yes	yes	no	13.5	18.4
no	yes	yes	11.7	1.9
no	yes	no	13.1	1.2

Severity of Defoliation

Like timing, severity of defoliation can affect the productivity and persistence of forages. Cutting to near ground level or hard grazing may increase the total forage production over a short period compared to more elevated cutting or grazing but the practice is non-sustainable. Severity of defoliation affects plants in the same way that frequent defoliation reduces plant vigour.

Optimum cutting height varies with forage species and stage of maturity. Upright species are less able to tolerate cutting to a low height as compared with prostrate types. Crowder and Chheda (1982) reported research from Nigeria which found that a cutting height of 15–18 cm above ground level was required to maintain a sward of the upright grass *Andropogon gayanus* and of *Cynodun dactylon* IB8 but that the productivity of a *Cynodun–Centrosema pubescens* mixture was unaffected by cutting heights varying from 5 to 15 cm.

Jones (1973) found an interaction between severity and frequency of defoliation (Fig. 4) in a *Desmodium intortum* cv. Greenleaf–weed (mainly *Cynodon dactylon*) pasture in Queensland, Australia. At a frequent cutting interval of 4 weeks a cutting height of 3.8 cm resulted in a lower yield of centro than cutting at 7.5 or 15cm. No effect of cutting height was recorded when cut at 8-weekly intervals whilst with 12-weekly cuttings yields were reduced at the higher cutting height. Less frequent (12-weekly) and more severe (3.8 cm) cutting resulted in the highest centro yield.

Imrie (1971), working in Queensland, Australia, found that severe defoliation resulted in a marked reduction in leaf and stem weight and number in 6 lines of *Desmodium intortum* whilst in another introduction of the same species (CPI23189) these yield parameters were generally unaffected (Table 4).

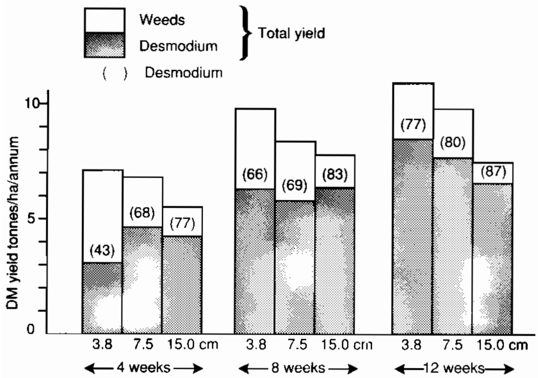

Figure 4. The effect of severity and timing of cutting on a *Desmodium*-weed pasture in Queensland, Australia (Jones 1973).

Table 4. The effect of severity of defoliation on seven lines of *Desmodium intortum* (Imrie 1971).

Line Severity of grazing	CPI23189 Light	 Heavy	Mean of 6 other lines Light	 Heavy
Leaf wt (g)	22.8	22.1	23.0	13.9
Stem wt (g)	14.5	11.9	16.8	8.8
Leaf number	441	595	519	440
Stem number	119	144	130	105

When forages are severely cut there is little photosynthetic area remaining and hence there is a considerable delay in the commencement of active growth. In addition to low-leaf area the recovery rate of forages after defoliation is a function of both the amount of labile carbohydrate in the roots and crown or stem bases of the plant. This was demonstrated in an experiment with *Panicum maximum* (Table 5) conducted by Humphries and Robinson (1966).

Table 5. The effect on rate of regrowth (g/day) of residual LAI and carbohydrate status of *Panicum maximum* (Humphries and Robinson 1966).

Residual LAI	Relative initial carbohydrate status 0	 100
0	1.21	1.65
0.3	1.95	2.15
0.8	2.79	2.89

In this experiment the effect of residual LAI was greater than that of carbohydrate status. This is because the photosynthate produced in the residual leaf is immediately available for leaf expansion or new leaf production.

The severity of grazing not only affects the productivity of forages but can also affect the ability of a sward to resist weed invasion.

In an experiment conducted at Armidale, NSW, Australia, George et al. (1974) found that severe defoliation resulting from a high sheep stocking rate reduced the basal cover in grass pastures which allowed spear thistle (*Circium vulgare*) to invade. Grasses that are resistant to grazing such as phalaris were least affected whilst cocksfoot (*Dactylis glomerata*) which has a high crown was severely affected.

Frequency of Defoliation

The frequency with which forages are defoliated is most often determined by animal demand rather than the physiological requirement of the plant. As mentioned in the previous section, residual leaf area is a major determinant of the rate of recovery of forages from defoliation. This means that if plants are defoliated at frequent intervals the effect will become more severe on subsequent production and survival when only a small amount of leaf remains.

As for severity and timing of defoliation, frequency effects are manifest via carbohydrate metabolism and movement. In an experiment with

Table 6. The effect of severity of defoliation of four grass species on plant basal cover (%) and thistle density (plants/100 sq m) (George et al. 1974).

	Grass basal cover (%)		Thistle density (plants/100 m²)	
Stocking rate (an/ha) Grass Species	19	38	19	38
Phalaris aquatica	34	24	0	1
Festuca arundinacia	21	4	1	28
Lolium perenne	6	2	19	50
Dactylis glomerata	1	0	678	1202

Cenchrus ciliaris at Gayndah, Queensland, Australia, Humphries and Robinson (1966) found marked changes in the total available carbohydrate (TAC) level in plant parts following defoliation to 5 cm either at the end of winter or every eight weeks (Fig. 5).

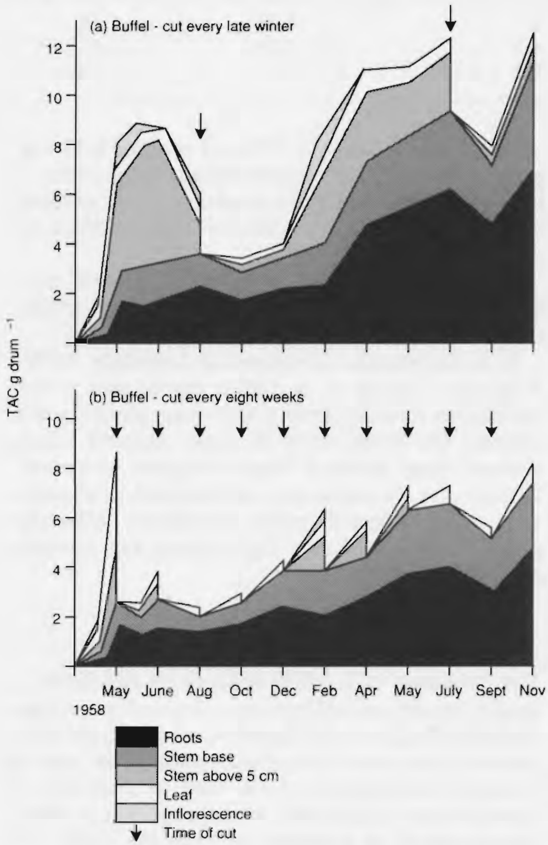

Figure 5. Pattern of accumulation of total available carbohydrates (TAC) in various plant parts of *Cenchrus ciliaris* grown under two cutting regimes. (Humphries and Robinson 1966).

In the sward that was defoliated at the end of winter there was a marked increase in the TAC stored in stem above 5 cm in May when the plants ceased active growth. There was no TAC accumulation during the December to February period when active growth was taking place. Plants defoliated at 8-weekly intervals stored approximately the same amount of TAC in stem bases as the plants cut annually, but root TAC levels were substantially lower. This indicates that frequent defoliation reduces partitioning of TAC to roots and hence root growth would be restricted. The poor overall productivity of frequently cut forages then becomes a product of low total photosynthesis, as a consequence of low LAI, and of restricted moisture and nutrient uptake through poor root development.

The shedding of root tissue that occurs following defoliation has serious consequences for legumes. The interruption in carbohydrate supply to the nodule results in a reduction in nitrogen fixation and, under severe and frequent defoliation, sloughing of the nodules from the root.

Use of Nutrients to Manipulate Productivity

The application of plant nutrients can be used as a management tool to alter forage productivity. Fertilizers or organic residues can be applied to alter:
(a) the total productivity of forage,
(b) the seasonal distribution of production,
(c) botanical composition,
(d) forage quality, and
(e) cold tolerance.

Total productivity. Numerous examples of forage responses to fertilizer application are presented in these proceedings. On the red soils it is vital that a balanced fertilisation program be undertaken if the maximum benefit is to be obtained from the application.

Seasonal distribution. Strategic applications of nitrogen can be used to increase spring and autumn production from grasses and legumes. Fertilizer N should be applied at times when temperature restricts the availability of N from organic matter and/or limits N fixation by legumes.

Botanical composition. Fertilizer applications can be used to alter the grass–legume balance in mixed forage stands. In soils deficient in N, application of this nutrient to mixed grass–legume swards generally results in a greater increase in grass, than in legume production. Whilst this may result in a short-term increase in productivity care must be taken not to stimulate grass growth to the extent that it results in too severe competition for the legume.

On soils low in potassium (K) application of this nutrient to mixed grass–legume forages generally results in an increase in the legume component of the pasture because of the higher K requirement of the legume. Follett and Wilkinson (1985) report data from USA showing the effect of K application on the yield and botanical composition of four grass–legume mixtures (Table 7).

Table 7. Effect of K fertilizer on the yield and botanical composition of grass-legume mixtures grown on a K deficient soil in USA (Follett and Wilkinson 1985).

Mixture	K Application	Yield (kg/ha)	Legume (%)
Ladino*/*D.glomerata*	0	4192	7
	+	6792	12
Ladino/*F.arundinacea*	0	4573	8
	+	5963	28

* *Trifolium repens* CV Ladino

Forage quality. The crude protein and mineral concentration in forages can be manipulated by nutrient applications. In the example given in Table 7 the applied K would be expected to increase the K content of both the grass and legume and the N content of the forage mix would probably increase because of the higher legume component.

The effect of N application on pure grass pastures may have either a positive or negative effect on tissue N concentration. In an experiment with *Hyparrhenia rufa* grown in Costa Rica, Tergas et al. (1971) found that increasing rates of N increased the N concentration in the grass in the wet season following application (November, in Table 8). In the standing forage however there was a decline in N concentration with time and the N level was lower in the 75 kg N/ha treatment than the control (Table 8). This phenomenon is often observed when low rates of N are applied. Under these conditions the dry-matter yield response is greater than the N uptake response so there is a dilution of the N concentration in the tissue.

Table 8. The effect of fertilizer N on the N concentration (%) in *Hyparrhenia rufa* grown in Costa Rica. (Tergas et al. 1971).

	N Applied (kg/ha)		
Month	0	75	150
		%N	
November	0.80	1.00	1.44
January	0.44	0.37	0.47
February	0.27	0.24	0.28
March	0.21	0.22	0.30

In situations where there is both a dry-matter yield response and an increase in N concentration animal production responses can be higher than anticipated because of higher intake and digestibility in the forage and a more favourable N balance (Table 9).

Table 9. The effect of N on the nutritive value of chopped *Digitaria decumbus* hay (Minson 1967).

Character	−N	+N
N (%)	0.59	1.15
Sol. Carbohydrate (%)	14.0	7.9
Voluntary intake (g/W /day)	31	48
Dry matter digestibility (X)	48	52
Apparent N digestibility (Z)	8	50

Cold tolerance. It is known that different species have different tolerances to cold and freezing. Within a species the degree of cold tolerance can be altered by nutrient application, particularly N and K. Application of N generally reduces cold tolerance (Fig. 6) by encouraging plants to grow and hence producing large leaf cells that are less resistant to freezing. By contrast, K application is often found to increase cold resistance (Fig. 6). The mode of action of K is unclear but is generally thought to be via an effect on cell sap osmotic stength.

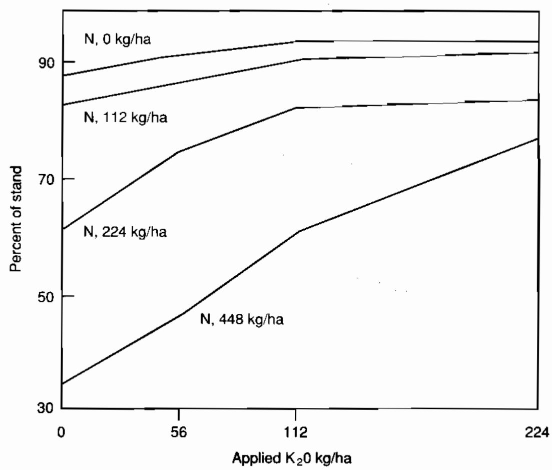

Figure 6. The effects of N and K on the survival (% of stand) of Coastal Bermuda grass (*Cynodon dactyloa*) (Smith and Nelson 1985).

Conclusions

An understanding of plant growth and physiology aids in the development of more productive and sustainable forage systems.

The effects of timing, severity and frequency of defoliation are very much related to the interruption of carbohydrate production from photosynthesis and its movement within the plant.

In species with a limited number of growing points, such as twining tropical legumes, removal of growing points has a major effect on plant productivity. This contrasts with rhizomatous or stoloniferous plants where multiple growing points exist.

Residual leaf area after cutting or grazing is a major management factor that can be used to manipulate forage productivity and persistence. Sufficient leaf area should remain to allow rapid carbohydrate production to initiate new growth.

Plant nutrient additions can be used as a major management tool to manipulate the amount, timing and quality of the forage produced and in changing cold tolerance.

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Plant Adaptation to Aluminium Toxicity and its Role in Forage Production

D.A. Macleod*

SOIL acidity is a major limitation for forage production on the red soils of China. Plant growth is affected by soil acidity in a number of ways:

- direct H^+ effect,
- Al and Mn toxicities, and
- deficiencies of P, Ca, Mg, N and Mo.

These factors interact with each other and produce diverse effects on plant growth.

It is widely accepted that when soil pH is <5.0 Al toxicity is the most important factor limiting growth. This paper discusses how Al toxicity affects growth, how plants have adapted to it, and how adaptation can be used in forage production. P and Ca nutrition of plants are discussed in so far as they are affected by Al in acid soils.

Strategies for Overcoming Soil Acidity

Liming

The most widely used strategy to overcome soil acidity has been to add liming material, usually ground limestone ($CaCO_3$) to the soil to raise its pH. However, this approach suffers from two drawbacks.

Firstly, liming may be prohibitively expensive. The main components of cost are grinding the limestone to a sufficiently fine particle size, and transport. The higher the desired pH, the greater is the cost of liming.

Secondly, lime is broadcast at the surface and mixed into the topsoil, but this does not ameliorate subsoil acidity. This is a serious limitation in the red soils of south China, in which acidity and hence Al toxicity generally increase with depth. Roots of plants sensitive to acidity are therefore unable to explore the subsoil for nutrients and water. Where rainfall is limiting, as occurs in the red soil region in late summer and autumn, such plants are particularly susceptible to drought. Marschner (1991) has shown that plants can compensate for restricted root development in acid subsoils by increasing root length densities in the topsoil. However, this mechanism is of limited value for survival where the topsoil suffers severe desiccation during the growing season.

Selection of species

In the liming approach the soil is changed to suit the plant. On account of the problems described above, attention has been given to the alternative strategy of selecting plants to suit the soil. It has long been known that some species are more tolerant than others to soil acidity, and specifically to Al toxicity. It is also known that large differences exist between genotypes within species.

An example of difference in tolerance to Al toxicity of four tropical grasses grown in solution culture is shown in Figure 1. *Brachiaria decumbens* is highly tolerant, followed by *Panicum maximum*. Both these species, in fact, show an increase of about 20% in dry matter yield when 0.5 μg Al/ml is present in solution. In contrast, *Cenchrus cilliaris* rapidly declines as Al concentration increases from 0 to 2 μg/ml.

Some of the differences in Al tolerance between plant species and genotypes are genetically controlled (Foy 1988). There would appear to be considerable potential for selecting or breeding genotypes with good tolerance of Al toxicity.

The two approaches of liming and breeding tolerant species should be seen as complementing each other. In many instances forage production is unacceptably low unless lime is applied. Such is the case with the red soils of Menggongshan Experimental Station in Hunan Province. However, by selecting cultivars tolerant of soil acidity smaller amounts of lime achieve economic yields. Thus both liming and using acid-tolerant species have a role to play in increasing production from acid soils.

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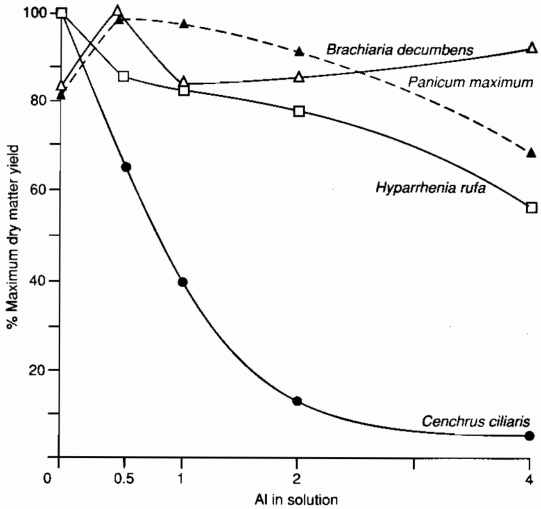

Figure 1. Differences in tolerance of Al toxicity shown by four tropical grasses (Spain 1979).

Effects and Symptoms of Aluminium Toxicity

Symptoms of Al toxicity are not easily identified. There are no specific foliar symptoms. As Al interferes with the uptake of nutrients, in some instances Al toxicity resembles P deficiency, in others Ca deficiency. Al toxicity mainly affects the roots of plants. It inhibits cell division and/or cell elongation in the apical meristem, which leads to roots developing a characteristic stubby appearance. Lee and Pritchard (1984) describe the roots of Al-stressed *Trifolium repens* as showing stunting and browning of root tips, inhibition of newly emerging lateral roots and extensive damage to the root cap region, with extensive swelling and destruction of epidermal and cortex cells.

Laterals are more sensitive to Al toxicity than are primary roots so that fine branching and root hairs are greatly reduced leading to a decrease in the efficiency of roots. Four aspects of this decreased efficiency are considered here.

Reduced water uptake

Soil acidity can reduce a plant's resistance to drought in two ways:

1. Root penetration into acid subsoil is restricted resulting in shallow rooting depth and low utilisation of water (and nutrients) present in the subsoil.
2. Even when roots are present, Al can damage roots to the extent that they cannot absorb sufficient water (Foy 1988). In the red soil region of China, where forage production is limited by seasonal moisture shortage and soil acidity, plants should be able to resist drought arising from both Al-induced water stress and limiting rainfall.

Reduced P uptake

Reduction in root length and root hairs caused by Al toxicity means that less soil is explored by roots. This results in less uptake of relatively immobile elements such as P. There are also a number of interactions between Al and P which adversely affect P nutrition. It was originally believed that the main effect of Al was to precipitate P as sparingly soluble aluminium phosphate outside the roots, making it unavailable for uptake. While this reaction undoubtedly occurs, evidence that roots exposed to Al in solution contain more P than those not exposed has led to the suggestion that precipitation occurring within root tissue is of greater significance for P nutrition. Precipitation of aluminium phosphate is believed to occur (i) at the surface of root cells or in the free space of roots, and (ii) within the cells, possibly within the mitochondria (Andrew and Jones 1978).

Precipitation of P within roots makes it unavailable for onward transport so that concentration of P in shoots is reduced. This effect is well established for the legumes *Medicago sativa* and *Trifolium subterraneum* (Munns 1965). Foliar symptoms of P deficiency shown by forage species growing in acid conditions include purpling of leaves and leaf veins and smaller darker green leaves, often curled. Tolerance to Al has been shown for some species to be correlated with the ability to absorb and utilise P in the presence of excess Al (Foy 1988).

Intereaction between Al and Ca

Al toxicity decreases the uptake of Ca resulting in lower Ca concentrations in roots and tops. It is often expressed as a Ca deficiency, e.g. collapsed petioles in white clover (Jarvis and Hatch 1987). Al reduces Ca uptake by competing for or blocking Ca binding sites on root surfaces. A high concentration of Ca^{2+} is required near the plasma membrane or along the apoplasmic pathway for uptake of Ca (Marschner 1991). At low pH, decrease in the concentration of Ca in the soil solution and increase in Al concentration inhibit Ca absorption. The concentration of Ca^{2+} in solution required for maintaining root elongation increases as pH declines and the concentration of toxic Al species increases. Consequently the Ca:Al ratio in the soil solution or the ratio of exchangeable Ca:exchangeable Al is a better indicator of the likelihood of Al-induced Ca deficiency than concentrations of these elements.

One of the benefits of liming acid soils is an increase in Ca uptake by plants. This occurs through increased concentration of Ca^{2+} in the soil solution and precipitation of soluble Al as a result of increased pH. For species with a good tolerance of Al toxicity per se it may only be necessary to add sufficient lime (or other Ca source) to achieve a Ca:Al ratio in the soil solution for adequate Ca uptake.

One aspect of tolerance to acidity appears to be an ability to resist Al-induced Ca deficiency. Thus Hutton (1985) showed that the ability of selected cultivars of *Centrosema* species to root in an acid Oxisol depended on their ability to absorb Ca in the presence of high levels of Al.

Effect on rhizobium-legume associations

Legumes depending solely on symbiotic N_2 fixation are usually more susceptible to soil acidity than those supplied with inorganic nitrogen. Nitrogen fixation by rhizobia can be reduced by Al through injury to the host plant, reduced survival of rhizobia, and interference with various stages of nodulation and fixation (Foy 1988). Wood et al. (1984) concluded that rhizobia multiplication and nodule function are the most susceptible aspects of the symbiotic relationship to excess Al.

Because of the importance of symbiotic N_2 fixation for the N economy of forage production systems the capacity of forage legumes, not only to grow, but also to fix N under acid conditions assumes much significance in the selection of species. Fortunately many forage legumes of economic value are well adapted to acid conditions (Table 1).

Just as plants differ in their tolerance of acidity so do rhizobia strains. Therefore, both legumes and their symbiont rhizobia should be selected to tolerate soil acidity.

Table 1. Relative symbiotic tolerance of soil acidity for forage legumes. (Adapted from Munns 1978).

1. Highly tolerant
Centrosema sp., *Lotononis bainesii*, *Macroptilium lathyroides*, *Pueraria* sp., *Stylosanthes fruticosa*, *S. guyanensis*, *S. humilis*, *Trifolium rueppellianum*, *T. semipilosum*
2. Moderately tolerant
Desmodium intortum, *D. canum*, *Glycine max*, *Lablab purpureus*, *Macroptilium atropurpureum*, *Trifolium subterraneum*
3. Moderately sensitive
Glycine wightii, *Lotus corniculatus*
4. Highly sensitive
Medicago sativa, *M. scutellata*, *M. truncatula*, *Trifolium repens*

Adaptation Mechanisms

Adaptation to Al toxicity is shown by better root and shoot growth and more efficient use of nutrients (Wright 1989). An understanding of how species and varieties within species adapt to Al toxicity is needed for selection and breeding programs. However, the exact mechanisms involved are still not fully known. It is likely that adaptation is controlled by different genes acting through different biochemical pathways in different plants (Foy 1988). Proposed mechanisms of adaptation are summarised below. More detailed information is given in reviews written by Foy (1988), Marschner (1991), Roy et al. (1988), Taylor (1988) and Wright (1989).

As soil acidity involves a complex of factors affecting plant growth and as these factors vary with location and with soil depth, plants have had to acquire a variety of mechanisms to adapt to acidity (Marschner 1991). These mechanisms may act separately or in conjunction with each other (e.g. Al tolerance and efficiency in acquiring P). As with other forms of stress, plants adapt to Al toxicity by tolerance and/or avoidance strategies. Both strategies are probably required simultaneously, although to differing degrees.

Avoidance

Avoidance is achieved by exclusion of Al from roots. Exclusion occurs at the cell wall so that Al is prevented from entering the symplasm and reaching sensitive metabolic sites (Taylor 1988). The following mechanisms have been proposed:

1. Plant-induced pH changes in the rhizosphere. The pH of the rhizosphere can differ by more than two units from the main body of soil. This arises from differences in the net excretion of H^+ by roots to counteract imbalances in the ratio of uptake of cations to anions. The form in which N is taken up by roots (NO_3^- versus NH_4^+) has a large effect on rhizosphere pH. The preferential uptake of N as NO_3^- along with high nitrate reductase activity in apical root zones are the two main causes for the increase in rhizosphere pH in acid tolerant species (Marschner 1991). The increase in pH decreases the concentration of phytotoxic Al species in solution.
2. Low cation exchange capacity (CEC) of roots. Acid tolerant cultivars of wheat and cotton have been found to have low root CEC and accumulated lower concentrations of Al in their roots than did Al-sensitive cultivars (Foy 1988). Fewer sites on cell walls to which Al could bind would be expected to reduce the inhibitory effect of Al on cell wall expansion.
3. The plasma membrane acts as a barrier to uptake of Al and diffusion into the cytoplasm.

4. Release of chelating agents. Roots release organic carbon into the rhizosphere as mucilage, free exudates and sloughed-off cells. Organic compounds derived from these sources chelate Al and thus reduce its activity and toxicity. Mucilage, in particular, has a high capacity for binding Al at apical root zones and in the rhizodermal cells in the extension zone (Marschner 1991). Wright (1989) has pointed out that a large and continuous supply of chelating agent is needed to detoxify Al and that this would impose a considerable energetic cost to the plant. The amounts released may be as high as 30% of the total dry matter production (Whipps and Lynch 1986).

Tolerance

Once Al has penetrated plant tissue other mechanisms, such as detoxification, immobilisation and changes in metabolism, may operate to enable the plant to tolerate Al. Mechanisms of Al tolerance include:

(i) Al is compartmentalised in the vacuoles, which may be insensitive to Al toxicity;
(ii) Al is inactivated in the cytoplasm by binding with proteins or other chelating agents, such as carboxylic acids; and
(iii) differential distribution of tissue aluminium between tops and roots.

Phosphorus Nutrition

P deficiency is a major limitation of acid soils on account of their ability to fix large amounts of P. Al tolerance in plants is often associated with a low P requirement and/or increased efficiency in absorbing P from soils of low P status and in utilising P.

Table 2 shows that tropical forage species differ considerably in their requirement of available P in the soil to achieve near maximum growth (Sanchez and Salinas 1981). Of the legumes, Al-tolerant cultivars of *Stylosanthes capitata* have much lower P requirements than *Desmodium* and *Macroptilium* spp. The grass *Panicum maximum* also has a high P requirement. The use of this species without adequate maintenance of P fertility in the Oxisol-Ultisol regions of Latin America is a major cause of pasture degradation (Sanchez and Salinas 1981), and is a clear case of not matching species to soil constraints. Table 2 also illustrates the caution that must be exercised in interpreting soil analytical data. A given level of available P may be deficient for some species, but quite adequate for others.

One means by which acid tolerant plants are believed to absorb P from the soil in the presence of high levels of Al is by roots exuding organic acids.

Table 2. Critical level of available P in soil to achieve about 80% of maximum yield for forage species. (Sanchez and Salinas 1981).

Species and accession number	Critical level of Bray II available P
Legumes	
Stylosanthes capitata CIAT 1978	2.5
Stylosanthes guianensis CIAT 1200	2.5
Zornia latifolia CIAT 728	2.8
Desmodium ovalifolium CIAT 350	3.0
Stylosanthes capitata CIAT 1315	3.2
Stylosanthes capitata CIAT 1097	3.3
Zornia sp. CIAT 883	3.4
Pueraria phaseoloides CIAT 9900	3.5
Stylosanthes capitata CIAT 1019	3.5
Stylosanthes capitata CIAT 1338	3.6
Stylosanthes guyanensis CIAT 1153	5.5
Desmodium scorpiurus CIAT 3022	8.0
Macroptilium sp. CIAT 536	9.5
Desmodium gyroides CIAT 3001	11.4
Grasses	
Andropogon gayanus CIAT 621	5.0
Brachiaria decumbens CIAT 606	7.0
Panicum maximum CIAT 604	10.0

In addition to detoxifying Al by chelation, these acids dissolve sparingly soluble Al and Fe phosphates so that the released P is available for uptake. In some species part of the root mass has developed an enhanced capacity for acquiring P. For example, white lupin (*Lupinus albus*) has developed clusters of highly branched proteoid roots. Their rhizosphere soil is strongly acidified by the release of citric acid and it contains more reductors and chelators than the rhizosphere soil of the remaining roots (Marschner 1991).

In acid soils organically bound P may be the dominant form present in the soil solution. The presence of root-borne phosphatases enables plants to utilise this form of P. As the rhizosphere becomes strongly depleted of P, the activity of phosphatase increases enabling roots to use the organic P (Marschner 1991).

Another adaptation in P deficient soils is for plants to develop roots with large surface area in order to extract nutrients that move by diffusion from a larger soil volume. The formation of highly branched proteoid roots is an example of this adaptation. The surface area available for acquiring P is also increased when roots become infected with mycorrhizae. The most important group is the vesicular-arbuscular mycorrhizae (VAM), which extend their external mycelia into the soil. It is well established that several types of VAM increase uptake of P from soils deficient in P. Many tropical species tolerant of acid soil have been found to be heavily infected with mycorrhizae (Sanchez and Salinas 1981). These include the forage legumes *Centrosema pubescens*, *Pueraria phaseoloides*, and *Stylosanthes capitata*, and the grass *Brachiaria decumbens*.

The Role of Plant Adaptation in Forage Production

The most efficient means of increasing forage production from acid soils is to apply lime in conjunction with selecting species and varieties adapted to soil acidity. The use of tolerant cultivars does not mean that lime is not required. Many soils have levels of Al which are too high and/or levels of Ca and Mg which are too low to give economic yields without liming. Rather the use of cultivars adapted to acid soils enables more efficient use to be made of lime and fertilizers. The aim is to maximise the output per unit of applied chemical input (Sanchez and Salinas 1981).

The response of some tropical forage species to liming an Oxisol (pH 4.5) is shown in Figure 2. The acid tolerant grasses (*Panicum maximum*, *Brachiaria decumbens* and *Andropogon gayanus*) and legumes (*Stylosanthes capitata* and *Zornia latifolia*) produced maximum growth at liming rates of 0 and 0.5 t/ha. In contrast, the highly sensitive *Centrosema plumieri* gave negligible yields at these rates, and even at 6 t/ha its dry matter production was less than that of the tolerant legumes. The addition of 0.5 t/ha did not significantly alter the pH or Al saturation of the soil (Sanchez and Salinas 1981). The response shown by some cultivars, particularly *Desmodium ovalifolium*, to this low rate of lime is attributed to more Ca and Mg being available. Three factors may be involved in this response:

(i) the demand for Ca by these species is relatively low and is satisfied by the low rate of lime application,
(ii) these species are able to absorb Ca in the presence of large amounts of Al in the soil (Hutton 1985), and
(iii) Ca in solution can partially reduce Al toxicity (Foy and Fleming 1978).

Figure 2 also illustrates the need for including low rates of application (0-2 t/ha) when assessing response to lime. Thus the strong response of *D. ovalifolium* would not have been identified if the 0.5 t/ha treatment had been omitted.

The benefits of using cultivars adapted to soil acidity is widely accepted. However, their indiscriminate use without due attention being paid to soil fertility has led to a number of criticisms.

1. A species may be tolerant of acidity but does not necessarily yield well. *Digitaria decumbens* illustrates this point in Figure 2. It is therefore essential that for a given location a range of cultivars are evaluated in order to identify those that are both tolerant of acidity and give acceptable yields, such as *Panicum maximum* in Figure 2.
2. After establishment of forages insufficient attention is paid to their maintenance requirements. Failure to maintain soil fertility is recognised as the main reason for pasture degradation in Latin America. Forage development programs need to address the questions of maintenance requirements of species, the residual effects of lime and

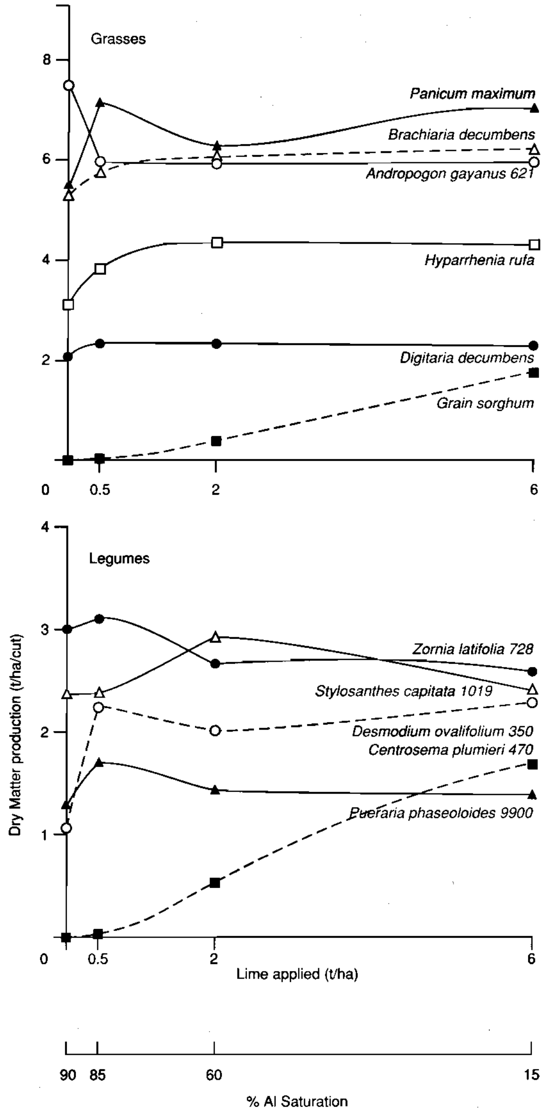

Figure 2. Response to lime application by grass and forage species grown on an Oxisol at Carimagua, Colombia. (Sanchez and Salinas 1981; adapted from Spain 1979).

fertilizers, weed infestation and the effects of grazing and harvesting.

3. It has been suggested that tolerant plants have a lower mineral content and hence lower feed quality. Table 2 shows that forage species differ considerably in their P requirements. Sanchez and Salinas (1981) reported that *Andropogon gayanus* required 50 kg P_2O_5/ha to achieve maximum yield, *Panicum maximum* 100 kg/ha and *Hyparrhenia rufa* 200 kg/ha or more. At levels of inputs where less demanding grasses produced good gains in cattle liveweight, *H. rufa* produced serious losses. CIAT (1979), however, found no evidence that the use of pastures requiring less P provides insufficient P to meet animal requirements. Furthermore, many mineral deficiencies can be overcome by supplementing animal feed. Forage development programs need to investigate not only the plant but also the animal response to chemical inputs.
4. The use of tolerant species is a temporary palliative and soil fertility will eventually be run down to the point where even tolerant species cannot be grown. This view often assumes that no chemical inputs are to be used. An essential requirement for achieving sustainable production is that adequate lime and fertilizers are used in conjunction with tolerant species, full attention being given to maintaining soil fertility. In addition, the processes causing soil acidity have to be addressed and farming systems have to be devised so that their effects are minimised. For example, farm management practices are being developed in southeast Australia to reduce leaching of nitrate from the soil, a major cause of acidification in legume-based pastures.

Considerable progress has been made with the selection of species and varieties adapted to Al toxicity. In some species the genetic control mechanisms are beginning to be understood and cultivars have been developed for tolerance to Al toxicity (Foy 1988). A good example is the breeding of tolerant lines of *Phalaris aquatica* by Culvenor et al. (1986)

Breeding for Al tolerance is, however, still in its infancy. Further progress depends on a better understanding of the genetic, physiological and biochemical mechanisms involved, and how these operate at the cell, tissue and whole plant levels. As yet no generally accepted theory on how plants withstand Al toxicity exists. There is also the need to establish critical Al and nutrient levels in the soil for a wide range of forage species.

Once soil and climatic requirements have been identified species and varieties can be matched to local conditions. Much work needs to be done in this respect for the red soil region of China. The reward will be efficient use of lime and fertilizers and, given sound management, the establishment of viable forage production systems.

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Principles of Forage Establishment for the Upland Red Soils

J.M. Scott*

PASTURE establishment can be risky and expensive. In order to minimise the risk and cost, it is necessary to understand the limitations which constrain establishment and how we can overcome these limitations.

Pasture establishment can be described as the entire process of germination, emergence, seedling growth and survival until a stable population is achieved. The level of final establishment which is achieved depends largely on the size of young plants which, of course, depends on the speed of seedling growth. Final establishment is only indirectly related to emergence and germination. In order to achieve successful establishment of pasture plants it is important that seedling growth be as rapid as possible, particularly when compared to the growth of any weed species.

Establishment can be conveniently grouped into two principle phases. During the first phase — germination/emergence — the most critical factor is usually soil moisture. The second phase is that of seedling growth/survival during which the most critical factors are the length of dry periods, the degree of competition, and the characteristics of the seedlings.

Limitations to Establishment

Forage establishment can be limited by a great range of factors. The main factors will be described in more detail below under the headings of environmental, soil, biological, and management constraints.

Environmental limitations

Moisture. Ideally, a seed should make good contact with available water which should be freely available and the atmosphere should be moist. Moisture transfer from the soil to the seed needs to exceed that from the seed to the atmosphere. Soil moisture depends not only on the quantity, duration, and intensity of rainfall but also on evaporation.

Soil moisture not only affects germination but also the hardness of soil, thereby affecting the entry of the radicle (the primary root) into the soil. Hard soil can be particularly serious for surface sown seeds as they rely on getting access to soil moisture following entry of the radicle into the soil. For surface sown seeds, establishment is usually best when the soil moisture is high for at least six weeks after sowing.

Limiting soil moisture leads not only to wilting of plant tissues such as the radicle and leaves, but it also leads to reduced nutrient uptake and reduced root growth.

Shading reduces the effects of low moisture and results in higher germination and emergence. As shown in Figure 1, covering seeds (e.g. with mulch) can result in higher germination, especially of seeds sown on the soil surface.

The soil type affects the access which seeds have to soil moisture because fine-textured soil restricts the flow of moisture more than does coarse textured soil. In contrast to the common occurrence of too little soil moisture, too much soil moisture can lead to waterlogged conditions; this can restrict the oxygen supply to the seed and/or encourage fungal disease, thus affecting germination.

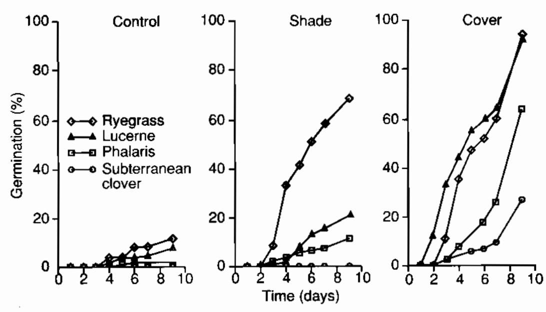

Figure 1. Influence of simulated cover (straw) and shading on the cumulative germination of four pasture species (McWilliam and Dowling 1970).

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In general, it is a desirable establishment strategy to maximise seedling growth while soil moisture is non-limiting.

Temperature. Temperature tends to influence germination rate more than total germination; thus, unless the temperature is extreme, establishment will not be severely affected. Although very high temperature will severely limit germination, low temperatures will slow germination, reduce seedling growth rate, reduce the effectiveness of the legume-*Rhizobium* symbiosis and can result in an increase in the incidence of seedling diseases.

Temperate species germinate best at alternating temperatures of 15–25 °C; tropical species have a somewhat higher optimum temperature for germination (e.g. kikuyu, *Pennisetum clandestinum*), 19–29 °C). In addition to affecting germination, temperature also affects growth and hence competitive relationships between species. Thus, the temperate species, ryegrass (*Lolium perenne*), is favoured by 23 °C (max)/17 °C (min) whilst a tropical C4 grass, *Bothriochloa macra*, is favoured by temperatures of 31 °C (max)/25 °C (min) (Cook et al. 1976).

Light. Light is not usually limiting to plant establishment, provided that competition is controlled. Low light caused by shading does, however, markedly reduce moisture loss from seeds. In a few species, light is required for the germination of seeds, although this is not common.

Microclimate. Microclimate refers to the atmospheric conditions immediately surrounding the sown pasture seed. These conditions are especially important for surface sown seed. Residues of dead plant material lower the soil temperature, reduce light and increase humidity, thereby often increasing germination.

Soil limitations

The soil is a major influence on the success of establishment from the germination stage through to the ultimate survival of established seedlings. Any soil conditions which constrain root growth will result in lower water uptake by roots, lower nutrient uptake, thereby restricting root and shoot growth and ultimately leading to reduced survival.

Physical

Soil structure, or the degree of aggregation of soil particles, is closely related to the amount of seed/soil contact which affects the speed of water uptake during imbibition (Bruckler 1983). The loss of structure can result in crusting which reduces the emergence of seedlings, especially legume seedlings.

The texture, or fineness of a soil, affects the water holding capacity and also the tenacity with which the soil holds water. This means that, whilst coarsely-textured soils cannot hold a lot of water, they do give it up freely in contrast to soils with a high clay content.

Compaction is often measured as bulk density (i.e. dry weight per unit volume). Work by Eavis (1972) has shown that root elongation is inversely proportional to soil bulk density. Hence seedling growth and establishment depend on compaction and this interacts with soil moisture. Figure 2 shows the relationship between root growth, bulk density and soil moisture.

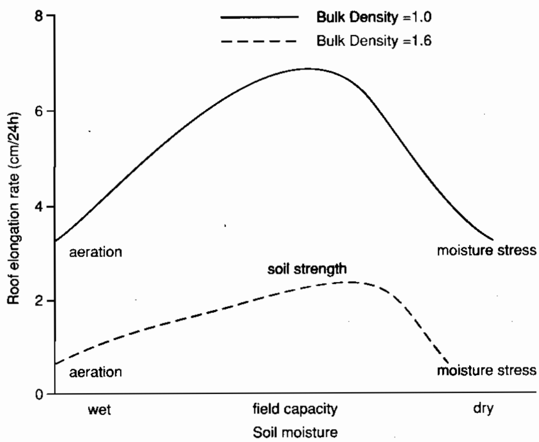

Figure 2. Effect of soil moisture and bulk density on root elongation rate (Eavis 1972).

Microtopography. Just as microclimate is important to the germinating seed, so is microtopography — that is, the degree of surface roughness determines how suitable small sites are for seeds to germinate, anchor themselves and achieve entry of the radicle into the soil.

Chemical

Nutrients. The most common nutrient deficiencies which limit establishment are nitrogen (N), phosphorus (P) and sulfur (S). If any of these deficiencies are present, seedling growth will be restricted leading to reduced establishment. Root growth can be promoted greatly by additions of P and N. Lin (1985) showed large responses to N and P fertilizers in Jiangsu Province. The influence of early nutrition on seedling growth of phalaris is shown in Figure 3.

Nutrients need to be readily available — especially for young seedlings — because the capacity of young seedling roots to extract nutrients from the soil solution is very much less than that of older plants. For example, the critical concentration of P in the soil solution for *Desmodium* is 0.2 ppm during establishment but, 0.01 ppm after establishment (Fox et al. 1974).

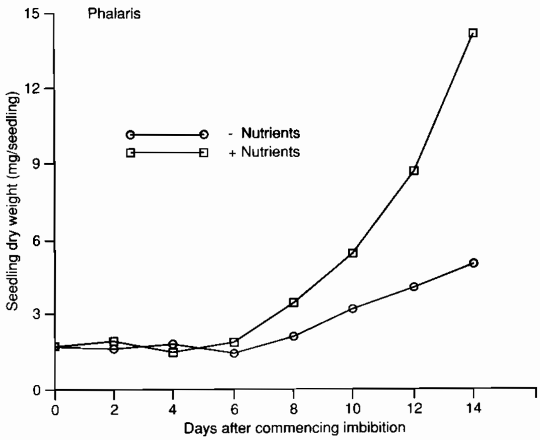

Figure 3. Dry weight of phalaris seedlings grown with or without nutrients (McWilliam et al. 1969).

pH. Although high pH can be associated with poor establishment in some situations, it is more common for low pH to limit establishment. Acid soils, which are common in southern China (Liu et al. 1978), limit the supply of P, Ca and Mo and can increase some elements, such as Al and Mn, to toxic levels.

Low pH can also influence the success of the legume-*Rhizobium* symbiosis. This can be overcome by lime pelleting seeds to protect the rhizobia and/or by liming the soil.

Biological limitations

Competition must be controlled if sown species are to have access to sufficient resources to survive a period of stress. If they are to dominate a sown area, establishing pasture plants need ultimately to grow larger than neighbouring weeds; the extent of establishment success depends on differences between the weeds and sown species in their time of establishment, their nutrition, and their susceptibility to mortality under stress.

Competition occurs for limiting resources of moisture, nutrients and light (with a strong interaction between all three). Commonly, root competition is very much more intense than competition between shoots. Species differ greatly in their capacity to compete for resources. For example, an establishing cocksfoot sward has a root volume about 20 times that of establishing white clover.

Competition is imposed not only by established weeds but also by seedling weeds. Whereas normal sowing rates for pasture species are often 100–700 seeds/sq m, weed seed populations in some soils can be up to 100 000 seeds/sq m (Kwon and Chung 1980). If even a small proportion of the weed population germinate soon after sowing pasture seeds, the resulting intense competition can result in establishment failure.

Nutrient additions influence the competitive ability of various species (especially competition between legumes and grasses). If a soil is low in N then legumes will have a competitive advantage and hence legume dominance may result. Alternatively, if the soil is high in N, then grass dominance is likely to occur. These results are due partly to differences in the cation-exchange capacity (CEC) of the roots (legumes having a higher CEC) and partly to differences in root morphology (grasses have a more fibrous root system and greater root volume).

Competition for light can be important if moisture and nutrients are not limiting. Even slight differences in plant height or in leaf orientation can confer large competitive advantages on the species with better access to light (Donald 1963).

Allelopathic effects. Allelochemicals (or toxic materials released from vegetation) may be leached from dead or dying plants, especially those killed by herbicide. Thus, when planting after competition is killed by herbicides, it may be necessary to delay sowing for one or two weeks, depending on environmental conditions. However, in general, allelopathic effects are minor compared with competitive effects.

Diseases. 'Damping-off' diseases (often caused by the fungi *Fusarium, Pythium* and *Phytophthora*) can cause serious losses of seedlings. They are usually more damaging under cool, damp conditions as shown in Figure 4. These diseases can be controlled

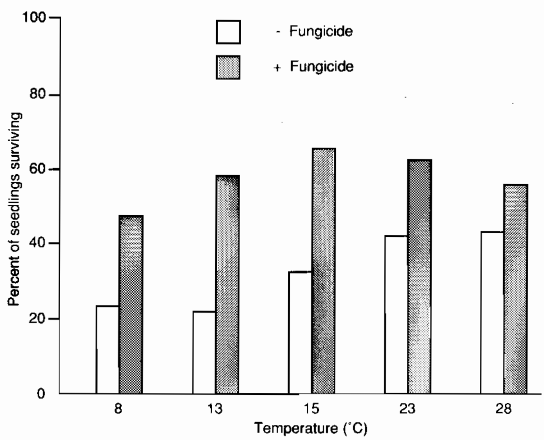

Figure 4. Survival of ryegrass seedlings 28 days after sowing with or without fungicide in soil at different temperatures (Falloon 1980).

adequately with seed-applied fungicides which not only can increase plant numbers, but can also reduce effects of sub-clinical fungal infections and thus result in more vigorous growth.

Fungal infections which reduce pasture production after establishment are best controlled through the use of resistant or tolerant varieties as control with fungicides is difficult to achieve and costly.

Pests. Ant-theft can be a serious problem, particularly for seeds sown directly onto the surface. The application of insecticides in a seed treatment is effective in reducing such losses.

Some of the other insects which can be very serious in limiting establishment include various mites, aphids, grass grubs, crickets and grasshoppers. If they occur, treatment with sprays and/or chemical baits can be effective in reducing the problem.

Molluscs (e.g. slugs) are usually most damaging under wet conditions and where the soil has not been cultivated. Whilst control is difficult to achieve, plants usually become resistant once they reach the 5-leaf stage.

Genotype. To achieve adequate pasture production and persistence, it is essential to sow plants which are well adapted to the target environment. However, species which are well adapted and highly productive are not necessarily those which are easy to establish. Thus, many productive species have relatively weak seedlings. Whilst it is possible to select for establishment ability (e.g. as with phalaris) it is expensive and time-consuming as 'establishment ability' has a relatively low heritability.

There are large differences between species in their establishment ability, especially when they are surface sown. These differences diminish as sowing conditions improve. The reasons for these differences in establishment ability include variations in germination at limiting moisture (see Fig. 5), root growth under nutrient limitations, and seed size — larger seeds tend to establish better when sown in the soil whilst smaller seeds have an advantage when sown on the soil surface.

A productive and persistent pasture normally requires a suitable balance between grasses and legumes. In order to establish both components satisfactorily, it is useful to consider some of the differences that exist between legumes and grasses.

Legumes normally have faster imbibition and germination rates than grasses. For example, at 10 °C, legumes can germinate in 4 days whereas grasses may take as much as 12 days (see Fig. 6 below). Legumes tend to have faster root extension rates, have the capacity to fix N, and have a higher CEC at their root surfaces.

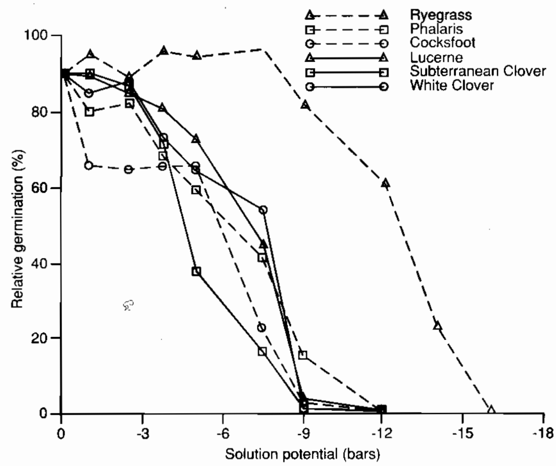

Figure 5. Germination of a range of temperate legumes and grasses over a range of moisture tensions (McWilliam et al. 1969).

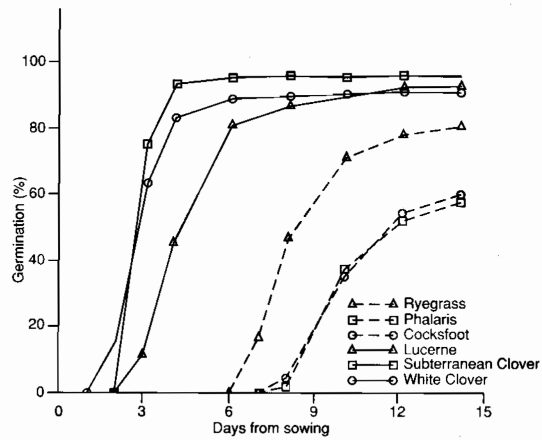

Figure 6. Germination over time of a number of temperate grasses and legumes (McWilliam et al. 1969).

Grasses are better able to emerge through a soil crust (due to their fine coleoptile); their fine roots can enter soil cracks more readily and thereby gain access to water better than legumes; they can extract lower levels of soil nutrients; and they have a lower physiological requirement for light.

Management limitations

Sowing rate. The choice of sowing rate is generally a compromise between the rate which will achieve a satisfactory stand and keeping costs to a minimum. Sowing rate varies enormously due to differences in the germination percentage of different seed lots and the large range of seed sizes. If weed control is good, increasing the sowing rate can increase the speed with which the sown area is dominated by the sown pasture. However, in competitive situations, increasing the sowing rate will not necessarily result in successful establishment.

In all cases it is desirable to sow seed of high quality which has good vigour, a high germination percentage and which contains minimal weed contaminants.

Sowing depth. Because of their relatively small size, pasture seeds normally emerge best when sown at a relatively shallow depth (5–20 mm). The preferred depth depends on:

- seed size (shallower for small seeds),
- soil texture (shallower for fine texture),
- aggregate size (shallower for fine size), and
- soil moisture (shallower in wet soil).

Sowing time. The choice of sowing time depends largely on the expected seasonal conditions as these will affect not only soil moisture and germination rate, but also weed growth and pest activity. Thus, in general, the preferred sowing time is normally at the beginning of a reliable wet season and at a time when temperature favours germination and growth of the sown species.

Conclusion

If the ruminant livestock production from the upland soils of South Central China is to be increased substantially (Wang 1988), then productive pastures will need to be established over large areas. Achieving successful establishment will depend on the sowing of the most appropriate species, the use of high quality seed, and overcoming many of the limitations to establishing seedlings listed above.

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The Characteristics of Forages Growing on Red Soils in the Subtropics of China

Ma Zhi Guang and Li Bo*

PLANTS have a critical role in the flux of energy and gas circulation in terrestrial ecosystems. They also have a profound effect on soil formation and fertility.

Native plants are adapted to the prevailing climatic and soil conditions via a variety of mechanisms and morphological features. As a consequence of this and the wide range of environments found in China there is, in China, a wide variety of natural plant communities.

In China temperatures decrease from south to north and the vegetation changes from tropical rainforest to evergreen broadleaf forest. A declining gradient of rainfall from east to west is superimposed on this temperature gradient with the vegetation changing from forest, steppe, desert grassland to desert. Some plants can be found in a range of climatic environments and they do so by changing their phenotype.

Subtropical vegetation

Subtropical regions of the world, around the tropics of Cancer and Capricorn, are generally characterised by deserts. By contrast the subtropical region of China is characterised by evergreen broadleaf forests which cover nearly 25% of the total land area containing species of *Cyclobalanopsis*, *Schima* and *Cinnamomum*. Some heat tolerant legumes and grasses found in the region are *Mimosa pudica*, *Dicranopteris linearis* and *Miscanthus floridubus*. These plants and their associated communities have developed on both the red and yellow soils.

Soil and climate characteristics

The area of land classified on the basis of degree days ⩾10 between 4500 and 7500 °C extends from the tropic of Cancer to 34 °N and covers 17 provinces. The soils of the region are red to yellow and acid (pH 4.5–5.5).

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The region is characterised by extremes in temperature with a range of 0–15 °C in winter with minimum temperatures as low as −17 °C. High temperatures occur in summer (25–30 °C). The frost-free period ranges from 250 to 300 days. Although the annual average rainfall is in the range of 1000 to 3000 mm the distribution throughout the year is uneven resulting in periods of excess and extreme moisture deficits.

Where the forest areas are cleared predominantly grass communities of both native and naturalised species quickly develop. Species that make up these communities have a range of adaptive characters that proffer a comparative advantage to them. These include:

- *Adaptation to high soil and air temperatures and high evaporation*. Some perennial forage grasses such as *Ischaemme ciliare* and *Saccharum spontaneum* have short white hairs on their leaf blades and sheaths. In *Sporobolus virginicus* the ligule has degenerated into a series of long hairs which reflect heat. Examples of other adaptive features of plants of the region are a waxy surface on the leaf to reduce water loss (*Sorghum sudanesis*), ability to incline the leaf away from direct sunlight (*Macroptilium atropurpureum* and *Stylosanthes humilis*), leaf rolloing to reduce heat load and water loss (many grass species), high temperature dormancy (*Phalaris aquatica*) and a well developed tap root that is able to extract water from cooler soil layers (*Medicago sativa*).

- *Low winter temperatures*. Most of the C4 grasses found in the region lose all green leaf as temperatures fall. When frosting occurs the mature tillers are killed so that new growth is initiated from auxiliary buds protected in the base or crown of the plant. Some plants adapt via osmotic regulation of the cell sap. An osmotic strength of −26.06 bars has been recorded in the temperate Russian wild rye.

- *Grazing pressure*. Some species such as *Arundinella hirta*, *Axonopus compressure* and *Saccharum spontanean* possess rhizomes or stolons which allows them to withstand heavy grazing or cutting. These characteristics also bind the soil and therefore reduce erosion.

Because of the high temperatures and favourable moisture conditions during spring and autumn the naturalised grass communities are dominated by C4 species. These species are generally high in fibre, low in protein and their vigorous growth habit makes them difficult to combine with legumes. The dilemma facing agronomists in the region is whether to try and introduce other C4 grasses and tropical legumes with more favourable quality characteristics or to concentrate on C3 temperate species.

The genus *Setaria* contains both C3 and C4 members which provides a wide gene pool for selection and possible crossing. Recent research at Nanking University has successfully developed a new *Festuca* × *Lolium* hybrid which is drought tolerant. Studies have shown that the yield of the hybrid is greater than either parent. Both breeding and selection from within present germplasm are likely to produce plants better adapted to the region.

Introduced forage productivity

By understanding the characteristics of each species it is possible to match the plant more closely to the ecological niche into which it is sown. This will lead to a wide range of forages being sown in the region either as monocultures or as mixtures.

Paspalum wettsteinii is a creeping rooted C4 perennial grass that is tolerant of cold temperatures and can survive winter temperatures as low as 0–3 °C. Sowing of this species in a mixture with *Stylosanthes guayanensis*, *Macroptilium atropurpureum* and *Trifolium repens* is likely to produce a pasture with favourable growth and quality characteristics.

Another cold tolerant grass, *Setaria anceps*, appears promising. A *Setaria anceps–Leucaena leucocephala* pasture cut four times per year yielded 25.6 t/ha. In the same study a mixed *Macroptilium–Leucaena* stand produced 42.2 t/ha.

By understanding the soil and climatic conditions in a particular location appropriate forage species with adaptive features suited to that location can be selected. Understanding their physiology and the feed requirements of the system will lead to the development of appropriate management systems.

The Major Pasture Insect Pests in Southern China

Tu Mingyi*

THE grasslands of southern China at altitudes between 800 and 2000 m experience a mild climate with adequate rainfall. These conditions provide insects with favourable conditions to flourish. They therefore multiply rapidly, causing pasture losses to the detriment of animal production.

The pasture pests which occur on the State-owned Nanshan Pasture Farm in Chengbu County in Hunan Province are typical of the region as a whole. The two most damaging species are army worms and chafers. To date the Farm has overcome the problems caused by changes within army worm populations and has developed strategies to control them. Satisfactory measures to control chafers are still to be developed.

Army Worm Damage

Extensive infestations of army worms have been recorded since 1979 when sown pastures were first established. These infestations have affected hundreds of hectares of pasture and population densities of several hundred worms per square metre have been recorded. After destroying an area of pasture the army worms move, en masse, to another area. As a consequence large areas are left devoid of herbage. The proportion of sown pasture affected by army worms and population densities are shown in Table 1.

Table 1. Army worm occurrence at Nanshan Pasture Farm.

Year	Total sown area (ha)	Area affected (ha)	Population density (worms/m^2)
1979	110	110	624
1980	200	200	680
1981	1 000	670	450
1982	2 300	670	117
1983	3 300	1 300	117
1984	4 000	1 300	93

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In 1976 there was a large infestation in natural grassland with larval densities up to 185/m^2. In 1977 and 1978 the population was too low to be calamitous. In May 1979 110 ha of newly sown pasture was eaten by army worms within 20 days between June and early July. This pasture had to be resown in August.

In 1980 an infestation became so severe, with larval densities of up to 826/sq m, there was no grass available for cattle or sheep. Since then the severity of infestations has waxed and waned and potential damage has been limited by successful control strategies. Nonetheless, army worm infestations remain a problem in pasture management and consequently in animal husbandry.

Population fluctuation

The major species of army worms are *Mythinma separata* (Walker), *Mythinma loreyi* (Duponchel) and *Mythinma compla* (Moore). Of these three major species *M. separata* is the most serious comprising 80% of worm infestations; *M. loreyi* 8–10% and *M. compla* and others about 2–3%.

At Nanshan Pasture Farm army worm damage occurs from the end of June to early or mid-July. By light trapping it has been found that the first insects appear in mid-March, but these do not multiply to harmful levels. In mid-June there is a population explosion. For instance, in an insect forecasting survey, in which 20–30 bowls with sugar and vinegar were put out, the average number of larvae trapped per bowl in early June was 1 to 2 per bowl. In mid-June the number had jumped to 20 to 30. Trap lamps in the last few years have caught a small number between mid-March and early June and a large number of adults after June 10. The adult peak in mid-June causes a larval explosion at the end of June. In mid-June larvae reach the 4th and 5th instar stage and have such a large appetite that they do severe damage to pastures until late July. At Nanshan, damage occurs mostly from the end of June to early or mid-July. From August to September the second and third generations of larvae appear but these populations are not great enough to cause serious damage.

Insect infestation

Anecdotal evidence supports the notion that army worm moths are migrants from areas further to the south. Moths caught in mid-June have an untidy shape, breaks on the wing edges, little wing powder and small fat reserves. These factors all point to them having flown from distant locations. In addition, the high temperature in the south, prevailing southerly or south-westerly winds and milder, moist, conditions at Nanshan give support to the notion that the moths migrate to a more favourable environment. The sudden appearance of adults in large numbers in mid-June is consistent with the behaviour of army worm seasonal-group migration.

The over-wintering area for army worms is to the south of latitude N 33° and although Nanshan is located on latitude N 25° only a small number of insects survive because of its altitude (1000–1800 m a.s.l.) which results in occasional low temperatures. Winter surviving pupae can be found in the soil of severely damaged pastures in late autumn and early winter.

In addition to there being a large number of immigrants, there are a number of other factors which promote high populations.

Factors favouring army worms

Army worms thrive in a warm and humid environment. The optimum temperatures for egg laying and larval development are 9–22 °C and 18–25 °C respectively. In Nanshan the temperature between June and August is 18–25 °C and the relative humidity is above 80%. Thus climatic conditions are favourable for egg laying and larval development.

These same conditions at Nanshan are also favourable for pasture growth which in turn provides a favourable micro-environment for army worms and abundant food. In June, sown white clover is in full blossom which provides nectar for the moths and adults soon become fertile and lay large numbers of eggs. Female moths caught ten days after hatching have been found to have 600–2000 eggs. Sown ryegrass is a preferred food of larvae which feed on the grass causing substantial damage.

Chafer Damage

Chafers are generally not observed in newly sown pastures therefore little attention has been given to them. However, by the summer of 1984 chafer activity had increased markedly and previously thriving ryegrass pastures had been severely damaged. The root systems were damaged to the extent that simply pulling the above-ground parts separated the stems from the roots. Examination of the soil showed a chafer population of 50–60/sq m. Since 1984 damage to pastures by chafers has increased in severity.

More than ten species of chafer have been trapped by lamps. The most common species are *Maladera orientalis* (Motsch), *Maladera verticalis* (Fairmaire), *Metabolus flavescens* (Brenske), *Metabolus tumidifrons* (Fairmaire) and *Melolontha hippocastani mongolica* (Mentries) from the Melolonthidae family and *Callistethus plagiicollis* (Fairmaire) from the Rulelidae family. The most common species are *C. plagiicollis* and *M. tumidifrons* which caused severe damage in 1985 and 1986.

Chafer densities

The number of chafer larvae in the top 10 cm of soil has been found to increase from 50–60/sq m in mid-March to 130–150/sq m in April. In mid-May densities of 50/sq m are common. Very little activity is detected in June, July and August.

The population increases again in September and may reach 100–150/sq m in October. The larvae move down in the soil profile in late November reducing the population in the top soil to less than 50/sq m. The population rises again in the following March.

Pupation begins in early May leading to a peak in late May and reaching its end in mid-June. Emergence of adults begins in early June with a peak in mid- or late-June and climaxing at the end of July. Fluctuations in population result in damage to root systems in March–May and July–November.

Pasture root systems are concentrated in the top soil (0–10 cm) and therefore grass which has been damaged by chafers can be rolled away from the soil surface.

The growing of legume crops, across large areas, is thought to be a major contributing cause of a build-up in chafer numbers. The use of light traps since 1987 has successfully reduced chafer populations and pasture damage.

Natural Enemies

There are many natural predators of both army worms and pasture chafers but no systematic investigation has been undertaken to identify these. Amongst the predatory insects caught by net are *Apanteles kariyai* (Watanabe) and *Apanteles nificuis* (Haliday) together with predatory species and ants.

There are micro-organisms too that play a part in the control of army worms and chafers. Some of the pupae dug from grasslands have been found to be infested with *Beauveria brongniartii* and the fungus *Melarrhizium anisopliae* (Melschan).

Control

Army worms

In recent years physical measures have generally been the major method of insect control with less emphasis on biological control.

Common physical control measures include trapping the army worm adult with a sugar-vinegar-wine solution and lamps, trapping eggs by distributing bundles of straw throughout pasture lands on which the eggs are laid. The bundles are gathered every 3–4 days and burnt — using this method the number of egg masses destroyed varied from 7–61 per bundle, with the average number of eggs per egg mass being 300. By grazing heavily from early June the feed supply for larvae was reduced contributing to effective control.

Duck grazing has also been shown to be an effective control strategy for army worms. A duck can prey on 1500–2500 larvae per day, is relatively simple and has the added advantage of supplying food for the ducks.

Chafers

For chafers the main method of control is light trapping of adults. At the peak of adult emergence a single lamp can trap several thousand (up to 5400) each night. The lamps now operating at Nanshan Farm can trap tens of thousands of chafers each night which is significant in reducing grub populations.

The Purpus privet trees growing throughout the pasture also attract chafers. At around 2100 hours the chafers fly to and stay on these trees to mate. By exploiting this insect habit it is possible to attract and then kill many of the pests which congregate on the trees.

Conclusion

The methods of control described are effective to an extent but will not eliminate the pests. The success of physical control measures is affected by a number of factors which will always prove difficult to overcome. For instance the climate in Nanshan is such that fog and rain can reduce the effectiveness of light trapping. Similarly power supplies are often not reliable. Sugar-vinegar bowls and straw bundles are also limited in their use by labour and the availability of materials.

Greater emphasis needs to be placed on the natural predators to these detrimental pests. This will only occur if thorough investigations are undertaken of the ecology of both the pests and their predators.

For the control of insect pest in southern grasslands, emphasis should be placed on biological methods with physical methods only being employed where absolutely necessary. Biological insecticides such as the powder solution and emulsion of *Bacillus thuringiensis* (Berliner) can be spread to control army worms and segregated *Beauveria brongniartii* and *Metarrhizium anisopliae* (Metsch) can be made into a bacterial powder to infest the larvae and winter-surviving pupae of army worms.

Researchers need to be aware of the need for an understanding of the interactions which exist between plant disease, insect pests, weeds, fertilisation and grazing.

Tree planting to improve landscape stability and to provide a habitat for predator birds is another opportunity which should not be overlooked.

An Approach to Agricultural Development and Soil–Soil Moisture Conservation in Red Soil Areas of South China

Richard G. Grimshaw and James W. Smyle*

CHINA has the need to increase agricultural output. Towards this objective there are two opportunities. The first is to increase yield per unit area now under cultivation. The second is to open new areas to agricultural development.

Although there are clearly possibilities of intensifying production in existing areas through more efficient use of technology and physical inputs such as water, the potential for major yield increases in lowland agriculture and irrigated small grains is limited. This applies particularly to the traditionally irrigated areas growing rice. In contrast, a great deal more attention has to be given to those lands dependent on rainfall, for it is there that the greatest depletion of soils is taking place and where there is good potential for bringing under utilised land into higher levels of production.

Red Soils Development

South China in particular is an example where the potential for rainfed agriculture is great. Less populated than the central and northern plains, its population is generally poor, and yet it is endowed with long growing seasons and ample rainfall for good crop production. Given the favourable climate and fertile soils, the region can be highly productive; however, low natural fertility is characteristic of a major soil group which occupies some two million square kilometres of the 14 provinces in south China. These are the 'red soils', so-named due to their characteristic red or yellow subsoil colours. They are variously classified as Ultisols or Acrisols and Ferralsols, or Lateritic soils and Latosols. However referred to, they are acidic in nature, tend to have low cation exchange capacity (in the order of 10 to 30 meq/100g); high aluminium saturation (in the order of 50 to 90%); major nutrient and some trace element deficiencies with P most often limiting; relatively low organic matter content; and low available water-holding capacity. With the low available P and organic matter status, Al toxicity is a major problem.

In their degraded state, these soils are also likely to be poor in a biological sense, which has significant implications for nutrient cycling. Despite their problems, a large percentage of red soils should respond well to management. The soils, where not heavily eroded, are generally deep and well structured, and the 1:1 type clays along with oxides of iron and aluminium assure workability. Those lands which are not too greatly degraded can, with careful husbandry, support a diverse agriculture that includes both annual and perennial crops and livestock. Being close to the important south China industrial and export coastal cities of Guangzhou, Hangzhou, and Hong Kong it is likely that the red soil areas will ultimately play a vital role in China's long-term development.

In practice, red soils development requires large amounts of manure and organic carbon inputs. In Fujian and Jiangxi provinces between 20 and 30 t/ha of farmyard manure (FYM) and about 30 t/ha of green manure may be utilised in the first year for fruit tree establishment on red soils. For annual cropping, between 15 and 45 t/ha of FYM may be utilised to initiate production. As high as these inputs may seem, yet even higher initial inputs can be called for, even up to 70 to 100 t/ha (Brady 1984).

It is not possible to take a short cut and bring these soils into productive use with inorganic fertilizers only. Work at the Red Soils Institute in Jiangxi has demonstrated that in the absence of organic inputs there is a deterioration in soil structure and yields cannot be sustained; nor would inorganic fertilizers alone have sufficient effect on a number of the other systemic problems of red soils. Recent experience has shown that with these levels of organic inputs, nutrient availability is increased significantly and the soils' moisture holding capacity is increased by about 30% (Gruenwald 1990), resulting in the time to

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The opinions expressed in this paper are those of the authors, and not necessarily endorsed by the World Bank.

wilting after soil saturation being doubled (Chisolm 1990).

The benefits of organic matter inputs have also been reflected in the incomes of farmers participating in the Red Soils I Agricultural Development Project (supported by the World Bank) with Jiangxi project farmers experiencing a 155% income increase over five years and Fujian farmers incomes increasing between 30% and 90% dependent on the time the farm had been operational. In the last three years Jiangxi Project farmers following the practice of using these high organic inputs had net incomes that ranged from about 35 to 55% higher than from non-Project farms (Gruenwald 1990). The solution to red soils development has been to provide sufficient manure and organic carbon; the problem, however, is how to do so.

Producing sufficient organic material is not the only problem. Cultivation of red soils without appropriate management measures will only accelerate soil losses from the uplands with relatively immediate impacts on the near lowlands. One county in Guangxi has lost 30% of its irrigation capacity to sedimentation of reservoirs and irrigation canals (Dr. Lou Guozhang, Agricultural Regional Planning Commission of Guangxi, pers. comm.); based on official figures for reservoir sedimentation rates, upland erosion in one Guangxi watershed is of the order of 80 to 100 t/ha/yr. In Zhejiang, a maize–potato intercrop on 15° slopes resulted in a 28 t/ha/yr soil loss (Dr Yan Xue-zhi, Soil & Fertilizer Station, Bureau of Agriculture, Zhejiang Province, pers. comm.).

Over large areas of south China up- and down-slope cultivation of rainfed crops is too common. Even where soil conservation measures, such as terraces, are taken they may often be inadequate. Terraces which have excessive outward slopes and/or lateral slopes (due to design or as a result of erosion) are a common sight in red soil areas. In one Fujian township, where the entire upland has been converted to citrus terraces, the amount of sediment removed annually from irrigation canals suggests that the erosion rate in that watershed area is of the order of 65 to 130 t/ha/yr.

In addition to the costs incurred in the lowlands as a result of upland soil losses, more immediate are the costs to the farmers themselves. It is well documented that increasing erosion results in increased surface runoff leaving less available soil moisture for crops; crop water-use efficiency declines and yields are depressed (Doolette and Smyle 1990). In Fujian, some 7000 ha of maize are planted each year in an up- and downslope pattern on 5° to 15° slopes. According to the Fujian Agriculture Development Corporation in 30% to 40% of years these crops fail due to drought stress. Significant yield gains are therefore shown to be possible from even the simplest intervention, such as contour cultivation.

Soil and Moisture Conservation

South China is well suited to producing coarse feed grains such as maize and sorghum that are in high demand by an expanding livestock industry. In its own right, the area has high potential for livestock production. Because the temperatures are not unduly low the energy demand by cattle, pigs, and poultry during the winter months is much less than in the north, hence feed conversion should be more efficient. The potential for growing high value fodder crops including some of the nitrogen-fixing tropical and temperate legumes adds to the potential of the area. It is through such mixed livestock and crop farming that the neces ary animal and crop residues can be provided. In addition, with the use of manures, basic subsistence crops of sweet potatoes and other vegetables have good possibilities.

Cropping of coarse feed grains would, naturally enough, not take place in irrigated lowlands, rather on the lower slopes on rainfed lands. On such lands in south China, crop failure often occurs due to inadequate or poorly distributed rainfall. Because of frequent failures, farmers are often reluctant to invest scarce resources in the production of these grains. As a result yields are even further depressed.

The main problem is often moisture. Two possible solutions are contour cultivation to slow runoff and increase infiltration; secondly, contour vegetative barriers to stabilise the contour cultivated areas and cause surface runoff to be spread more uniformly and increase infiltration. Contour cultivation alone has been shown to increase yields by about 25% on slopes up to 7° (Bhatia and Choudhary 1977; Dhruva 1986; Liao 1981; Mittal et al. 1986; Padmaraju and Rao 1990).

With the addition of an appropriate contour vegetative barrier such as Vetiver grass, yields have been shown to be increased another 15% over contour cultivation alone or almost 45% higher than from non-contour cultivated land (Bharad and Bathkal 1990; Padmaraju and Rao 1990). These techniques are relatively simple and cheap to implement and a logical precursor to the utilisation of improved seed, increased organic or inorganic inputs, improved crop management, etc. As well, they assure a larger and more stable source of animal feed thus allowing increased livestock numbers with more manure and crop residues for red soil rehabilitation. As a secondary benefit, these two interventions perform an effective soil conservation function (Doolette and Smyle 1990).

Chinese farmers are very aware of the need to conserve moisture and soil. With regard to the latter, the centuries old custom of returning to the land soil from sedimentation collection traps or canals is still practiced today. Likewise the farmers' appreciation for the need for continuous crop cover and the use of mulches is a clear indication of the value given to moisture conservation. In the past, terracing has played an important role, but today terraces are costly to construct and maintenance is often neglected.

In the last two years another age-old conservation system has been tested in China. These barriers should not be confused with grass strips or general ground covers. A contour vegetative barrier is a narrow strip (less than one metre) which is planted for its extreme density and erect form. Ground covers, such as creeping grasses and legumes, are not comparable. They serve a different purpose altogether. They cover large areas and reduce direct raindrop impact on the soil. They are not barriers which detain runoff and cause the deposition of sediments, as does Vetiver.

The Vetiver system originated in India, and was then tried in the West Indies, Pacific Islands and Southern Africa. The system involves the establishment of biological hedges on the contour using Vetiver grass — *Vetiveria zizanioides* (L.) Nash (Zeng Geng Chao). This grass was introduced to China in the 1950s for the extraction of a low volatile oil from the roots to be used in the perfume industry. It had never been used for conservation purposes.

The main purposes of contour hedgerows are:

— to break the slope length, reduce velocity, and increase infiltration opportunity time,
— to reduce the erosivity and transport capacity of runoff,
— to cause deposition of erosion products, trap scarce nutrients and induce terracing,
— to cause cultivation and planting operations to be carried out on the contour, and
— to stabilise contour cultivated areas on steeper slopes.

While vegetative hedge technologies are still emerging systems that remain to be sufficiently characterised, there is enough evidence, both anecdotal and from research, to confirm that contour hedge barriers can be very effective in reducing erosion, soil loss, and surface runoff (Abujamin et al. 1985; Abujamin et al. 1983; Basri et al. 1990; Lal 1989; Subagyono 1988). Several studies have compared vegetative barriers with terraces and in aggregate they found vegetative barriers as effective (Chan 1981; Liao 1981; Wang 1969).

Vetiver grass has a number of features that make it desirable both from a farmer and a wider conservation point of view. It is a densely tufted, perennial clump grass, the leaf blades of which are relatively stiff. The foliage is mainly basal with the leaf sheaths closely overlapping, strongly compressed and keeled which creates a physical barrier of great density at ground surface. This barrier is firmly anchored by a mass of strong and deeply penetrating roots. It is adapted to a wide range of climatic and edaphic conditions; is reasonable easy to propagate; requires low maintenance; requires minimum space, and has an ability to withstand grazing and burning. To date it has shown minimal competition with the associated crop plant.

Because of the density and durability of Vetiver grass, Vetiver hedges can control runoff and act as a water spreading system, increasing plant available moisture. They minimise the need for engineering surveys since the hedges do not channel water. Rather they create natural and stable terraces. In addition Vetiver persists as a hedge for decades with little or no maintenance and spread effect.

The experience in China with Vetiver grass for soil and soil moisture conservation dates only from 1989. Where it has been tried, farmers are looking beyond its use in soil and moisture conservation to use it for mulching, fodder, wind breaks and bedding for livestock.

Over the past two years Vetiver has been tested over a range of conditions and soils in nine provinces with the main field-testing and demonstrations in Fujian and Jiangxi where on-farm trials are taking place on about 600 ha of agricultural land. In Sichaun, testing is being done at many sites including those at higher and cooler altitudes and in Guangdong, Vetiver has been established in heavily degraded areas on steep slopes.

Results to date show that the grass grows well in South China, but the existing cultivars will not survive the cold northern climate where temperatures are very low. Preliminary data from runoff plots on 20° slopes in Fujian showed that a hedgerow in its first season of growth reduced soil losses almost 55% compared to no conservation practices; terraces without Vetiver hedgerows along the front reduced soil loss 63%, with Vetiver hedgerows reduced it 87% (Wang Zisong pers. comm.). As the hedgerows had not yet closed, greater reductions can be expected in succeeding years.

In India, since 1987, a number of research stations and farmers' field trials have been carried out to compare the impact of Vetiver hedgerows on surface runoff, soil losses and crop yields. In total the trials represent 27 plot years of data from two areas and two soil groups. The data are preliminary, and are not statistically significant. On slopes under 5%, contour hedgerows of Vetiver, planted at one metre vertical intervals, have reduced surface runoff an average of 30% (±23%) and 47% (±9%) compared to conventional practices of graded banks (Bharad and Bathkal 1990; Krishnappa 1989) and cross slope cultivation (Bharad and Bathkal 1990).

Compared to contour hedgerows of *Leucaena*, Vetiver hedgerows have reduced surface runoff an average of 24% (±14%) (Bharad and Bathkal 1990; Krishnappa 1989). Plots and fields with Vetiver hedgerows have shown a reduction in sediment yields of an average of 74% (±5%) compared to across the slope cultivation (Bharad and Bathkal 1990) and 43% (±9%) compared to conventional practices of graded bunds (Bharad and Bathkal 1990). Compared to contour hedgerows of *Leucaena*, Vetiver has reduced sediment yields an average of 54% (±4%) (Bharad and Bathkal 1990; Krishnappa 1989). Crop yield data show that yields averaged 6% (±10%) and 26% (±20%) higher from areas with Vetiver hedges respectively (Bharad and Bathkal 1990; Krishnappa 1989).

Subsets of the data available from India (Bharad and Bathkal 1990) are presented in Figures 1 and 2. There were four treatments (across slope cultivation, contour hedgerows of Leucaena, graded earthen bund, and contour hedgerows of Vetiver); plots were about 0.35 ha, slopes were <5%, soils are vertisols, climate is semi-arid. Figure 1 shows the three year total soil loss and Figure 2 the three year total surface runoff. In Figure 1, the majority of soil loss occurred in Year 1 (68 to 79% of the totals) with a substantial percentage of this loss coming from one storm event.

The numbers on top of the histogram (Fig. 1) are the total soil loss (t/ha/3 yrs.) and the lighter areas represent the soil lost in the one major storm event in Year 1.

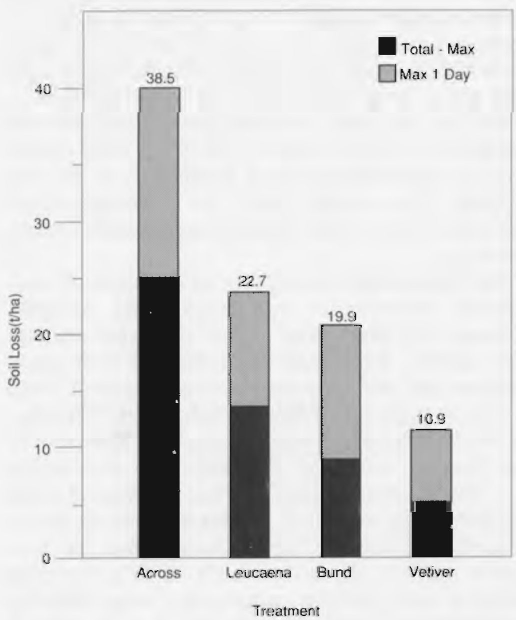

Figure 1. Three year soil loss.

In Figure 2, the numbers on the top of the histograms are surface runoff as a percentage of the rainfall from storm events which caused surface runoff. The difference between Vetiver and the across-slope plots represents almost 200 mm of rainfall. In Year 2, a drought year, runoff from the Vetiver plot was 55%, 35% and 41% less than from the across-slope *Leucaena*, and bunded plots, respectively.

In red soil development, an added value of Vetiver is its substitution for rice straw for mulching purposes and for animal bedding to produce farm yard manure. When the leaves are cut regularly they make good fodder with a market value of the order of one yuan/10 kg (the crude protein in Vetiver is estimated from 6.1 to 6.7%, compared with 7.8% for Napier grass (*Pennisetum purpureum*) (Table 1).

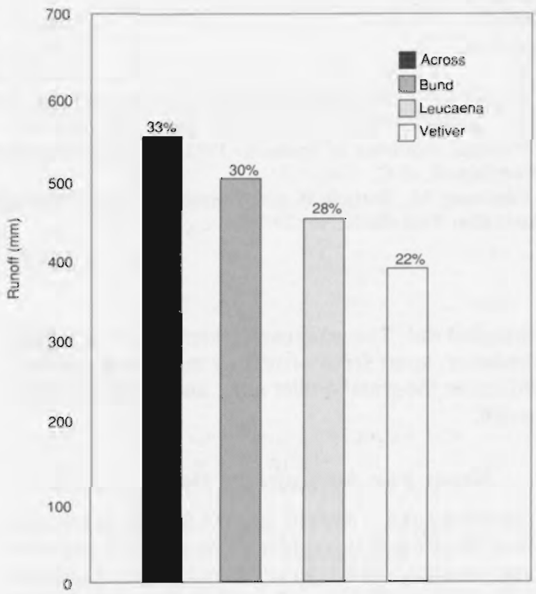

Figure 2. Three year total surface runoff.

Vetiver grass is easily and inexpensively propagated and established; costs in India and China are of the order of 30–70 yuan for sufficient material to plant 1000 metres of hedgerow. One hectare of Vetiver nursery will supply sufficient material to establish about 50 to 125 km of hedgerow; 10 man days may be used as a conservative figure to calculate planting costs per 1000 metres of hedgerow. Depending on the climate and soils, it will take from nine months to four years for the Vetiver hedgerow to completely close. Once established, the hedgerow is a dense, permanent barrier that can be maintained at a width of 50 cm and still perform its function. If in the future, it is no longer desired, it can be

Table 1. A comparison of the fodder value of *Vetiveria zizanioides* (Linn.) Nash managed for fodder with the fodder value of some other hedgerow grasses and major sources of ruminant forage.

Name	Crude protein (%)	Ether extract (%)	Crude fibre (%)	Total Ash (%)	Calcium (%)	Phosphorus (%)
Vetiver[1] (fresh young leaves)	6.1–6.7	1.1–2.1	38–42.0	5.3–9.0	0.28–0.31	0.05–0.60
Zea mays[2] (maize stover)	6.6	1.3	34	7.2	0.49	0.08
Sorghum bicolor (sorghum stover)	5.2	1.7	34	11.0	0.52	0.13
Pennisetum purpureum (napier, fresh)	7.8	1.1	39	5.3	0.44	0.35
Paspalum notatum (Bahia, fresh)	8.9	1.6	30	11.1	0.46	0.22
Pasture[3] (grass dominant)		5.1			0.17	0.07
Maize (maturing cobs)		3.20			0.17	0.07
Millet		3.00			0.10	0.05
Sorghum		2.50			0.11	0.05

[1] Council of Scientific and Industrial Research (CSIR). 1976. Vetiveria. In: The Wealth of India. X. Publications of the Information Directorate, CSIR, New Delhi. 451–457.

[2] National Academy of Sciences. 1982. United States–Canada tables of feed composition. National Academy Press, Washington, D.C.

[3] Cochrane, M., Bartsch, B. and Valentine, S. 1983. Feed composition tables. Department of Agriculture, South Australia, Australia. Fact Sheet No. 29/83.

ploughed out. The grass can be kept low by pruning; the latter, apart from providing mulch and fodder, will cause the grass to tiller more and create a thicker hedge.

Needs For Agricultural Development

There is a special need in South China to accelerate work on nitrogen fixing plants and generally improve crop rotations. Work done by the Chinese Academy of Agricultural Science (CAAS) in Hunan Province in association with ACIAR, based on both temperate and tropical grasses and nitrogen fixing legumes, looks promising and should be tested widely.

Programs to encourage the greater use of lime (interestingly lime deposits in large quantities are associated with the red soils) would have a major role in increasing soil pH and hence improving the availability of exchangeable soil nutrients, particularly phosphorus. The introduction of deep rooted plants, such as Vetiver and *Amaranthus* (the latter is an excellent fodder crop), together with farm forestry (e.g. *Paulownia*) could not only provide additional income but help recycle the nutrients from lower soil profiles that are beyond the reach of many other plants.

The role of livestock in South China will be the critical factor in sustaining agricultural production on these highly leached soils. Pigs, cattle, and small livestock have a vital role to play in the fertility cycle. All evidence shows that organic manures release their nutrients at a slower rate than inorganic fertilizer — in the hot, wet south, leaching and volatilisation of inorganic fertilizer is rapid. One of the main limitations to expanding livestock production is the lack of feed. Concentrate feeds are becoming more expensive and compete with human demands for raw materials.

The technology is available to significantly supplement concentrates with green feeds. Already, farmers feed sweet potato tops and other residual crop matter. Beans and other fodders show good promise and also provide important ground cover to reduce erosion and evaporation losses. The work by Professors Sun Hongliang and Yue Shaoxian of the Institute of Crop Breeding and Cultivation (CAAS) on *Amaranthus* spp has resulted in some 400 000 mu of improved Amaranthus being grown in northern China for fodder. Amaranthus has been grown traditionally in South China as a vegetable and new high yielding varieties are being tested in Fujian and Jiangxi. Amaranthus is deep rooted, drought tolerant, and can yield up to 100 t/ha of green fodder with protein levels of 27% in the leaves and 15% in the stem. It is also high in lysine. Trial results show significant weight gains and cost reductions when pigs are fed Amaranthus.

Another feed that is showing promise and which might be adapted to South China is the microbiotic plant, duckweed — *Laminae* spp. This plant has been grown in Bangladesh on sewage waste ponds and has produced enough feed (50% protein) to increase the yield of fish from 2 t to 10 t/ha/yr. Duckweed can also be harvested and dried and fed as a high protein feed to chickens. Jiangxi Agricultural Development Corporation is proposing to test this system.

Technology transfer

A critical aspect of agricultural growth involves technology transfer to and between farmers. A recent audit by the World Bank of five extension projects in India concluded that extension did accelerate the rate of adoption of technology by farmers, but this was more apparent in irrigated than in rainfed areas. There are a number of important aspects that should be taken into account in disseminating technology, and these are particularly important in China where standards of farming are already high. Even so, in critical areas such as soil conservation and fertility improvement, where farming practices need modification and where sometimes benefits to farmers are not immediately apparent, special attention should be given to a number of factors.

Farmers will adopt technology if they believe it will significantly improve their income. In other words the rate of adoption can be accelerated if the technology is relevant to a farmer's circumstances and is communicated rapidly and presented to the farmer in a convincing manner. The level of relevance of technology will dictate its uptake.

It is therefore very important that farmers are involved in testing and providing feedback to extension staff and research workers. Often technologies, although sound, do not fit farmers' resources and economic and social conditions. In India, technology transfer was poor when the messages were programmed on a 'top down' basis, and when the extension workers were ill equipped professionally to understand the circumstances of a farmer's operation. They were therefore unable to respond adequately to farmers' questions and concerns.

Some of the best extension and research staff are those who have grown up in the farming community and consequently understand farmers and their problems. Today, in India, much more time is being spent on joint diagnostic analysis at farm level by scientists, extension workers, and farmers with a result that technology is becoming more relevant to farmer needs. The level of communicating technology is vital in accelerating acceptance.

It is found that although contact farmers can play an important role, it is even more important to determine existing 'farmer reference groups' that have great influence on the internal dialogue that occurs when new techniques are marketed.

In India, it has been suggested that the initial target for extension should be the farmer reference groups, and it appears that the same could apply to China. The level of visits is less important than the level of the interactive relationships between provider and the user of the technologies. This interaction should be mainly with groups.

Another area of communication is the use of mass media. China has done this well, but the same issue of relevance should apply. Potentially good farmer radio programs often fail to arouse farmer interest because the information included is not always relevant to the farmers' needs. Radio programmers need special training to understand the way farmers react and the information included in programs must be up-to-date and relevant.

Finally, there are enormous opportunities for improving the quality, quantity and levels of distribution of farm literature. In China, most farmers can read. There is an enormous thirst for knowledge. Farm magazines, printed at low cost, should be distributed widely giving farmers the options of adopting new technologies. Again farmers and technical staff respond to professionally prepared articles that contain relevant information presented in an understandable form.

In the USA, one of the reasons for the revival of organic farming, on quite a large scale, is the persistent effort of the Rodale Press that has for the last 40 years consistently documented and presented, in a readable and understandable form, information on organic farming and gardening and farmers need to be convinced. This takes time and depends on the anticipated benefits, the risks and the effort required in adoption.

We therefore need to look for technologies that meet these criteria. The introduction of Vetiver grass is one such example. There are immediate benefits in soil and moisture conservation, there are also benefits from its use as a forage and mulch; the risks are low, and the effort of adoption is much less than the alternative of building terraces.

Other examples meeting these criteria include simple techniques such as ammoniating straw for improved animal feed and improved citrus pruning techniques. In forestry the better selection of seed and the culling of weak plants from nurseries are virtually costless but have significant benefits.

Persistence in technology transfer is essential. Major efforts are required to continually discuss the technologies, demonstrate benefits and generally participate with farmers in the introduction process.

Technology transfer arrangements in South China need to be improved if the red soils are to be better utilised. Farmers will be exposed to crops, both annual and perennial and livestock that are quite new to them; for example, the expansion of sericulture or the introduction of dairy cows. Careful assessment will be required to develop appropriate marketing strategies for these and other technologies. Extension and research workers will need training so they can produce quality and relevant radio programs; video films, magazines articles and other components of extension programs. Equipment too will need to be put in place.

In the case of a technology such as Vetiver grass planting, material will have to be propagated and be available to farmers. Staff will need to have some means of transportation or at least funds to travel on buses to enable them to meet with their clients. Such efforts need not be expensive and must be so designed that they can be sustained over a long period of time.

Rural infrastructure

The majority of case studies undertaken on the impact of rural infrastructure, particularly roads, substantially supports the economic benefits of such investments. The infrastructure developed under the ongoing red soil project in Jiangxi and Fujian is one such case, where roads, water, and electricity have all added to the growth of these projects. Initially road development should have priority, and once established all other investments, incomes, and services can flow. The most important social impact from road construction is the access provided to medical facilities and to education. A case study in the Philippines showed that, when roads were constructed, transportation costs were reduced by 50%, farm income increased by 40%, non-farm income by 22% and gross income by 30%.

In Thailand, roads were instrumental in the shift from lower value to higher value crops, particularly perishables — fruits and vegetables. In the Indian State of Himachal Pradesh a 40-fold increase in road length resulted in a 400-fold increase in horticultural production. In another Indian state, Uttar Pradesh, the construction of roads led to a significant increase in technology transferred to farmers. The same was shown for a study in Bangladesh. Compared to India, China has one fifth the density of roads per unit area. In comparision to South Korea, China has about half the length of roads per 1000 head of population, and one tenth that of Japan.

In the opening up of the southern red soil areas of China, an investment in infrastructure is both sound and essential. Under the ongoing World Bank sponsored Red Soils I project, development of small ponds, minor irrigation, low cost roads and farm electrification has been impressive. In the next phase, the quality of infrastructure needs improving, particularly roads and irrigation. Roads should be better aligned to assure lateral drainage of the road surface. Road embankments require protection (Vetiver does a good job here). Irrigation design needs improvement and the banks of ponds and canals need greater protection. Farmers should be fully involved in the design of these infrastructures as they will have to be responsible for their maintenance after construction.

Land tenure

Both farmers and officials in the Red Soils I Project in Jiangxi fully recognised the importance of a reliable tenure system if family farmers are to settle successfully on these new lands. They need the protection of fair tenure laws in order to have the incentive to invest their time and money in land development. Settler farmers have 50-year leases that are transferable to their heirs or to new tenants at the market value of the improvements. Because farmers have a secure title, they are prepared to invest in quality houses and other sustainable investments. Under the second phase Red Soils project it would be beneficial if tenure was extended to the steeper land for farmer afforestation. Such activities would not only give the farmers another source of income, but would also, at no cost to the public, assure protection of the many micro-watersheds that make up these areas.

Agricultural credit

Development of the red soils, particularly when the settlement of new farmers is involved, requires considerable investment in physical assets. These include the building of farm houses and animal and crop sheds, domestic water and biogas generators, land development including terracing and farm ponds, investments in livestock — pigs initially — followed by cattle, perennial fruit trees, farm implements, and working capital for annual inputs. Most of these investments come through credits from the Agricultural Bank of China.

The credit program has been successful and contributed significantly to farmer prosperity. Because farmers get little grant money from the Government they are anxious to find ways of reducing investment costs. Thus technologies such as Vetiver hedge barriers that replace costly earth structures may turn out to be popular. Likewise, with labour costs rising quite steeply farmers are looking for techniques that will reduce the demand for labour. Research and extension workers need to bear these two facts in mind when identifying research topics.

Marketing arrangements

In any large-scale development of the red soil areas special efforts will have to be given to developing markets. Markets become quickly over-supplied when harvests are good, and therefore the need for good market research and forecasting will play an important role. Diversified cropping patterns can help alleviate some of the peaks in output and diversified perennial tree crop production will remain an important factor under the project. A more careful analysis of processing and storage requirements are needed as it appears that, for many of the markets, added processing and storage may not have priority. Local markets for perishables play an important role in the buying and distribution of vegetables and fruit, and will remain so for the foreseeable future.

Institutions

The success of the existing Red Soils I Project has also been due to the dedication and support of the top provincial officials, the management and staff of the Agricultural Development Corporations that manage and co-ordinate the work program and most importantly to the dedication and the hard work of the county officials and benefiting farmers.

The involvement of project clients (the farmers) at this level and the understanding and enthusiasm of the lowest level of support staff shows the importance of strengthening and supporting the county and township levels in their efforts.

Like the farmers' husbandry traditions which are based on age-old and sound practices, the administration of county development also has traditions that have reputations of efficiency and service over many centuries. The combination of the two should provide well for the future of agriculture in south China.

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Soil Erosion Control in the Red Soil Area of Southern China

Xu Daping and Yang Minquan*

MOST of the hilly red soil land in China (45 million ha) is distributed in Hainan, Guangdong, Guangxi, Fujian, Jiangxi, Hunan and Zhejiang provinces, accounting for 44.3% of the total area of these seven provinces. In this region of south China, the large area of hilly and mountainous land results in there being less than 0.07 ha of farming land per person. There are 20.2 million ha of forest, 7.8 million ha of grassland and 3.0 million ha of barren land. The combination of high population densities, extensive deforestation, inappropriate cultivation methods and intense rainfall have resulted in serious soil erosion. At present, one-quarter of the hilly and mountainous lands are without forest cover and significant areas of red soil land are completely barren. The area subject to serious soil erosion is increasing and is currently estimated to be more than 17 million ha (Table 1).

The climatic conditions in most areas of the region are conducive to the production of various tree crops of high economic value, such as *Litchii chinensis*, *Dimocarpus longan*, *Mangifera indica*, *Citrus reticulata*, *Piper nigrum* and *Hevea brasiliensis*.

There are many measures that could be used for soil erosion control in this region. Potentially the most effective and economic of these will be a combination of fuelwood and multi-purpose forest plantations, agroforestry systems and engineering controls.

Firewood and Multi-purpose Plantations

High population densities and extensive deforestation in this region have resulted in serious shortages of firewood. Some farmers are forced to use forages and straw as alternative fuels. If trees are not planted after deforestation, the area is typically colonised by shrubs and grasses which can only be cut several times before the land becomes barren and subject to more serious soil erosion. It is now common in this region to see barren, hilly land around villages. To prevent the existing forests from being cut too frequently and to reduce soil erosion problems in the hilly lands, it is essential that firewood and multi-purpose plantations be established to satisfy local farmers' demands for firewood and timber.

Attempts have been made to establish large areas of such plantations but in many cases the species used were unsuitable. In the 1970s, large areas of pure plantations of *Pinus massoniana* and *Cunninghamia lanceolata* were established in the red soils region. Generally speaking, the two species grow well on the more fertile land after the primary or native forest is cut. However, they both grow poorly on the barren land or on areas where several successive forest plantings have been harvested. The large areas of *Pinus* are now suffering serious damage from the insect pests *Dendrolimus* spp and *Hemiberlesia pitysophila* Takag. Many plantations of the two species have become stunted, providing little firewood and timber and negligible protection against erosion.

For soil erosion control, broad-leaved trees are generally better than coniferous trees (Table 2). The quantity of leaf litter from broad-leaved trees is commonly much higher than from coniferous trees. The canopy of broad-leaved trees is also generally more extensive than that of coniferous trees and they establish much faster than the conifers.

Some suitable tree species for firewood and multi-purpose plantations in the southern part of the red soils region are *Eucalyptus urophylla*, *E. tereticornis*, *E. camaldulensis*, *E. leizhou*, *Acacia mangium*, *A. auriculiformis*, *A. crassicarpa*, *A. cincinnata*, *A. holosericea*, *A. aulacocarpa*, *Casuarina equisetifolia*, *C. junghuhniana*, *C cunninghamiana*, *Albizzia falcata*, *Khaya senegalensis* and *Pinus caribea*. In the northern parts of the region, *Acacia mearnsii*, *A. dealbata*, *A. filicifolia*, *A. fulva*, *Eucalyptus grandis*, *E. globulus*, *E. camaldulensis*, *E. citriodora*, *Pinus elliotii*, *Quercus acutissima*, *Q. variabilis*, *Liquidamber formosana*, *Morus alba*, *Castanopsis fissa* and *C. hystrix* are likely to be well adapted.

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Table 1. The estimated extent of soil erosion (million ha) in the red soil region of China. Percentage values are shown in parenthesis.

Province	Estimated total area	Area affected by erosion	Heavily eroded	Moderately eroded	Lightly eroded
Guangdong[1]	17.80	2.53 (14.2)	1.39 (55.0)	0.44 (17.4)	0.70 (27.6)
Guangxi	23.60	3.80 (16.1)	1.78 (46.9)	0.83 (21.8)	1.19 (31.3)
Fujian	12.20	1.34 (11.0)	0.63 (46.8)	0.27 (20.0)	0.44 (33.2)
Hunan	21.1	4.41 (20.9)	2.10 (47.6)	1.40 (31.8)	0.91 (20.5)
Jiangxi	16.7	3.79 (22.7)	1.97 (51.9)	1.09 (28.7)	0.74 (19.4)
Zhejiang	7.9	1.48 (18.7)	0.56 (37.7)	0.47 (31.8)	0.45 (30.5)

[1] Guangdong Province includes Guangdong and Hainan Provinces

Table 2. Comparison of productivity of two coniferous and one broad leaved tree species.

Name	Type	Trees/ha	Mean DBH cm	Crown density (%)	Age (years)	Litter weight (kg/ha/yr)
Cunninghamia lanceolata	Conif.	2715	10.8	95	26	3001.2
Pinus massoniana	Conif.	1620	15.6	80	20	4015.8
Erythrophleum fordii	Broad.	795	15.1	95	22	6375.9

Agroforestry

Agroforestry is a technology for the comprehensive utilisation of land. Adapted and compatible trees, shrubs, forages, crops and micro-organisms are combined in a mixed agro-ecosystem, providing a wide range of products and income sources as well as a more sustainable method of land utilisation. In agroforestry, land utilisation and protection against erosion can occur concurrently.

On land with low or moderate erosion hazard, agroforestry has proven to be the best method of land utilisation. As terrace cultivation can reduce soil loss, it is widely used in conjunction with agroforestry on the hilly land. An example of the benefits of terraces over contour strip cropping is presented in Table 3.

A common and economically successful agroforestry model in the tropical areas of southern China is based on terraced land. The width of the terraces is 60–100cm. Fruit tree species, such as *Litchii chinensis*, *Dimocarpus longan*, *Mangifera indica*, *Clausena lansium*, *Citrus sinensis*, *C. reticulata*, *C. grandis*, *Canarium album*, *Pyrus salicina*, *Castania mollissima* and *Eriobotrya japonica* have been planted on terraces integrated with legume forages and crops such as *Stylosanthes guianensis*, *Desmodium intortum*, soybean, peanut, watermelon and vegetables. The leguminous forages can contribute as much as 300–400 kg symbiotic nitrogen per ha per year to the system if green manured. To conserve water and soil, *Pennisetum purpureum* and *Vetiveria zizianoides* can be planted on the slopes of the terraces and nitrogen-fixing or coniferous tree species on the tops of the hills. Around each fruit garden, bamboo or shrub species are often planted as a living fence.

The production of crops under young plantations is also common. An example is the integration of tea with pine trees, rubber and *Albizzia falcata*. Research results have shown that if the density of the mature trees is not too high, the mixed ecosystem can not only improve the quality of the tea but also increase the yield of spring tea.

Medicinal plants often used in agroforestry include *Smilax china* L. , *Alpinia villosum* and *A. chinense* integrated with rubber trees, *Coptis chinensis* integrated with *Cunninghamia lanceolata* and coffee integrated with teak.

Combining Biological and Engineering Erosion Control

On land with serious soil erosion problems, the combination of biological and engineering controls is necessary. On the red soil hills derived from granite and quartz-sandstone, gully erosion is common and

Table 3. A comparison of soil loss from terraces and contour strips cropped with peanut, soybean and maize.

Crop	Cultivation	13 May–16 May		6 August–15 August	
		Cover (%)	Soil run off (t/km²)	Cover (%)	Soil run off (t/km²)
Peanut	Terrace	5	339.0	33	21.4
	Strip	5	1500.0	36	20.5
Soybean	Terrace	10	333.0	60	38.6
	Strip	12	768.0	70	14.0
Maize	Terrace	0[1]	3.9[1]	55[2]	28.9[2]
	Strip	0[1]	7.6[1]	55[2]	229.0[2]

[1] 24 July–25 July
[2] 9 September–11 September

often most of the topsoil has been washed off the slopes, leaving exposed subsoil in which the content of small stones and sand is between 30 and 80%. Most tree species cannot grow well in these exposed subsoils with the exception of some promising species of *Acacia* (Table 4). The data in Table 4 were obtained from a site in which the soil had a stone and sand content of 70%, pH of 4.4, organic matter content of 0.7%, total nitrogen of 0.02% and available N, P and K of 2.6, 0 and 1.1 mg (per 100 g) respectively.

Table 4. The performance of one-year old acacias growing on slope land in Xinhui county, Guangdong Province.

Species	Mean height (m)	Mean canopy width (m)
A. auriculiformis	1.96	0.95
A. leptocarpa	2.05	0.98
A. brassii	1.97	1.00
A. flavescens	2.10	0.74
A. tumida	0.43	1.27
A. holosericea	1.67	0.77
A. torulosa	1.98	0.86
A. brassii	1.70	1.18
A. difficilis	1.49	0.79
A. auriculiformis	2.07	1.44
A. flavescens	2.17	0.90
A. simssii	1.74	0.69
A. torulosa	1.46	0.94
A. leptocarpa	1.56	0.70
A. auriculiformis	1.49	0.98
A. torulosa	1.41	0.80
A. holosericea	1.12	0.55
A. auriculiformis	2.19	1.17
A. plectocarpa	2.10	1.37
A. holosericea	1.93	0.97
A. aulacocarpa	1.53	0.98

On the sloping land with serious erosion, one model for erosion control in Guangdong Province is *Acacia holosericea* interplanted with *Melinus minutiflora*. At the site in Xinhui county (Table 4), the average height and width of the canopy of *Acacia holosericea* after one year were 2.2 and 1.1 metres respectively. At this stage, the land had been completely covered by the Acacia and the grass.

Melinus minutiflora is a drought tolerant, fast growing, perennial grass. In Wuhua county, Guangdong Province, this grass was sown in March and harvested in September, yielding 30.5 tonnes dry matter per hectare. The planting of this species can improve the fertility of the land and improve the permeability of the soil by increasing the organic matter content (Table 5). This species has the capacity to efficiently protect the soil from splash erosion and reduce transportation of sediment by slowing down surface runoff (Table 6).

If gully erosion is very active, drainage ditches should be constructed to divert water from gullies. Behind the gullies, dams can be built to store the runoff and sediment. On the dam wall, species of bamboo can be planted to strengthen the wall and act as an additional barrier for gathering sediment.

Table 5. Soil composition, in the top 20 cm of soil, in different treatments.

Treatment	Organic matter (%)	Total N (%)	Total P_2O_5 (%)	Total K_2O (%)
Barren land	0.40	0.01	0.01	0.43
One year after planting *Melinis minutiflora*	0.68	0.02	0.02	0.45
Two years after planting	1.70	0.06	0.04	0.05

Table 6. Soil runoff and erosion under different vegetation treatments in Xinhua county. Total rainfall received over the period of measurement was 326 mm.

Runoff plot	Total runoff (M^3)	Runoff modulus ($m^3/km^2/year$)	Soil loss (kg)	Erosive modulus ($t/km^2/year$)	Sand content (kg/m^3)	Cover (%)
Melinis minutiflora	4.512	150415	3.6	128.9	0.80	93
Pine	5.585	186175	195.6	6983.9	34.98	30
Barren	5.783	192760	467.5	16697.0	80.89	0

Gradually, a natural terrace will be formed behind the dam on which fast-growing trees, such as species of the genera *Eucalyptus* and *Acacia*, can be planted and integrated with legume and grass forages. At the bottom of active gullies, many shrubs and herbaceous plants grow very well naturally in response to the better soil moisture conditions. Some economic species, such as *Musa nana* and several species of bamboo (for shoots) can be planted to make full use of the bottom land. Under precipitous cliffs, some climbing or palm rattan species can be planted, such as *Pueraria javanica*, *P. pseudohirsuta*, *Calamus tetradactylus*, *C. simplicifolius* and *Daemonorops margaritae*.

Most of the examples presented in this paper relate to the sub-tropical areas of Guangdong Province. Soil erosion control measures will differ regionally depending on local social, economic and natural conditions. However, the three basic methods of control outlined in this paper (the establishment of firewood and multipurpose forest plantations, agroforestry and the combination of biological and engineering controls) will be applicable everywhere.

Forest Development in Upland Grasslands in South China

Tu Mingyi*

TREES can play an important role in maintaining stable grassland systems. Forests modify climate, conserve water and soil, and therefore can have benefits to livestock.

In many countries the integration of trees into animal production systems is well advanced and the benefits are now well documented. In South China harnessing the benefits of trees has only just begun.

At Nanshang State Farm on the border of Hunan and Guangxi Provinces experiments are underway to evaluate different agro-forestry systems. The farm comprises 10 000 ha of pasture — half natural, the remainder improved. The farm is presently running 1000 dairy cattle, 1000 beef cattle and 2000 sheep.

Natural Resources

In order to better determine the most appropriate agro-forestry systems for this region experiments were conducted to evaluate the potential of different soil types and water regimes, assess the value of local forest resources and evaluate potential sources of seed and seedlings. Commencing in 1981 a number of trial plantings were established to evaluate the agro-forestry value of a range of species.

Nanshan Farm lies at an elevation of 1400–1800 metres ASL with an annual rainfall of 1800 mm and a 11 °C mean temperature. The temperature ranges from a summer maximum of 26 °C to a winter minimum of −8 °C. Cumulative annual sunshine hours is approximately 1200.

The dominant native grasses are Chinese silvergrass (*Miscanthus sinensis purpurascens*) and hirsute arundinella (*Arundinella hirta*). Other important varieties are from the Compositae, Polygonaceae and Rosaceae families. The major introduced species are perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*).

The native trees have been extensively cleared. Those that remain are mainly along streams and in the valleys. The soils are derived from granite and tend to be acidic (pH 5.0).

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In the 1950s attempts were made to establish Chinese fir (*Cunninghamia lanceolata*) and Masson pine (*Pinus massoniana*). These plantings failed mainly due to the species being unsuited to local conditions. However, at altitudes greater than 1650 m, Chinese cedar (*Cryptomeria fortunei*) planted in 1958, calyxless sweetgum (*Liquidamber acalycina*) planted in 1967 and officinal magnolia (*Magnolia officinalis*) planted in 1970 have now grown into big trees. The circumference of Chinese cedars has reached one metre and their foliage is extensive.

Through the grasslands there are small areas of evergreen or deciduous broad-leaved trees, mainly composed of shining-leaf beech (*Fagus lucida*), Hunan oak (*Cyclobalanopsis multinervis*), trabeculate alder (*Alnus trabeculosa*), common sassafras (*Sassafras tzumu*), calyxless sweetgum, Oldham meliosma (*Meliosma oldhamii*) and heath family (Ericaceae). On streamsides and in the valleys, there are bushes of panicle hydrangea (*Hydrangea paniculata*), Chinese weigela (*Weigela japonica* var. *sinica*) and the like. On the low marshland in valleys there are groves of Hunan (Yushan) mountain chinacane (*Yushania hunanensis*), fishscale bamboo (*Phyllostachys congesta*) and scattered fountain bamboo (*Sinarundinaria nitida*). Within the grassland, there are some spaciously scattered groves of simon bamboo (*Pleioblastus amarus*) and moso bamboo (*Phyllostachys pubesens*).

The remnants of natural woodlands are a rich source of seed and seedlings and are therefore a valuable resource for reafforestation programs.

Forestry Trials

At Nanshan State Farm a number of experimental forestry areas have been established in the past 10 years.

Residential area. In April 1981, 31 saplings of common sassafras and calyxless sweetgum were transplanted from a natural woodland with an elevation of 1400 m. Each was approximately 3 m in height and these were planted along a 60 m line beside the residential area. The residential area is at an elevation of 1650 m. By 1985 the saplings had produced strong canopies and all have survived to the present time.

Grassland windbreak. In March 1984, 400 one-year-old saplings of Chinese tuliptree with an average height of 44 cm were planted in a 1500 m line at an elevation of 1750 metres. The seedlings were obtained from Zhuchashan Forest Farm. The survival rate has been reasonably high with 376 still alive.

Slope planting. In April 1987, 350 London plane tree saplings, 3 m in height and supplied by the local forest bureau, were planted on the slopes along a path at an altitude of 1650–1700 m. The tree line is 1000 m long and 241 trees among them are stil alive.

Recommendations

In addition to the four experiments detailed above a number of smaller evaluation plantings have been established at Nanshan Farm. All these plantings are now demonstrating that reforestation is a practical option at elevations between 1000 and 2000 m in southern China.

There are grasslands similar to those of Nanshan Farm in Yunnan, Guizhou, Sichuan, Hubei and Guangxi provinces. The key to successful planting of these areas is the correct selection of species. To maximise the benefits careful consideration must be given to the primary purpose for which the trees are being established.

Windbreaks. Ideally these should be established on steep slopes unsuitable for grazing. Species capable of establishing on less fertile soils such as Hunan oak, shining-leaf beech and heath family trees planted on a 3 m × 4 m grid are ideal. At the foot of grazing slopes big trees such as Chinese tuliptree, calyxless sweetgum and common sassafras in 4–6 lines are ideal. To control cross-slope wind, trees such as shining leaf beech and rhododendron, again in 4–6 rows, are useful.

Shade. Trees with large canopies on tall trunks such as calyxless sweetgum and London plane tree planted in clumps of 600–700 sq m for each two hectares are recommended in grazed grasslands.

Living fences. Grazing plots can be divided with bushes with thorns such as Japanese rose (*Rosa multiflora*) and wintergreen barberry (*Berberis julianaea*).

Terrace stability. Species such as calyxless sweetgum and Chinese tuliptree give good protection to the soil and are therefore an ideal border to pathways. Hunan oak is ideal for planting around water sources.

Amenity value. London plane tree and Chinese cedar are both particularly attractive trees and therefore useful for their ornamental value in residential areas.

The stock required for all these different plantings are readily available from remnant patches or native vegetation. In many instances large saplings can be transplanted from natural forest areas of similar altitude to accelerate the benefits afforded by trees.

Conclusion

Experience elsewhere has demonstrated the benefits to be derived from afforestation of grassland areas. In China this approach is in its infancy but with the rapid development of grass-fed livestock enterprises it is paramount that forestry practices are given due emphasis. In Hunan, Hubei, Yunan, Guizhou, Sichuan and Guangxi Provinces considerable potential exists to transform the grasslands into productive agro-forestry units.

Restoring Native Vegetation and Its Effects on some Soil Conditions in the Hilly Red Soil Region

Liu Geng-ling*

THE tropical and sub-tropical zone of China, covering some 2.2 million sq km, accounts for 23% of the land area of China and is home to 43% of the population. Most regions within this zone have abundant water and heat resources for agricultural production. The red soil areas of China, which lie wholly within this tropical and sub-tropical zone, are important for the production of grain, meat and cash crops (Table 1).

Table 1. Production of grain, meat and cash crops on the red soils of Southern China as a percentage of China's total production.

Activity/Commodity	% of total
Cultivated land	39.6
Grain products	58.7
Meat	69.4
Freshwater fish	87.0
Tea	92.0

Further improvements in food production in this region will depend on either an intensification of the existing agricultural systems, with greater labour requirements and artificial inputs, or development of under-utilised land. Despite recent successes in increasing yields from paddy soils, agriculture in the region faces some serious problems. Extensive erosion on the red soil hills has depleted soil fertility over large areas and continues to cause siltation of waterways and reservoirs. High summer temperatures and seasonal droughts have hindered the development of pastures and hence a ruminant industry. Deforestation has resulted in a severe shortage of fuelwood.

In an effort to solve these problems, the Chinese Academy of Agricultural Sciences has been conducting research into controlling erosion with vegetative cover at the Red Soils Experiment Station, Qiyang county, Lingling prefecture, Hunan Province. These experiments, which commenced in 1981, have included experimental plantings of tea and citrus, chinese chesnut and tung tree, American pine and paotong tree and forages, and have investigated various techniques for restoring native vegetation.

Despite the problems imposed by the red soils on plant growth (such as low pH, potentially toxic concentrations of aluminium and a deficiency of major plant nutrients), we have observed in our experiments that some trees and forages grow very well. This is especially true of many native species, which have exhibited strong seed viability, acid tolerance and rapid growth to maturity. Therefore, the restoration of natural vegetation is considered an effective measure for improving soil fertility and preventing soil erosion.

The dominant species in the early stages of restoration

In the early stages of vegetation restoration, we have observed the following dominant plant species:

Grasses — *Eremochloa ophiuroides*, *Imperata cylindrica*, *Miscanthus sinensis* Anders, *Cymbopogon goeringii*, *Digitaria ischaemum* Schreber.

Shrubs — *Glochidion puberium* (L) Hutch, *Ilex cornuta* Linde., *Symplocos chinensis* (Lour) Druce, *Clerodendrum cyrtophyllum*, *Mattotus apelta*.

These species were able to not only tolerate acid soil conditions, high concentrations of toxic aluminium, high summer temperatures and seasonal drought but also produced large amounts of biomass and spread rapidly. We called these plants 'pioneer species'.

In our experiments we have observed that it was these same species that pioneered barren hill sites around the region, regardless of whether the sites were at the base of a hill, on the slope or at the top.

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Table 2. Invasion of *Eremochloa ophiuroides* communities by *Imperata cylindrica* (1984–87).

	Year 1	Year 2	Year 3	Year 4
Invasion rate (m/year)	1.06	1.05	1.09	n.a
Mean height of *I. cylindrica* (cm)	20–40	50–65	90–110	115–135
Mean height of *E. ophiuroides* (cm)	10–13	11–21	died	died
Mean cover (%) of *I. cylindrica*	<3	30–95	92–95	>98
Mean cover (%) of *E.ophiuroides*	>93	3–30	0	0

Competition and succession

With a gradual increase in plant population and biomass, competition and succession among species has been observed. Invasion of *Eremochloa ophiuroides* grass communities by *Imperata cylindrica* is shown in Table 2.

In experiments we have also observed the invasion of the pioneer grass communities by various species of shrub. In all, 50 species have been recorded in a population of approximately 15 000 shrubs. The major species are listed in Table 3.

Table 3. Main species of shrubs observed in restoration of native species experiment at Qiyang.

Species	% of all shrubs observed
Glochidian puberium (L) Hutch	39
Simlan chinensis (L)	15
Tymplocas chinensis (Lour) Druce	11
Clerodenrum cyrtophyllum Turcz	6
Mallotus apelta	5
Ilex aculealata Nakai	4
Others	20

Effect of vegetation on soil water and heat regimes

At the experimental station the annual rainfall of 1300–1500 mm is unevenly distributed, with a seasonal drought towards the end of summer. From late April until early October 1985 regular observations were made of the water regime under different types of vegetation. The treatments were:

- bare, undisturbed land;
- *Eremochloa ophiuroides* grass community, and an
- *Imperata cylindrica* grass community.

As shown in Figure 1 the soil water content (measured as a percentage) of the surface soil (0–20 cm) under vegetation was, on average, significantly higher than that under bare land. The maximum soil water content under vegetation was 14.8% compared with only 10.6% for the bare land.

The total rainfall during the period of observation was 771 mm. On the bare land, 201 mm of runoff (26% of the total rainfall) and 45.8 t/ha of soil loss were recorded. Under vegetation losses of only 23 mm of rainfall (3% of the total rainfall) and 1.2 t/ha of soil (3% of that for bare land) were recorded.

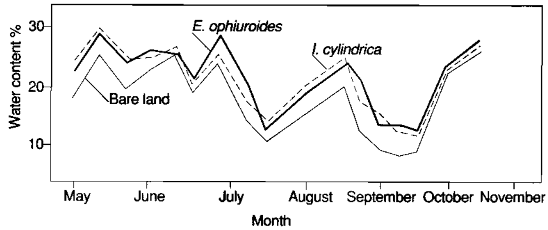

Figure 1. Dynamics of soil water in the top 20 cm under different grass communities.

Soil temperature

The rates of biological and chemical reactions and hence the rate of plant growth are influenced by the temperature of the soil. The soil temperature depends mainly on solar radiation fluxes, soil moisture content and surface cover (vegetation or mulch). The effects of vegetation on soil temperatures in this experiment are presented in Figure 2.

The soil temperatures under vegetation for the period of observation were, on average, significantly lower than for the bare land. Soil temperatures were also less variable as a result of vegetative cover (Table 4).

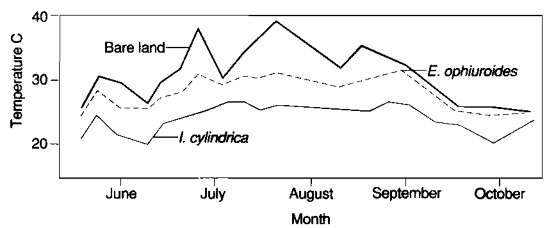

Figure 2. Soil temperatures under different grass communities.

Table 4. Effects of various treatments on soil temperature.

Treatment	Temp. sum (°C) (22 observations)	Max. temp. °C	Min. temp. °C	Temp. range °C
Bare land	680	36.4	22.4	16
E. ophiuroides	615	32.4	22.0	10
I. cylindrica	533	27.0	21.0	6

Soil fertility

In many regions, the fertility of the red soils has been reduced as a result of over-exploitation of the vegetation cover, deterioration of the ecological environment and the consequent serious soil erosion. It was observed that under the vegetation in this experiment, organic matter levels in the soil and the concentrations of available N, P and K all increased. (Table 5). This shows that the restoration of native vegetation can have a beneficial effect on soil fertility.

Conclusions

The research presented here shows that preventing over-exploitation of the hilly red soil areas can lead to, in the space of 4–5 years, these becoming revegetated and less prone to erosion. Furthermore, the surface soil water content is likely to be higher during periods of rainfall deficiency and soil temperatures will be moderated compared with bare land. These factors combined result in a general improvement in soil fertility.

In the early stages of restoration of native vegetation, farmers could harvest some of the forage grasses and legumes for fish feed, animal feed and green manure. Some shrubs could be harvested for fuel.

Table 5. Soil nutrient content under different grass communities.

Treatment	OM%	Available N (mg/kg)	Available P (mg/kg)	Exch. K_2O (mg/kg)
Bare land	0.76	57	0	59
E. ophiuroides	2.31	95	2	75
I. cylindrica	2.39	90	2	67

A Socio-Economic Survey in the Red Soils Region

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CHINA'S 'Red Soils Region' is so named because of its reddish-yellow and purple subsoils. Covered with highly erosive, acid soils, the region lies south of the Yangtze River and covers two million sq km, or approximately one-third of the total land area of South China in 11 provinces. Of this, 0.5 million sq km are unutilised mountains and hilly slopeland. The combination of deforestation, the erosive nature of the red soil complex, as well as poor management has led to a marked increase in the incidence of soil erosion in the region. This severe soil erosion problem not only results in decreased productivity in the eroded area, but in siltation of rivers and dams which, in the longer term, affects productivity in other areas. Thus, rehabilitation of the vast unproductive hilly red soils region is one of the high priorities for the development of China's agricultural production.

The Project

In 1986, an applied research project of the Red Soils Region was jointly carried out by Chinese Academy of Agricultural Sciences (CAAS), Australian Centre for International Agricultural Research (ACIAR), and Winrock International Institute for Agricultural Development (WI) to examine the feasibility of an integrated forage–livestock resource management project in the south of China. The overall objectives of the project were to conduct research to develop and demonstrate appropriate technologies with emphasis on improving:

(i) soil management — prevent erosion of red soils and/or recover productive capacity of eroded red soils through use of forages and trees; and
(ii) livestock production — increase productivity and profitability of farms in the region through conversion of pasture and cropping by-products to livestock products.

The initial phase of this project which included a more detailed examination of the sites and the acquisition and preparation of a new experimental area was completed in 1986. Lingling Prefecture in Hunan Province was identified as the potential target site. The focus of the efforts in Phase II of the project in 1988 was to conduct field research to identify the opportunities for an integrated forage–livestock project in Lingling Prefecture, and to determine the economic feasibility of development of a five to ten year project in Phase III.

The Survey

A socio-economic survey was carried out as part of Phase II of the Red Soils Project to investigate production, marketing, food processing industries, research institutions, and policy impacts and to determine constraints to increase production. Two of the major questions for this initial survey were whether a year-round feed supply is possible, and whether a marketing infrastructure exists or could be developed for meat and dairy products. Related questions addressed possible cropping systems, including trees, and the institutional enviroment.

A joint investigation team, composed of CAAS and WI physical and social scientists, was formed and the survey conducted in two provinces: Lingling Prefecture in Hunan Province and Guilin Municipality in Guangxi Autonomous Region. Counties of Qiyang, Menggongshan and Jiangyong in Lingling Prefecture were chosen for in-depth field work.

During the survey, two field trips were made to visit households, to understand the agricultural system, and to gather data on cropping, animals and resource utilisation. Most of the household interviews were done by CAAS researchers.

Field data were collected from personal interviews of farmers, processors, distributors and retailers in an effort to understand the potential and constraints for agricultural development in the Red Soils Region.

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Material in this paper is drawn from previous Winrock papers including G. Sullivan's report.

Lingling Prefecture

Lingling Prefecture is located in the southwestern part of Hunan Province with a population of 4.8 million in 1986. With 61% of the area covered with red soils, Lingling is regarded as a poor prefecture in China based on its level of net income. In the 1986 national survey, net income per capita was 472 yuan which is below the average for Hunan Province (Y 603) and the national average (Y 741). In Lingling, the agricultural growth rate was 12%, which was slow compared to growth for the province during the period of 1983–1986.

Agriculture is the main source of income in Lingling. Crop values were 57% of the total output value in 1986 while livestock was 25%. The major agricultural product in the area is rice, which is used for family consumption, sale to the state and feed for their animals. Sweet potato and corn are the most important upland crops. Sweet potato tops and corn grain are used as a major source of feed for pigs while corn stover is used for ruminant feed as is rice straw. The most numerous and important livestock are non-ruminants, with pigs being dominant.

Grain output in Lingling has increased 129.7% during the period 1978 to 1986. This increase, however, is in line with the national average of 128.5% for the same period. Livestock enterprises have developed rapidly during the period 1980–87, with an annual increase of 7.3% in meat production which is greater than for agriculture in general. This implies that producers have become more market oriented and have been positively impacted by the removal of government regulations allowing farmers to slaughter livestock without a permit from the government. In Lingling, natural pastures are equal to 4.05 million mu or 0.3 million ha with 1.5–2.8 t/ha as the estimated annual production of forage from wasteland areas. The production on forest lands is low, averaging 100 yuan in output value per ha per year.

Agro-economic area

The three agro-economic areas in Lingling Prefecture, selected for in-depth investigation, reflect different ecological conditions and different production characteristics that affect optimal strategies for economic development. Data from research in these areas will provide a complete set of relationships for application to other areas in the Red Soils Region.

Qiyang County is on the northeast border of Lingling Prefecture and characterised by high population density, intensive cultivation, with unproductive hillside agriculture. The population was 850 710 in 1986, the greatest for the prefecture. This county has a shortage of inputs of feed, fuel and fertilizer. Even though this county is the largest supplier of coal in the prefecture, households use large amounts of rice straw for fuel.

The average per capita income at the county level in 1986 was 464 yuan, slightly less than the prefecture average of 472 yuan. This county has more motive power (130 600 kw) and irrigation pumps (8154) than any other county in the prefecture. Farmers in the county had an above average application rate of chemical fertilizer of 46 kg/mu. Moreover, the county had the highest total agricultural output value for the prefecture, being the largest producer of rice, wheat and soybeans. In 1986, Qiyang was the largest producer of red meat with 27 161 t with the majority being pork. Grain output has increased 126% from 1980 to 1986 which is approximately equal to that of the prefecture.

Menggonshan – Lengshuitan municipality is characterised by moderate population density, moderate intensity of crop cultivation and severe soil erosion. Statistics in this area are more difficult to interpret because the target area is within the large municipality of Lengshuitan, a growing industrial town. Agriculture is not as intense as in Qiyang County but soil erosion is much more severe. Agricultural lands are less productive than those in Qiyang. The opportunity for small-scale livestock production is greater because of more available land area. Hillsides are more seriously eroded, and there are fewer tea oil trees planted in the area.

Jiangyong County is located in southern Lingling Prefecture and is characterised by low population density, less intensive cultivation and extensive pasture land. The population in 1986 was 257 800, which is the second least populated county in the prefecture. Seventy percent of the population lives in rural areas. The area being less populated means less pressure on the natural resources with more extensive grazing land available. The potential for livestock production is greater with large-scale production systems possible. This county is the largest producer of metal ores in the prefecture.

The county per capita income in 1986 was 382, the second lowest in the prefecture, which is partly because of its agrarian base and the poor transportation infrastructure linking it with other large markets. The county has little motive power or irrigation and drainage equipment. The average fertilizer application rate is 38 kg/mu, close to the prefecture's average. The total value of output is the second lowest; however, large livestock number is 43 000 head which is the third highest in the prefecture. Pig production is not an important enterprise when compared to the other two counties.

This area is not an important grain producing county with growth in production increasing only

1.8% since 1980. The comparative advantage of this area is commercial, large-scale livestock production.

Household demographics

The household size for the three areas averaged 5.75 people living at home at the time of the survey. The total household labour available for agriculture was 2.73 labour days with the amount per household the highest in Jiangyong (3.25). The average level of schooling for respondents was under six years with about 30 percent having gone to school for nine years or more. The selection of several of the respondents was influenced by local government officials who may have chosen the more literate farmers to be interviewed. Low education levels present a problem in introducing new technologies which require higher levels of farm management.

Animal Production Systems

Animal production is an important component of agricultural production in Lingling, amounting to 25% of the total agricultural value in 1986. Pork production is the major livestock enterprise followed by poultry while large ruminants have not been important. There are more buffalo than cattle in the area with very few dairy or beef cattle in the study area. No commercial milk production was reported for Lingling Prefecture. Data for Lingling (Table 1) are similar to those of the province in percentages of the total.

Non-ruminants

Pigs. Farmers in Lingling have a long tradition of raising pigs. They buy and fatten pigs for resale. Local breeds of swine (predominantly white with black head spotting) and crosses of locals with large whites were most frequently seen. Pigs were kept by all respondents. The average number of pigs owned is approximately four head with households averaging one sow per family. During the period 1980 to 1987 the pig inventory increased 81%. The majority of the respondents preferred to sell pigs rather than slaughter them for home consumption. The market for pork remains strong because increased personal income has had a positive impact on demand, which is shifting from fatty pork meat to leaner cuts of meat. In addition, the Hong Kong market is also having a positive impact on pork with pigs being shipped live from Hunan to Guangdong and transshipped to Hong Kong. However, feedstuffs for commercial pig production are in short supply. Pig producers require large amounts of green forage to supplement the shortage of compound feed.

Poultry. Rearing chickens is another major livestock activity in the area. Each household interviewed had approximately 30 chickens. Chickens are primarily for home consumption with some being sold for cash. Feed for chickens is also in short supply. Ducks were owned by 28% of the respondents with an average flock size of 20 birds. Flocks are herded from field to field to glean grain after harvest. Ducks are primarily for home consumption.

Fish. Aquaculture is an important source of food and cash income for the family according to respondents. Fish value was two percent of the total agricultural output values in 1986. A greater proportion of households had more pond area than wasteland. Fifty-eight percent of respondents reported having ponds with an average size of 3.03 mu/household. Some of the ponds were shared by several families. With the introduction of the Production Responsibility System (PRS), families can lease pond acreage from the commune paying an annual user fee.

Table 1. Yield of animal husbandry production from Lingling Prefecture, 1981–1986.

	1981	1982	1983	1984	1985	1986
			('000 t)			
Total meat yield	63.8	—	85.4	109.8	131.8	158.7
pig meat	63.7	—	85.3	109.4	115.1	138.2
cattle (beef)	0.059	—	0.057	0.034	1.0	1.1
sheep	0.034	—	0.033	0.034	0.041	0.056
poultry	—	—	—	—	15.7	19.3
Milk yield	—	—	0.005	0.020	0.028	0.048
Meat yield (from draught cattle & buffalo)	0.277	—	0.312	0.332	0.348	0.368

Ruminants

Buffalo. The principal ruminants in the region are swamp buffalo kept for draught, especially for paddyland cultivation. Usually, mature cows weigh 400–450 kg. Calving intervals were reported to be two years with first parity between three and four years of age. These buffalo are hardy, well-adapted animals but opportunity for increasing productivity through selection appears limited. Families in the northern part of Lingling have limited space to house and feed buffalo and their cultivated area is smaller requiring less time for ploughing than in the south. The number of days buffalo are used per year (average 85) is low. In Qiyang and Menggongshan over 90% of respondents said that they shared the use and care of the buffalo. An average of 3.56 families share in the care of a water buffalo. The implication is that, if households have a tradition in sharing of livestock, then introduction of improved livestock may be possible on a cooperative basis.

Cattle. The local variety of 'yellow cattle' or *Bos indicus* is quite small in size. Shoulder humps on males and some females are common, suggesting a combined *Bos indicus–Bos taurus* genotype. Mature cows weigh 200 to 250 kg and were reported to have 16 to 18 month calving intervals with first parity at 26 to 30 months. A few Holstein and Simmental crosses are present on those government stations with access to artifical insemination, however, milking for commercial markets is not now practiced. The major reason for keeping cattle is also for animal traction. Cattle are less efficient than buffalo in the rice paddy soil. Their thin legs and sharp hooves become mired in the mud. A cost:return estimate for 1987 for cattle production was a net income of 132 yuan per head for approximately a three to four year investment. The breakdown is illustrated in Table 2.

Table 2. Cost and returns for cattle raising.

Total income			Y 350
Total outlay			
	cost of calf	50	
	fine feed	30	
	fed grass	66	
	depreciation	20	
	vet. & med.	10	
	human expenses	36	
	3% loss	6	
	Total		Y 218
Net income			Y 132
Net return/ha of grasslands (1.8 A.U./ha)			Y 220
Percent return on direct costs			60%

Regional differences in livestock holdings were evident from the survey. No respondents in Qiyang and Menggongshan reported owning cattle while four of the eight respondents in Jiangyong said they owned cattle. The average herd size was 8.5 cows per household.

Dairy cattle. No commercial milk production was reported for Lingling Prefecture. An average of 125 labour days are required for caring for a dairy cow with an average annual cost of 1192 yuan/cow/year. The household will have to allocate labour from other current activities to undertake a new livestock enterprise like dairy production.

Small ruminants. Small ruminants are surprisingly unimportant in the study area. There is no preference for mutton and goat meat in southern China compared to the northern areas. Principal markets for goat meat appear to be early spring festivals.

Animal Feed

Very little animal feed was purchased by respondents. Only seven people said that they had purchased compound feed. The principal sources of feed were grass and weeds from hillsides. One member of the household cuts and carries feed every day for the animals. The average weight of a load carried from the hills is 20 kg. On several occasions, elderly members of the household were seen herding pigs or collecting grass for livestock.

Crop by-products are the most important source of animal feed in Lingling prefecture with rice straw as the major one. Respondents estimated approximately 6000 jin of rice straw available for animal feed. In Qiyang County, rice straw is used for fodder, fertilizer, and for fuel instead of animal feed because of a lack of fuel. Straw is fed to buffalo mainly during the working season from March to July. The rest of time buffalo are taken to pasture. Rice straw is also used as bedding for pigs. The rice straw is mixed with the pig manure for composting and returned to the paddyland as fertilizer and organic material.

Over 33% of respondents (all in Menggongshan and Qiyang) mentioned using rice husks as animal feed. The average amount fed is estimated at 1800 jin per household. The husks are mainly fed to pigs with two people reporting that they sell the by-products.

Other minor crop by-products mentioned were sweet potato tops, dried peanut tops and soybean tops. In Jiangyong sugarcane tops are an important source of livestock feed.

Animal traction versus tractors

The opportunity cost of not owning a bullock for use in ploughing is determined by rental rate for ploughing. In Qiyang county, bullocks are rented at 10 yuan/day and can plough 2–3 mu/day plus an additional expense of meals (4 yuan/mu) for the worker. A tractor can be rented for 4 yuan/mu and can plough 4–5 mu per day. There is a trade-off between using bullocks and greater mechanisation with the increased dependence on fuel and parts but the work can be done four times faster releasing labour for other activities such as animal raising. Currently, the wage for off-farm labour is low so that mechanisation is not being introduced to replace farm labour. On the other hand, water buffalo require only grass and rice straw but they are only used for two months out of the year. Water buffalo could be replaced with more productive large ruminants, such as beef or dairy cattle.

Livestock development

On the national level, recent economic reforms in China have resulted in rapidly rising incomes. Per capita consumption expenditures have risen faster in urban than in rural areas. Consumption patterns have thus changed because of rising incomes, improved marketing systems and expanded freedom for private initiatives to produce for the market. Food preferences are generally found to shift in favour of higher value animal products such as leaner pork and beef as incomes increase. The consumption of beef increased 40–50% over consumption in 1980 although cattle are principally raised for traction and not for meat production. In Lingling prefecture, approximately 150 000 t of red meat is produced per year. The reasons for these increases are greater disposable income and the new policy that cattle can be slaughtered and sold without government permission. These changes should remove some constraints to the introduction of a forage and livestock system in the area.

However, 75% of respondents said that crop production is more important than raising livestock. In addition, the majority of respondents preferred raising pigs (66%) compared to cattle (16%) and goats (9%). The priority for food production requires that the introduction of improved animal systems be fitted into labour and capital availabilities after satisfying crop needs. The major constraints and some considerations for improved agricultural development are summarised as follows.

Custom. The major constraint for improved forage-livestock production is that farmers said they have no 'custom' in caring for beef, dairy cattle and goats (Table 3). The introduction of improved management systems for attaining high yields will require an intensive education program. Currently, indigenous 'yellow cattle' and water buffalo are maintained at low levels of production partly because of the poor genetic base of the herds. In some cases respondents said that they lack money, feed and their own available labour to care for additional livestock. Attention should be given to fitting forage-livestock activities within the current farming system.

Table 3. Major constraints in raising livestock in Lingling Prefecture, 1988.

	Beef cattle	Dairy cattle	Goats
No custom	47	58	64
No money	22	14	3
No feed/pasture	22	6	11
No labour	—	14	6

Opportunity cost. Since the major agricultural activity is rice production, alternative enterprises have to be judged relative to the returns from rice production. For example, recent data indicate an annualised net return to management of 220 yuan/mu for double cropped rice. The net present value for raising beef cattle is 90 yuan/head/year using an 8% discount rate. Though not as financially attractive as rice production, an opportunity exists for additional household income if labour, credit and feed are available.

Feed. An important limiting constraint to livestock production in the study area is clearly the availability of year-round feed supply. This is currently inadequate in both quality and quantity to support increased levels of productivity at least seasonally if not throughout the year. Even in the case of pigs, 64% of respondents mentioned the lack of feed as a primary constraint to increased production. The potential for increased pig production from non-specialised households may have an overall greater impact than attempting to introduce completely new livestock enterprises. Some respondents said that lack of fuel adversely affects their ability to raise more pigs because some agricultural by-products have to be used for fuel rather than for feed. Applied agricultural research is needed to design cropping systems for maximum economic benefits to the family and for conservation of natural resources.

Capital. Respondents said that capital to undertake livestock enterprises was limited. Forty-two percent of households interviewed currently had a loan with an average amount borrowed of approximately 600 yuan. The township bank is the most common source of loans. Loans are generally used to purchase fertilizer. Of the households which currently did not have a loan, 62% of respondents had borrowed money in the past. The average time period since a loan is ten years. The major reason for requiring funds is for agricultural inputs, such as fertilizer, insecticide and hybrid rice seeds.

Labour. Labour available to cut and carry feed or to herd livestock will likely become less as family size declines and children spend more time in school. Attention should be directed to developing less labour-intensive methods of feeding and caring for livestock. For example, electric fences may have a role in containing livestock on fallow or harvested fields or on pasture on nearby marginal lands. The practicality and affordability of such interventions should be investigated.

Health. Other than external parasites (ticks and flies) livestock observed in the study area did not show signs of acute health problems. Almost certainly, however, internal parasites are a problem. Incidence of respiratory and other diseases may likely increase as livestock become more productive, especially if they are kept in confinement.

Early research priorities should include a comprehensive survey of health status of local livestock. Subsequent attention should be directed to prevention and control of health problems through farmer-controlled, low-cost management rather than purchased medicines, whenever possible. Farmers' management in preventing or treating production diseases, such as mastitis, should be encouraged.

Specific nutritional deficiencies (e.g. phosphorus) may be a problem in the region. Supplements may be required to correct these deficiencies.

Reproductive management. Generally, age at first parity and long intervals between parturitions are major contributing factors to the minimal offtake levels from buffalo and cattle in the study area. Improved nutrition and health care will help rectify these problems. However, greater attention needs to be paid to controlling mating so that gestation and lactation appropriately coincide with fluctuating feed supplies. Farmers do appear to keep bulls separate from cows (buffalo or cattle); however, it is not clear if this is to avoid herding problems or to control mating. Calves of widely different ages were observed, suggesting that matings were not limited to specific seasons of year.

If artificial insemination is used to introduce more productive genotypes, management to assist oestrus detection and timely insemination will be required.

Genetics. In general, all species in Lingling prefecture are less productive than the provincial and national averages. Efforts to improve yields of meat and especially milk would quickly run up against genetic limits within the local breeds. For example, improved nutrition and management would do much toward shortening intervals between parturitions, but the local breeds are not likely to rebreed while lactating — a necessity if annual calving is combined with dairy production.

Not only is there a shortage of genetic variation for production traits within local breeds, but farmers in the study area do not have ready access to species of sheep and goats which might fit better into the production environment. These deficiencies in useful genetic variation can be readily solved through introduction of highly productive species and breeds. Elsewhere in China, there are breeding studs maintaining imported stocks, and AI facilities are well-established. As part of a longer-term development of livestock potential, these same capabilities should be established in the study area. However, the short-term research priorities should be to match genotypes to the production environment to achieve profitable production efficiency.

The Marketing System for Meat and Livestock

The food marketing system in China is in transition with the emphasis on less reliance on government as the major buyer of agricultural products. As a result, many individuals are providing marketing services and seeking to do more as the government reduces its involvement. The State has removed itself from livestock marketing. The major livestock marketing system in Lingling is for pigs which includes marketing channels for small-scale and commercial producers. In the various State factories visited, processing capacity was at a very low level, as a consequence of cheap raw materials no longer being available.

Transportation systems

Development of an efficient marketing system will be constrained by the present transportation infrastructure. Trains are the major form of transport linking major cities. Most of the region relies on mountainous roads of varying qualities and distances from potential development areas. An early and continuing task of economic analysis is to assess the limits on the market imposed by the transportation constraints.

In Lingling Prefecture most livestock are transported to Guangdong Province by truck. Trucks can carry varying lots of livestock, giving flexibility to the shipper. The 600 km road to Guangdong is considered a first-class road. Also, there is a shortage of rail cars, especially for livestock. Livestock for export, however, would have to be off-loaded in Hengyang to a train going south to Guangdong and Hong Kong.

The transportation infrastructure has not yet been developed from Jiangyong County in southern Lingling. By the start of the 8th Five Year Plan, marketing of live animals either to Guilin or to Guangdong will improve because of current road improvements and the plan to build a narrow gauge rail link from Jiangyong County to Guangdong Province.

Feed mills

A major constraint facing the commercial livestock industry is the supply of quality feed for livestock.

Hengyang feed mill. This factory is the largest in Hunan Province. In an interview the manager said that raw materials were in short supply. The feed mill specialises in feed for pigs (90%) and the remainder for chickens and ducks.

The plant relies on the private market for 70% of its raw material. The major ingredient is corn from north China. Production in 1987 was sufficient to maintain 620 000 pigs, while there are 6.2 million head of pigs in Hengyang Prefecture.

The plant developed a ration for lean pork production and the government recognised it as a superior product. Most rations are distributed in the Hengyang area. The distribution of feed is rationed to customers and is based on farmers having a grain coupon received from the Government after selling commodities to the State. The demand for feed is greatest during the period January to June, especially before the Spring Festival in February.

Qiyang feed mill. The Qiyang Feed Mill is smaller than the Hengyang plant. The plant can produce 5000 t/year/shift. The major constraint is the availability of raw materials for the mixing of feed. Most of the raw materials are brought by truck from Lishapin. The road is in poor condition and transport fees are comparatively high.

The plant produces four pig rations which are sold mainly in Qiyang County. The amount of feed produced can maintain 30 000 pigs per year, although there are approximately 800 000 pigs in the county. The pig feed goes mainly to specialised pig farms or to state or collective operations. In 1986 approximately 20% was sold to individuals.

Specialised pig-raising households, which obtain a voucher from the local livestock officer, can pay the State price for feed, while individuals pay a slightly higher price.

Meat processing facilities

Meat processing facilities are important to the expansion of livestock industries.

Guilin Comprehensive Meat Factory. This facility was built in 1979 and slaughtered large numbers of pigs until there was a shift in government policy allowing direct selling by private traders. In 1984, 95% of the market was supplied by this integrated meat processing and cold storage facility. At the time of the survey this plant supplied only 50% of the market.

There are three comprehensive meat factories in the province and none are currently working at close to their capacity.

Hengyang Comprehensive Meat Factory. The city of Hengyang is located at the rail junction for trains from Beijing to either Guangzhou or Guilin. The location of this city is important for development of Lingling Prefecture as an outlet for livestock products.

The Hengyang Comprehensive Meat Factory is the largest in the Prefecture. It has a one shift capacity of 2500 pigs and 3000 chickens. Currently the plant is killing 1000 pigs. The factory receives its raw material from the County Food Company (CFC), which buys from the farmer. Supplies to the plant are based on the number of animals available from the CFC.

The plant exports pork to Eastern Europe, the USSR and Hong Kong. In 1987 the plant shipped 360 t to Hong Kong and 240 t to other export markets.

China imports frozen chicken parts from Brazil and Thailand, so that the domestic price is kept low. The Spring Festival is the peak demand period for chicken, with over 5 t/day being sold in Hengyang.

The supply of cattle is limited, and local demand exceeds local supply. Frozen beef is purchased from western Hunan and Hubei Provinces. The Food and Agriculture Organisation (FAO) of the United Nations has funded a meat factory in Lungshan which supplies frozen boxed beef to Hong Kong. Little information was available on the operation of this plant.

Wholesale and retail trade

Visits were made to several markets to assess the quality of products and the degree of competition. The markets were active and a large volume of products was present. Most markets had sections for state supplies of pork and other sections for private retailers. Large numbers of each type were present in the large urban markets. In the rural markets, only private retailers were present.

Most meat retailers slaughter their own animals at home and carry meat to the market. If meat inspection is done, it would be at the market.

The PRS reform has encouraged farmers to become more aware of markets and how to sell their products. Local markets are thriving and people are eager to take on new economic activities, particularly trading, if money can be made.

Prices for commodities in the Guilin market are listed in Table 4. Private retailers reported having to pay a market tax of 2% of sales plus a rental for the table of one yuan per day.

Evidence in the market indicates that a two-tier pricing scheme exists for certain essential food commodities. The consensus among those interviewed is that the State will remove all pricing structures and rely on market prices to adjust supply and demand.

Table 4. Market prices for commodities in the Guilin market, 1988.

Item	Price (Y/jin or 500g)	
Pork without fat	4.5	(private)
Pork without fat	3.5	(state)
Pork with fat	2.7	boneless
Pork with fat	2.3	bone-in
Pig feet	1.8	
Pig intestines	1.1	
Pig tail	1.7	
Pig tongue	2.0	
Pig liver	4.0	
Beef	3.5	
Hide	65.0/hide	
Beef offal	35.0/total set	
Chicken	6.0	(cooked)
Fish	2.5	(live)
Eel	8.0	(live)
Poultry	3.0	(Av.l.wt.6jin)
Duck	3.8	(live)
Chicken	3.3	(dressed)
Duck	4.0	(dressed)
Duck egg	0.26/egg	
Chicken egg	0.22/egg	

Guilin Market, Guangxi Autonomous Region. Guilin is an important tourist location and many foreign as well as Chinese tourists visit the city each year. As a consequence the potential for increased red meat consumption is great. The city already depends on supplies of frozen pork from Sichuan Province and Hunan Province (Lingling, Hengyang, and Shalyan). The procurement prices in 1986 ranged from 2300–3000 yuan/t. If meat is already arriving from Hunan, market channels exist which can be expanded as production increases in Hunan.

The demand for pork, the primary red meat consumed in China, varies according to the season of the year. A retailer said that demand can increase fourfold during the Spring Festival in February. The tax collector said that for his retail market in Guilin, approximately 3000 kg of pork are sold per day.

Beef is in short supply and is generally more expensive than pork. Since the State does not buy and sell beef, the private sector controls this trade. Beef operations are small in the surrounding area. In interviews, people said they preferred beef because it was leaner. People would buy more beef if it were available and cheaper.

Children and older people are the groups of people most likely to consume milk. There is only one dairy in the Guilin region.

Hotels in Guilin. In 1988, there were 19 hotels in Guilin, built with foreign capital, and the projection was for the number to increase to 37 in 1990. There are four international hotels in Guilin: Ramada, 350 rooms; Sheraton, 600 rooms; New World, 600 rooms; Holiday Inn, 258 rooms. The occupancy rate is 80% in the high season (April–October) and 40–50% in the low season.

The hotels serve imported beef mainly from New Zealand, which comes by truck from Hong Kong via Guangdong. Imports are handled by the Chinese Cereal and Oil Import and Export Company. Ground beef is purchased from the local market.

The livestock market in Guilin. A livestock market was recently built near the north railroad station in Guilin. This market is 5000 sq m and is being used primarily for selling oxen. The market has a rail unloading facility for livestock which provides an opportunity for live animals to be brought by train from Hunan for slaughter.

In general, the live animal markets are not developed for private entrepreneurs to buy and sell livestock. In interviews with meat retailers, one woman said she travels to villages to buy two to three head and arranges to have them brought by truck to her house. She buys every three days and butchers one head per day.

The general perception is that there is a mixture of marketing channels: retailers buy directly from villages and resell in the local markets, or farmers bring their products directly for sale to the market. In interviews in Beijing as well as in locations in the study area these types of market arrangements were documented.

The Hong Kong market. Hong Kong represents an important export market for livestock products from the Red Soils Region. Import data for 1986 indicate the importance of this market for China Table 5.

Hunan Province has been an important source of pigs for the Hong Kong market. Officials estimate that two million pigs per year are exported to the Guangdong Region and then to Hong Kong. Many trucks are available, both private and government, to transport these pigs. From Lingling Prefecture, officials estimate that 500 000 pigs are shipped to Guangdong Province with a large percentage going to Hong Kong.

A visit was made to the slaughter house in Hong Kong in 1987. At that time the plant belonged to a quasi-private corporation that had recently taken over the operation of the facility. The abattoir slaughters mainly pigs. A large meat processing industry exists in Hong Kong with finger foods (e.g. wieners) processed and sold on the local market. Hong Kong has a thriving meat processing industry for further-processed products.

Import data indicate that China has an excellent opportunity to increase its market share of the Hong Kong red meat market. The beef from Australia, Europe and South America is close in quality to beef produced in China. Most of the imported beef is grass fed or finished on limited grain. Australia supplies this market with 4000 t or HK$78 million (US$10 million) which could be replaced with Chinese beef. The Hong Kong market will be even more accessible to China after 1997 when the territory reverts to Chinese control.

A separate development is the economic zone planned for Hainan Island off the southern coast of the mainland. Hong Kong would be the likely transshipment location. This island will be a good market for red meat in the next decade.

Policy Issues

The Government has made great efforts to stimulate the rural economy. Some efforts are reflected in policy changes, such as the removal of control of wages and prices, a decrease in its involvement in the market, and approval for farmers to slaughter animals without a permit etc. However, information on these important issues is not complete. Further research is necessary to understand these policies as well as their impacts.

Food and dietary policies

The Government is finding it difficult to balance supply and demand for food grains. Grain production in 1987 was 402.4 million t which is close to the record set in 1984. By the year 2000, even if grain output can be increased to 500 million t, average per capita consumption will remain at current levels of

Table 5. Imports of live animals into Hong Kong, 1986.

	Head	Value — HK$
Bovine species for human food (no.)		
China	184 636	191 531 947
Total	184 636	191 531 947
Sheep and lambs live (no.)		
China	3 817	810 541
Total	3 817	810 541
Goats live (no.)		
China	17 246	3 394 357
Total	17 246	3 394 357
Swine live (no.)		
USA	31	93 000
Taiwan	16 010	11 177 628
Philippines	330	247 636
Thailand	47 795	36 624 039
China	3 019 126	1 360 606 572
Malaysia West	1 800	1 249 213
Total	3 085 092	1 409 997 988
Chicken domestic live		
Macau	420	4 700
China	42 666 071	358 447 744
Total	42 666 491	358 452 444

400 kg. Thus, the need to change dietary consumption patterns in order to reduce grain consumption was recommended by the Central Government (China Daily, March 31, 1988).

Part of the strategy to reduce grain consumption as the major source of protein is to rely more heavily on legumes, plants, meat or eggs. One way this will have to be done is through greater production of red meat from forage-based systems. Since 1984 the country has used more than 15 million t of grain each year for meat and alcohol production. Meat will have to become a more important source of protein and calories than in 1982 when it supplied 8% of total calories and 11.3% of total protein in the diet. It is recommended that meat and legumes need to increase to 30% of protein consumption.

Taxes

The Chinese government has established three tax structures for revenue generation: taxes on production, marketing and income. The production tax for livestock owners is 4% on the value of cattle or buffalo slaughtered and 3 yuan/head for pigs. There is a market tax of 5% on the value of meat sold by wholesalers of cattle and buffalo meat. The market tax for pigs is five yuan per head. Producers who slaughter and sell directly in the market pay only the slaughter tax. No tax is paid when a producer sells or trades livestock to another producer. There are no land taxes because all the land is owned by the State. Hay sales and feedstuffs are not taxed.

The Chinese government has a tax schedule for joint ventures at the rate of 30%, with the first two years free of tax, and years three to five at one-half the rate on profits. After five years, profits are taxed at the full-rate. There are additional taxes imposed in the form of a 10% local tax and a 15% industrial tax. Taxes can be shifted on a case by case basis, depending on the economic conditions facing the joint venture.

Land use regulations

Land use regulations for Hebei Province, passed by the Sixth Session of the Standing Committee of the Sixth Hebei Provincial People's Congress, on March 24, 1984, serve as a model for beginning to establish property rights for establishment and protection of grasses and trees on the wastelands. These regulations include ways livestock can use the hillsides for grazing while protecting the interests of all parties.

More recently the Ministry of Forestry issued a temporary regulation closing hillsides to livestock grazing and fuel gathering (China Daily, April 27, 1988). These types of regulation will work to the disadvantage of some areas where hillsides are an important source of forage for livestock. Livestock raising and fuel production should not be mutually exclusive in hillside agriculture.

The government is recommending closure for 3–5 years in some areas and longer in others. If the collective is unable to enforce the closure, then a contract can be made with individual households or the collective to enforce closure and receive a fee. Incentives for establishing closures may be through subsidies to the collective from the state government.

Credit

The government will provide interest free loans for certain enterprises. Loans for dairy cattle have the lowest interest. For beef cattle loan interest is 7.4% for one to three years; for loans of three to five years the interest rate increases to 8.3%.

Interest-free loans are available for planting trees and forages on hillsides. However, it would seem few farmers are taking up this opportunity as they have little experience with the concept of loans for forage establishment.

The southern county of Jiangyong has been designated as a preferential county for loans from the Financial Bureau of Hunan. The loans can be used for livestock and fish production as well as food processing. This area is part of the target area for Phase III of the Red Soils Project.

Subsidies

The State provides a subsidy of 20kg of grain and 5kg of fertilizer for each 50kg liveweight of livestock (probably including pigs) sold to it. The purpose of this policy appears to be less to encourage production than to compensate for the price differential between the State and the free market. At least in Jianyang county it does so inefficiently as no livestock are sold to the State (Table 6).

Provincial support for the production of cattle and water buffalo appears to be neither as well articulated nor as effective as that observed in 1984 in Sichuan by the PRC - Winrock joint study team on livestock development.

One possible source of the difficulty encountered in establishing sown pastures is an erratic supply of subsidised state fertilizer. The continuing presence of subsidised, rationed inputs is indicated in the offer of assistance to the project by the leadership of Lingling Prefecture in the form of materials and chemical fertilizer at the state price. The nature of input supply markets and (or) allocations bears further investigation, especially in assessing the possibilities for extension of research results into farmers' fields.

Table 6. Number and price of livestock sold on free market in Jiangyong, 1986.

	Cattle	Buffalo	Sheep	Goats	Pigs
Owned by State (no.)	500	300	—	—	—
Sold to State	—	—	—	—	—
Owned by farmers	12 000	31 000	—	1 800	180 000
Sold on free mkt	2 500	7 000	—	1 000	80 000
Prices/kg on free market (Y) (provided officially)					
Liveweight	2.2	2.0	—	1.8–2.0	2.2
Dressed weight	3.2	2.8	—	2.2–2.4	3.0
(provided in field)					
Liveweight	2.0		—	2.2–2.4	2.2–2.4
Dressed weight	4.0		—	—	3.4

Manpower Development

Critical to a sustained agricultural development in the Red Soils Region will be the ability of the Chinese staff in research and extension institutions to effectively transfer new technology. The field survey data indicate a low level of awareness in technologies for improved forage and livestock systems. When asked how they learn new farming techniques, only a small percentage (less than 25%) of farmers said they have attended training courses. Opportunities for continuing education are limited for farmers. Several farmers mentioned that they receive farm publications. A larger percentage (42%) of farmers were contacted by an extension agent from the township. The lack of systematic training and education are major constraints for the adoption of improved agricultural technologies.

There is no systematic and coordinated diffusion of market information to farmers. In survey interviews, farmers said their primary source of market information was friends and neighbours (Table 7). However, the government plans to improve the dissemination of market information on a regular basis.

Table 7. Sources of agriculture and livestock information.

Source	Number
Family and friends	36
Television/radio	19
Extension agent	16
Magazine	16
Other	7

Information transfer

In Qiyang County, every district has a small veterinary station, and there are twelve districts in the county. Every town also has a small veterinary station. Qiyang town has a large veterinary clinic with twelve staff members. Every township has a veterinarian with five townships per district.

The Qiyang Livestock Station does some extension education but little information was available to evaluate the materials or methods being used.

At the Jiangyong County Livestock Station, the staff mainly focus on cattle breeding using artificial insemination. Semen is kept in liquid nitrogen cylinders, and farmers bring their animals to the station to be inseminated.

A key component to successfully testing and implementing technical innovations for sustained agriculture will be the involvement of farmers in trials at the start of the project. Farmers will need to be closely involved in on-farm testing of forages, fuel tree production, and livestock feeding and raising. The linkages between the three research stations in each agro-economic area and the participation in on-farm trials will be important to the success of the Red Soils Project.

Conclusions

The recent government agricultural policy reforms have opened the way for increased productivity of the agricultural sector in China. The introduction of the 'Production Responsibility System' and the removal of control of wages and prices is stimulating the rural economy. Entrepreneurship is being encouraged and farmers are becoming market oriented. Furthermore, change in consumption patterns due to rising disposable income has resulted in an increased market demand for red meat, including beef. In light of these macroeconomic conditions, an applied agricultural project in soil management and livestock–forage systems can improve the overall agricultural development of the Red Soils Region of South China. However, constraints do exist hindering the development of the region.

Survey results indicate a low level of formal education and agricultural training among farmers. Specifically, farmers have limited understanding of forage–livestock production and they have no 'custom' in caring for beef or dairy cattle, or goats. Thus, the introduction of new forage–livestock technological packages will require an intensive education program. A cadre of research scientists and trained extension workers who have technical packages to extend will be important to the success of such efforts.

Both domestic and foreign demand for pork is high, a demand which is shifting from fatty pork meat to leaner cuts of meat. However, the forecast for limited supplies of compound feed will restrict this region's capacity to produce more pork. Pig producers require large amounts of green forage to supplement the shortage of compound feed.

Poultry production is increasing as the gross profit margins are currently attractive to producers. Feed availability is a constraint on future production.

Ruminants have not been important in the region, especially small ruminants. Potential consumers in the region have a very low taste preference for mutton. Although ruminant production, such as dairy or beef cattle, can provide positive net returns to the household unit because rising per capita income would increase the demand for red meat, the lack of forage and feedstuffs during certain times of the year limits the potential for these enterprises. Households in certain areas use crop by-products such as rice straw and sweet potato tops for household fuel. These could be better used as animal feed. Improving supply of feed requires research on utilisation of crop residues, crop by-products and the need for alternative sources of fuel.

Lingling Prefecture officials have targeted the southern counties of the prefecture for large-scale livestock production because of large areas of pasture land. The southern counties have the potential for quicker results from ruminants than the northern counties. A major limitation for extensive livestock systems in the south is the lack of phosphorus in the soil for forage production.

The potential market demand for beef in Guilin is high because of the volume of tourists visiting the city. Northern Lingling services this market better than southern Lingling (Jiangyong County) because of developed road and rail systems.

Although the distribution and marketing systems are adapting to privatisation and 'open markets', food processing remains rudimentary, especially for red meat and dairy products. The existence of a dual pricing system for certain key agricultural inputs and outputs distorts market signals for resources and products. Many products, however, are being moved to the 'free market' system.

The major livestock marketing system in Lingling Prefecture is for pigs, which includes marketing channels for small-scale and commercial producers. Commercial pig units are currently being traded from Hunan Province directly to Guangzhou for resale to Hong Kong. These market channels can assist market development of other animal products such as cattle, sheep and goats.

Improvements in the overall marketing system have occurred with the removal of government as the major buyer. Inter-regional trade is increasing though transportation infrastructure is inadequate for an efficient marketing system. The demand for pork in the Hong Kong and Guangzhou markets has a positive impact on promoting regional trade.

In general, the survey data reported above indicate that there are many inter-linked socio-economic factors constraining the development and utilisation of ruminant livestock–forage systems in the Red Soil region.

More productive ruminant livestock systems will be achieved not only through animal–plant and soil research but also by the creation of an infrastructure which facilitates such developments.

Socio-economic Factors Influencing Animal Husbandry and Forage Development on the Red Soils of South Central China

Xie Xiao Cun*

As China's population continues to expand, pressure will be placed on existing agricultural lands for increased production of food. Despite large increases in agricultural production since the mid-1980s, China soon faces the prospect of becoming a net-importer of grain. This situation has led the Chinese government to explore new ways of increasing food production, including relaxing controls on the pricing of agricultural commodities. Another initiative has been to promote the agricultural development of under-utilised lands such as the upland red soils of south central China. This paper presents some of the socio-economic issues involved in such development.

Land Resources

Land resource quality and location largely determine the utilisation capability of land. Land resource quality is determined by such factors as soil fertility and local climatic conditions. Location includes such factors as distance to markets, transportation costs, travel time and effort for farmers, security of crops from theft and pests and ease of communication.

The land resource quality in the red soils region has been the subject of several papers in this workshop. Broadly, the climate is distinctly seasonal with cold winters, warm to hot summers and annual average rainfall totals of 900-2000 mm (distributed unevenly with a late summer drought). In the upland areas, the soils are acid and infertile and subject to serious erosion.

The land resource can be divided into three broad categories on the basis of location:

Outskirts of cities and towns. This land is mostly serviced with good transportation facilities, water for irrigation and easy access to large markets and information.

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Outskirts of villages. This land is also generally well serviced and densely populated but without the advantages of the larger markets associated with the cities.

Remote regions. This land is sparsely populated and generally consists of poor soils on sloping and hilly lands with poor access to transportation and other services.

Land Ownership

Agricultural land in China is contracted to production units within which labourers have control over small areas of land. In the red soils region, there are several variations of this broad system of land tenure:

Individual households. In the more densely populated and intensively farmed areas, small parcels of land are commonly contracted to individual farmers.

Household pasture farms. In less populated areas bordering grazing land, individual households may be contracted to control both intensively cultivated lowlands and adjacent hillsides. Areas of land controlled by households are larger than in the system of individual household land tenure.

Joint households. For remoter mountain and hilly land, several households or a production unit are frequently contracted to control land use. In this form of land tenure, large areas of land may be controlled by one unit or group of households.

State-run pasture farms. These farms were established in the early years following World War II based around a central administration with farm activities carried out by contract labourers.

Uncontracted land. At present, most of the remote hilly land in the red soils region has not been developed either as State-run or household-controlled farms. Development of this final category of land, both on the outskirts of villages and in the remoter areas, is a high priority for improving land utilisation in southern China.

Development Prospects

Much of the undeveloped remote, hilly land is classified as grassland. However, the sparse native vegetation on these hills consists of shrubs and grasses that produce low yields of poor quality forage (high fibre, low digestibility and low nutritional value). This results in low carrying capacities and high susceptibility to soil erosion.

The potential for developing animal husbandry on these hilly lands is greater than that of cropping. In Lingling prefecture, southern Hunan, for example, 14% of the prefecture (305 000 ha) consists of intensively cropped paddy land. Cropping systems include rice–rice–green manure, wheat–corn–sweet potato, (wheat + canola)–(corn + peanut)–green manure and rice–rice–canola. The potential for increased production from these systems is limited. Wasteland, grassland and hills account for 24% of the prefecture (541 000 ha). Development of these areas with crops would require high inputs for only marginal returns. These areas, however, can be effectively and economically developed with forages.

Selection programs have identified a number of valuable forage species that are adapted to the soils and climate of the region, including red clover, white clover and ryegrasses. At Nanshan farm, Cheng Bu county, Hunan Province, a mixed pasture of ryegrass and clover yielded 49.5 t/ha fresh forage two years after sowing, compared with only 0.8 t/ha for the native pastures. Similarly, at a high altitude site in Guizhou Province, a clover–ryegrass pasture yielded 21.3 t/ha fresh forage one and a half years after sowing compared with only 0.3 t/ha for the native pasture. In both cases, protein contents of the forage were up to 10 times higher from the improved versus native pasture. Such forage developments also have the potential to reduce soil erosion and improve soil fertility through inputs of nitrogen and organic matter from the forages.

Economic Factors Controlling Development

Recent social reforms in China have provided economic opportunities for the forage development of the upland red soils. Implementation of the 'production responsibility' system means that farmers now administer their contracted land and make their own cropping decisions. This means that, if allocated land on the red soil hills, a farmer could gain direct benefit from the agricultural production of that land. To date, there have only been small-scale trials on production of herbivorous animals (cattle, sheep, rabbits, geese) on the red soil hills. However, the indications are that larger-scale developments would not be limited by labour shortages. For example, at present, in Lingling prefecture, the average cultivated area per farmer is less than 0.3 ha and only four months of the year are spent in tending this land.

In addition to China's rapidly increasing population, patterns of food consumption are changing, with demand for animal products (such as beef, pork, mutton and dairy products) increasing every year. Between 1984 and 1988 national annual consumption of pork increased from 13.0 to 14.9 kg/person, of beef and mutton from 1.2 to 1.6 kg/person and of fresh milk from 2.5 to 3.9 kg/person. There has also been a trend towards higher demand for lean meat, as produced from herbivorous animals. At present, beef and mutton supplies fall well short of demand and this has been reflected in recent price trends. The national average prices of beef in 1988 and 1989 were 5.53 and 6.73 yuan/kg and of mutton were 5.59 and 6.73 yuan/kg. These rises were not mirrored in pork prices which fell from the 1988 level of 4.96 to 3.59 yuan/kg in 1989. In Lingling prefecture, the average price of pork in 1980 was 30% higher than the price of beef but was 50% lower than the price of beef in 1988. This evidence of a high and increasing demand for beef and mutton and hence strong market prices provides a significant economic incentive for forage developments on the upland red soils.

A further incentive in some areas (for example, Weiling and Bijie counties, Guizhou Province and Qiyang and Jiangyong counties, Hunan Province) is the problem of disposing of agricultural residues, such as rice straw. In many areas of northern China, these residues are burnt but in the red soils region, they are commonly used for animal feed. Through the use of forages as a supplemental feed and chemical pre-treatments (for example, with urea) these agricultural residues can be more efficiently converted to animal products.

Initial trials with forage development of the upland red soils have shown economic promise. For example, in Shu Pu village, Weiling county, Guizhou Province, meat/wool sheep have been grazed for several years on red soil hills that were converted from wasteland to improved pasture. The result has been a carrying capacity of more than 12 sheep/ha with a net income of 293 yuan/ha/year. In the same area, the carrying capacity of cattle was 1.7 head/ha for a net return of 220 yuan/ha/year. A similar development at Dan Qing village, Jishou city, Hunan Province resulted in a carrying capacity of 86 rabbits/ha for a net income of 4064 yuan/ha/year.

Development of Forages and Animal Husbandry

Currently, widespread adoption of forage and animal husbandry development in the upland red soils region is restricted by poor land resource quality and low land utilisation capability (remoteness from markets, transport and information). Planning to overcome these problems through local production units will need to focus on the following areas.

Forage management

As mentioned previously, the large areas of remote hilly land in the red soils region that have not been contracted for agricultural development, provide the best opportunity for forage and animal husbandry development in the region. Various forms of land tenure (personal, collective, joint household and state-run enterprises) need to be enacted to encourage the development of individual household contracted grasslands.

Whilst farmers may recognise the importance of planting forages, they have no experience in forage management. Assistance and information must be provided through the production units in such areas as species selection, sowing practices, fertilisation, grazing/cutting management and erosion control. Various incentives could be used to encourage good forage management practices as has proved successful with cropping.

Livestock management

Unlike forage management, many farmers do have experience keeping livestock. However, their management practices are based on tradition and often do not result in sensible decisions for modern market systems (for example, animals are kept too long and rates of weight gain are low). Production units need to be assisted to produce marketable animal products more efficiently.

The numbers of livestock kept by a production unit should match the scale of the operation so that weight gain per hectare of grassland is optimised. More stock will be kept by joint households and household pasture farms, for example, than by individual households. The kinds of livestock to be kept (such as cattle, sheep and rabbits) will also need to be determined according to the needs of the production unit. Rabbits and sheep may be more suitable to the smaller operations, for example, except where draught power is required. Information needs to be provided on the best ways to breed stock, prevent disease, utilise forage and produce a product that will be marketable (by selecting the best age for slaughter).

Marketing animal products

The market is the key link providing feedback between producer supply and consumer demand, through which equality of supply and demand can be realised. In remote regions, far from urban markets and reliable transport systems, this feedback can be slow and considerable time, effort and money can be lost through the product (both quality and type) not matching market demand. Animal husbandry developments in the red soils region should provide production units with access to market information and should aim to supply the currently increasing demand, both internally and abroad, for lean meat.

Integrated planning

While the direct aim of forage development is to provide animal products for market, the farm labourer expects to profit from the production. If this does not happen, the developments will fail. So, in developing animal husbandry and forages on the upland red soils, it is necessary to develop each link in the chain of development (forage establishment, livestock raising, product processing, transportation and marketing) not just the production links. For example, a meat cold storage facility with a capacity of 5000 tons was built in Guilin because in 1984 slaughtering works had to be closed because of a shortage of cold storage space. Now the facility is under-utilised because of a shortage of livestock. It is therefore necessary to strengthen both processing and marketing in addition to forage and animal husbandry development to ensure that supply and demand are balanced.

The Present Status and Potential Use of Hill Land in Fujian Province

Liu Chung Chu and Lin Cang*

FUJIAN Province is located on the coast of southeast China within the area defined by 115°50′–120°40′E and 23°32′–28°22′N. It occupies 121 200 km^2 and has a population of 30.4 million. Several mountain chains occur in Fujian, such as Wuyi Mountain along the northwest border and Jinfeng-Dacyun-Bopinglin mountains in the centre. The Province may be broadly described as consisting of 80% mountains and hills, 10% cultivated land and 10% water (lakes, rivers, ponds). More precisely, hill land occupies 101 000 km^2 which is 84.1% of the total area. Clearly it is essential to use this hill land efficiently to increase agricultural production and improve the natural environment.

Present Use of Hill Land

Fujian lies within the south and central sub-tropical region of China. The topography is complex so that soils vary widely from place to place. The main soils of the hill land show a sequence of dark red earth, red earth and yellow soil from lower to higher altitude. Small areas of purple soil and limestone soil also occur. Most hill soils have an inadequate fertility. They are commonly deficient in P, K, Mg and B, are strongly acid and have low buffering capacity.

The soils of the hill land are mainly used for forestry, forage production and orchards. However, some areas have been developed for wetland and dryland cultivation as paddy fields in small valleys and terraced slopes.

Forest land. Fujian is one of the main areas of forest production in south China. The area classified as forest land in 1985 was 47.4% of the total area, but had decreased to 43.2% in 1988 due to felling. Of this area 78.8% was covered by high density of trees, 11.5% by low density of trees and 5.2% by shrubs. The remaining 4.5% was undeveloped land mainly covered by shrubs and grass.

The area covered by trees is used as follows:

(i) 69.3% for commercial forest production of which the main species grown are Chinese fir (23%), pine (44%) and various broadleaves (33%);
(ii) 13.5% for bamboo;
(iii) 10.4% for industrial trees, the main ones being oil tree (camellia) and tung;
(iv) 2.7% as shelter forest for wind breaks and soil erosion control;
(v) 3.3% for fuel woods; and
(vi) 0.7% for specialised crops such as tea.

The tree-covered area occurs mainly in the middle subtropical zone, i.e. Shangming, Nanping and Longyan prefectures, whose combined area of woodland constitutes about 68% of the Province's total forested land. Elsewhere, in south and east Fujian the topography consists mainly of hills and plateaus. Here soil fertility is poor and forest cover is low, with oil-tree camellia and shrubs being dominant.

Orchards. These occur mainly on the lower slopes of hills. In 1988 the total area of orchards was 5.69 million mu,[1] 1.59 million more than in 1985. The main crops grown were fruit (3.76 million mu), tea (1.805 million mu), mulberry (5000 mu) and rubber (0.12 mu). The main kinds of fruit tree were citrus (1.5 million mu), longan (*Dimocarpus logan*), banana, litchi and loquat. Ninety percent of the orchards are located on hillsides, the remainder being on alluvial flats. Citrus is grown widely throughout Fujian to an altitude of 500–600 m. The other crops are grown mainly in the southern sub-tropical part of the province.

Tea plants are grown mainly on red and red-yellow earths at elevations of 400 to 800 m in Nanping, Quanzhou, Ningde and Zhangzhou prefectures. In these areas conditions favourable for growing tea occur: the soils are acid and fertile, rainfall and humidity are high and solar radiation relatively low.

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[1] 15 mu = 1 ha

Tea is also planted at lower elevation on lateritic red earth and at higher elevation on yellow earth. However, the quantity and quality of the tea produced is poor in comparison to that grown on the red earths.

Grassland. The grasslands in Fujian are scattered. According to information provided by the Fujian Provincial Bureau of Animal Husbandry, the grasslands comprise 2894 parcels of land, each larger than 300 mu and suitable for growing forage; their total area is 7.863 million mu. Of these, 652 are larger than 1000 mu and collectively account for 3.12 million mu of the total area. Areas less than 300 mu have a total area of 22.86 million mu.

Grassland is widely distributed throughout the Province. It occurs in both low and mid-elevation zones and on all the soil types previously mentioned. Generally the smaller parcels of land (less than 300 mu), occur at lower elevations (below 800 m) and between the cultivated and forested land. In this zone red earths and lateritic red earths are common, soil fertility is good, slopes are gentle and irrigation is feasible. The dominant grasses are *Digitaria sangunalis*, *Cynodon dactylon*, *Setaria viridis*, *Paspalum thunbergii* and *Imperata cylindrica*. These species produce high biomass, their quality is good and they have a relatively long growth period. These areas are therefore the main stock-raising and grass-harvesting areas.

Areas of grassland larger than 300 mu are concentrated in the low to middle zone of the mountain area above an elevation of 500 m. They occur frequently in Longyan and Ningde prefectures, and Fuzhou city. The main soil types are red earth, yellowish red earth and mountain meadow soil, with small areas of lateritic red earth in grassland within forested areas.

The more extensive areas of grassland can be subdivided into four types:

1. *Herbaceous grassland.* It has been estimated that 1718 occurrences of this type exist, widely distributed throughout Fujian. Their total area is 4.883 million mu. The dominant grasses include *Miscanthus floribunda*, *Eulaliopsis binata*, *Imperata cylindrica*, *Arundinella birta*, *Eulalin* sp, *Paspalum thunbergii* and *Cyperus rotundus*. These grasses occur in association with legumes, *Dicranopteris dichotoma* and members of the Compositae family.

2. *Mixed bush and grassland.* 611 occurrences of this type have been recorded, having a total area of 1.28 million mu and accounting for 16.29% of the total grassland area. The main soil type is red earth, followed by yellow earth; in the southern subtropic zone the soil is dominantly lateritic red earth. The main grass species include *Miscanthus floribunda*, *M. sinensis*, *Dicranopteris dichotoma* and *Imperata cylindrica*; associated with *Lespedeza cuneata* and *Alnus* sp.

3. *Scattered trees with bush and grassland.* 543 occurrences of this type have been recorded, occupying 1.59 million mu and constituting 20.3% of the total grassland area. It has been estimated about 1.26 million mu can be utilised. The main soil type is red earth, followed by yellow red earth and yellow soil, which are deep and fertile. This type of grassland has developed from mixed bush–grassland being colonised by native trees. The flora consists mainly of perennial grass and weeds mixed with scattered shrubs and less frequent trees. The main species include *Miscanthus floribunda*, *Dicranopteris dichotoma*, and *Arundinella hirta*.

4. *Meadow grassland with bushes.* 22 occurrences of this type have been recorded, having an area of 0.10 million mu and accounting for 1.31% at the total grassland area. The utilisable area is 88 800 mu. This grassland classification is equivalent to high mountain grassland. The dominant soil type is mountain meadow soil which has an organic matter content of more than 10%. The dominant grass species include *Eulalin* sp, *Shibataea chinensis*, *Cyperus rotundus*, and *Carex* sp.

5. *Cultivated land.* In the hill area of Fujian cultivated land includes both rain-fed dryland and irrigated wetland cropping. About 63% of the Province's cultivated land occurs on hill slopes. In 1988 terrace fields within small valleys in the hill country accounted for 60% of the total area of paddy. The distribution of cultivated land with elevation shown in Table 1 indicates the importance of hill land for agricultural production in Fujian.

Table 1. Distribution of cultivated land in Fujian with elevation.

Elevation (m)	Percentage
Below 50	25
50–100	10.8
100–300	24.3
300–500	20.3
500–800	14.6
Over 800	4.5

A New Model for the Utilisation of Hill Land

Traditionally hill land in Fujian has been used solely for crop and animal production. The shortcomings of this type of utilisation are that it is time-consuming, generates low income, and provides poor soil protection which can lead to serious soil erosion. In recent years stereoscopic techniques to develop comprehensive management plans have been used to foster integrated farming systems in hill land.

The principle underlying this type of planning is that landform, soil and climate are first assessed to determine the land-use potential of areas. This forms a rational basis for integrating cropping, animal production, fishery, foresty and their by-products into a regional land-use plan. Because of the shortage of land, 'multi-layer' systems of production have been developed. For example, in the middle and high elevation zones forestry is combined with growing smaller crops such as tea and fodder grass. At lower elevations fruit growing is combined with forestry, tea, animal, fish and edible fungi production. Thus in integrated planning different enterprises form a sequence with elevation: forestry is developed on the highest land, fruit trees on the middle zone, pigs are raised on the lowest part of the hill land, and rice and fish are produced in the valleys. In addition, forage, green manure and edible fungi are grown under fruit and forestry trees. In this way all the resources of the Province are developed in a rational and comprehensive way. Thus mountain areas are developed in conjunction with lowland enterprises so as to complement each other.

Several benefits arise from this model:

1. The systematic and integrated development of agriculture, forestry, animal and fish production substantially increases economic benefits. Thus income is generated quickly from short-term enterprises part of which can be used to develop longer-term enterprises such as forestry which take many years to produce income.
2. Greater use is made of the resources of hill country by adopting multi-layer production, such as growing forages and green manure under fruit trees or forest. This system also provides greater vegetative cover and therefore better protection against erosion.
3. The incorporation of forage and animal production into the agricultural system increases the organic matter content and fertility of the red soils.

Impediments to Development

In planning the development of hill land in Fujian the following factors need to be kept in mind:

2. *The inefficiency of present land use.* Current land use is dominated by monocultures which have been shown to be inefficient in the utilisation of agricultural resources. In addition insufficient attention has been paid to land capability and therefore large tracts of land have been exposed to degradation through erosion. There is scope for better utilisation of gently sloping land which is presently not appropriately utilised. It has been calculated recently that only 80% of hill land suitable for forestry is being used for this purpose. Similarly only 25% of potentially arable land is being cultivated.

2. *Land degradation due to poor management.* The main problem is that insufficient attention has been given to growing forages to protect sloping land against soil erosion. Consequently erosion is widespread in Fujian, with 11.2% of the land area considered to be affected. About 66% of this erosion is believed to be due to deforestation, 32% due to cultivation practices on sloping land and 2% occurring in gardens. Most of the erosion occurs on red earth (70%), with lower amounts on lateritic red earth (22%), yellow soil (5%), aeolian sandy soil (2%) and purple soil (1%).

3. *Unsound agricultural systems.* The variation in topography in the hilly land produces variations in microclimate. These variations are not taken fully into account and hence scope exists to make adjustments which would lead to greater productivity. Although an intergrated model for combining different types of production has been developed in recent years, the extent to which it has been adopted is still limited. In most areas monocultures are still practised. For example in the land set aside for fruit trees 60% of the trees are citrus.

4. *Uncoordinated production, poor marketing strategies and information transfer.*

The Future

Potential exists for increased agricultural and livestock production in Fujian Province. The key to realising this potential is firstly a concerted effort to develop integrated farming systems. There are more than 11 million mu of moderate and low yielding paddy fields, 9 million mu of which occur as terraced and low-lying valley floor paddy. Here productivity could be greatly increased by growing green manure crops, returning rice straw to the soil, increasing soil fertility, improving water conservation facilities, and adopting new cropping systems. Also, there are more than 8 million mu of young fruit trees and tea plantations, which could be intercropped with forage and green manure crops in order to develop animal husbandry.

Secondly, a large area of undeveloped land exists which could be brought into production. A survey has shown that there are 49 million mu of undeveloped hill land in Fujian. Of this 10 million mu are considered suitable for forage and animal production and 20 million mu for forestry. About 10 million mu of gently sloping land could be used for the integrated development of agricultural cropping, forestry, fruit and animal production. The soil types in this latter area are mainly red earth and yellowish red earth, which occur mostly in the middle subtropical zone. The soils are deep and fertile, which along with the climate present a very favourable environment for developing integrated production systems.

Conclusion

A potential for increasing agricultural production in Fujian clearly exists. And since 80% of the Province consists of mountain and hill land and only 10% paddy field, it is obvious that this increase must come mainly from improved use of the uplands land. To realise this inherent potential the hill land must be developed in a rational and coordinated way taking into account all the attributes of the natural environment including those which predispose the landscape to degradation.

The Potential of Grasslands in Hunan for Animal Production

Gao Chengshi, Lin Yan, Nan Mu, Jiang Guangfei and Shi Faying*

HUNAN Province is located in the subtropical region of south central China. In general, the sunshine and rainfall resources are adequate for the growth of forages during the long frost-free period. In a recent survey of grassland resources in the Province over 800 plant species were identified of which 89% could be fed to animals. Of these 17% were grasses and 9% were legumes.

The total area of natural grassland in the Province is 6.4 million ha, of which 88% is potentially exploitable for animal production. The most extensive areas of grassland are either unoccupied lands (37%) or partially forested land (23%).

The distribution of these grasslands is not only affected by environmental conditions (climate, soils) but also by the patterns of agricultural activity. Hunan can be roughly divided into three topographic regions — the mountains, hills and plains.

About 64% of the grasslands of Hunan occur in the mountainous region, to the west and south, where the steep topography limits cropping activity and population densities. This compares with only 8% in the plains regions of the north, where cropping is intensive and population densities are high. The greatest potential for grassland development is in the 28% of grasslands that occur in the intermediate regions, where population densities are moderate and cropping activities are limited to the flat land between hills.

Current Grasslands Utilisation

Despite the large area of grassland in the Province, very little attention has been paid to improving utilisation by herbivorous animals. The animal husbandry industry has long been dominated by pig meat production, accounting for more than 90% of all meat products. Attempts to develop the grasslands for meat, milk and other animal products began only in the early 1980s.

In 1979, the Provincial Ministry of Agriculture organised a rangeland survey of the Nan mountains in the south of the Province. The survey group reported that cropping and forestry developments in this area were limited by low winter temperatures. They recommended that future projects should concentrate on developing the grassland resource for animal production. In order to improve forage quality and productivity, a small area (530 ha) was established with forage grasses and legumes with the assistance of Australian forage scientists.

The success of this project in the Nan mountains led to trials of aerial seeding of forages. Since then 40 000 ha of grasslands have been aerially sown with improved forages over 22 counties of the Province. A survey in 1990 revealed that the average yield of fresh biomass had increased from 9000 to 45 000 kg/ha as a result of aerial sowing. The forage quality had increased, with mean protein contents rising from 4–5% to 12% of dry matter. And species composition of the grassland had shifted to include 47% high quality (sown) forages and only 24% unpalatable species. This compares with 77% unpalatable species in the natural grassland.

The success of establishment of improved forages prompted an expansion of the livestock sector. Prior to improvement, only 2600 sheep and 5200 cattle were grazing the natural grassland. At the time of the 1990 survey sheep numbers had increased to 25 000, cattle 21 000 and there were an additional 3000 rabbits and 113 000 poultry where none existed previously. Agricultural activity also became more diversified with the introduction of related activities such as honey and fish production. In 1990 the improved grassland produced 265 000 kg milk powder, 9000 kg wool and meat from 3800 cattle,

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1400 rabbits, 90 000 poultry and 6600 sheep. The average income of farmers in the region has improved by 100–300 yuan per year.

The success of the early work in the Nan mountains has resulted in more than 1000 species of potentially useful forages being imported from other provinces and abroad. A research program was established to investigate technologies for producing forage seeds and seed production farms were set up to increase production of seeds and facilitate distribution. Research was also started to develop utilisation strategies for the improved grassland resources to maximise production of cattle, sheep and poultry. Productivity of Xiao-xi yellow cattle and Ximedare hybrid cattle was found to increase by 0.31 and 0.36 kg/day respectively; an improvement of 33% over growth rates of similar cattle on natural grassland. Plans have been made to extend the improved grassland area and over 6000 technicians have been trained in grassland improvement. In the plains and hilly regions, more than half of the grasslands are not utilised and attention needs to be given to the improvement of grassland resources.

Grassland Improvement Strategies

Despite the successes in the Nan mountains wider adoption of the technology is restricted. Firstly, grassland distribution in Hunan is very uneven and systematic planning for grassland development is lacking. Secondly, there is a serious lack of expertise in the fields of animal husbandry and forage management. Thirdly, the economic benefits of improving grassland are not well recognised by scientists, policy makers or farmers and will have to be demonstrated through a large and widespread extension program. Finally, there are few farmers with experience in forage management and animal husbandry.

Success of an emerging livestock industry in Hunan will also depend on easy access by farmers to commodities necessary for maintaining production (such as fertilizers) and to expertise. Of no less importance will be access to transport to deliver livestock to market and a strong market demand for animal products. These areas will require on-going research and improvement by provincial and central authorities.

The Agricultural Potential of Red Soils in Southern China and the Role of Forages

Xiao Ze-hong and Peng Ke-lin*

RED soils are the predominant soils of agriculture in southern China. They are distributed in the middle sub-tropical region including Hunan, Jiangxi, Guangdong, Guangxi, the western parts of Zhejiang, the northern parts of Fujian and parts of Yunnan and Guizhou Provinces. The total area of these soils is 61 million ha of which 2.8 million ha have been cultivated (Anon 1985). There are 3.3 million ha of wasteland in the red soils region of which at least 1 million ha are in Hunan Province alone (Yang and Xiao 1989).

Large areas of red soils occur in mountainous regions and can only be used as forest or pasture land. In the hilly regions, however, the high population densities and a shortage of cultivated land, have prompted interest in the agricultural development of these soils. There are large areas of hill country on which the only existing vegetation is shrubs, herbage and a few trees of low economic value.

Utilisation of red soils in the hilly regions has great potential for two main reasons. Firstly, yields of many crops (such as cereals, legumes, fruit and tea) which are currently grown on the red soils are lower than the maximum yields obtained from intensively managed small plots of the same crops (Table 1). Secondly, the physical conditions associated with the soils and the climate of the region have the potential for expansion in crop production from the red soil hills. There are many factors which limit crop yields to well below experimental yields in this region. These include low soil fertility, seasonal drought (Horne, these Proceedings; Lu and Shilin, these Proceedings), poor crop varieties and inappropriate farming techniques. If these problems can be resolved, crop yields are likely to rise rapidly.

Table 1. Potential production of four crops on the soils in Hunan Province.

	Crop yield (kg/ha)			
	Corn	Sweet Potato	Citrus	Tea
Present yield	2250	11250	4500	375–450
Maximum yield	15000	37500–600000	60000	7500

The nutrient status of red soils is shown in Table 2. The low percentages of organic matter will have negative effects on soil structural stability. Low pH and high levels of exchangeable aluminium cause reductions in the yields of many crops. Symptoms of deficiency of N, P, Ca, Mg, B, Zn and Mo are common.

The use of forages

Sustainable utilisation of the red soils will require biological, chemical and engineering inputs to improve and maintain soil fertility and crop yields whilst at the same time minimising soil losses due to erosion. Forages have an important role to play in improving soil fertility and conserving soil moisture.

The main effect of forages on soil fertility is an increase in the levels of organic matter and available nutrients in the soil. The accumulation of organic matter is particularly important for the upland red soils since organic matter decomposes rapidly in the high summer temperatures. An experiment conducted between 1985 and 1989 showed the change in soil organic matter under different forages grown on red soil (Table 3). In this experiment, the grass *Dactylis glomerata* (cocksfoot), the legume *Trifolium repens* (white clover) and a mixture of both were planted in 1985 and all the above-ground biomass harvested each year was returned to the soil. The results show that cocksfoot increased the organic matter in the soil more than white clover even though the total biomass of cocksfoot returned to the plots was less than that for the plots of white clover. The

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Table 2. Nutrients in red soils.

Soil	Organic matter %	Total nutrients (%)			Available nutrients (ppm)			
		N	P_2O_5	K_2O	N	P	K	pH
Uncultivated	0.77	0.052	0.094	1.05	26	9.3	23	5.0
Fertile	1.74	0.085	0.130	1.41	51	4.1	80	6.6

Table 3. Changes in soil organic matter content between 1985 and 1989.

Treatment	Total O.M. (dry) added 1986–1989 (kg/ha)	Soil O.M. (%)		O.M. change (%)
		1985	1989	1985–1989
Control	—	1.09	0.92	−0.17
Trifolium repens	8749.5	1.09	1.30	+0.21
Dactylis glomerata	7680.5	1.09	1.57	+0.48
Trifolium + Dactylis	9064.5	1.09	1.50	+0.41

changes in some major soil nutrients in this experiment are shown in Table 4.

Table 4. Changes in soil nutrient contents 1985–1989.

Treatment	P (ppm) 1985	P (ppm) 1989	K (ppm) 1985	K (ppm) 1989
Control	3.7	4.3	147.0	170.6
Trifolium repens	3.7	9.9	147.0	180.0
Dactylis glomerata	3.7	11.9	147.0	240.4
Trifolium + Dactylis	3.7	—	147.0	222.2

Forage mulches can be used to prevent soil erosion and the evaporation of water from the soil surface (Huang 1987). The results presented in Table 5 show that a straw cover on the surface of the soil can conserve soil moisture during the dry season. In this experiment, the straw mulch delayed the onset of potential moisture stress to at least 15 days after rainfall compared with only several days for the control. The mulch also significantly decreased soil surface temperatures.

Table 5. Effect of mulch on soil water potential and temperature.

	Water potential at various depths* (kPa)		Soil temperature (°C)**	
Treatment	20 cm	40 cm	0 cm	20 cm
Control	−2730	−1260	37.8	29.4
Mulched	−1160	−890	29.9	28.5

* Mean value within 15 days after rain
** Mean value measured between 16 and 21 August 1983 under sunlight

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Grassland Development on Red-Yellow Soils in Hubei Province

Huang Wenhui* and Nie Zhongnan†

RED-YELLOW soils are widely distributed in various parts of the world. In China, these soils are most common in the provinces (or regions) of Jiangxi, Hunan, Zhejiang, Fujian, Guangdong, Guangxi, Hunan, Guizhou and Taiwan and less common in Anhui, Hubei and Sichuan. These areas total 2.17 million sq. km and are inhabited by a population of 470 million people. Ninety percent of China's rice production is produced on red-yellow soils.

Generally red-yellow soils are classified as laterite, red earth or yellow earth according to their nature and form. A large proportion of the red-yellow soil group in Hubei is yellow earth, which occurs in the western mountains, northern hillocks and central hills. The red earths occur mainly in the low mountains and hills of south-eastern Hubei although they do occur less frequently in the rest of the Province.

The red-yellow soils are not ideal for growing crops due to their low pH, low organic matter content and poor structure. In the mountainous and hilly areas, infertility combined with limitations of climate and topography are serious impediments to crop growth. The native pastures of these areas are not well managed and yield only 750–3000 kg DM/ha/year (Cheng Qing 1989).

Uncontrolled felling of forests combined with intense rainfall has resulted in soil nutrients being washed and leached from red-yellow soils in the hilly regions. Yet despite major constraints to improved production, successful experimentation through the past 10 years has resulted in some 37 000 ha of pasture being established which presently carries 436 000 cattle and sheep (Chen Qing 1989).

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Hubei Province

Hubei Province is located on the Yangtze River (20°00′–33°20′N, 108°30′–116°10′E) covering an area of 187 400 sq km. Fifty six percent of the Province is mountainous, 24% hills and hillocks, and 20% plains. There are 3.5 million ha of arable land, 8.6 million ha of forest and 5.7 million ha of grassy mountains and hills. The Province receives 1150–2245 hours of sunlight per year; has a mean temperature of 15–17 °C; a record minimum temperature of −19.7 °C; a record maximum temperature of 43.4 °C and an annual average rainfall of 800–1600 mm.

With a population of 50 million people there is less than 0.07 ha of arable land per person.

Research in the 1980s

In China in the early 1980s an emphasis was placed on the development of grassland agriculture. In southern China this type of agriculture was poorly developed as traditionally cropping had taken precedence. The available agricultural land was fully utilised and attempts to make use of the mountainous and hilly areas with agro-forestry had largely failed.

In an attempt to reverse this situation a program was commenced in Hubei Province to select pasture species which could survive local soil and climatic conditions. Compared to crops, pastures are more tolerant of adverse conditions and easier to manage.

Evaluation trials of 93 grass and 81 legume cultivars were conducted in various regions of the Province. Of these white clover (*Trifolium repens*), red clover (*T. pratense*), ryegrass (*Lolium* spp.), orchard grass (*Dactylis glomerata*) and tall fescue (*Festuca arundinacea*) were selected on the basis of their high productivity (Table 1) on infertile, low pH soils.

On the yellow soil mountain slopes, where it is cool in summer, cold in winter and rainy throughout the year, the temperate species such as white clover, red clover and ryegrass are widely grown. On the red and

Table 1. Dry matter yields (t/ha) of several pasture species (from Zhou Wianhua and Bao Jianying 1985).

Region	Location	White clover	Red clover	Ryegrass	Tall fescue
Western mountains (elevation 1700 m)	Wufeng	10.3	17.0	6.5	5.5
Western mountains (elevation 1150 m)	Lichuan	8.5	8.8	9.6	7.5
Eastern hills	Hongan	5.9	7.9	7.1	8.1
Southern hills	Wuchang	16.6	14.4	11.0	5.9

yellow soils of the hills and hillocks, where drought and hot conditions are common, it is more difficult to select appropriate species. Although tall fescue and some annual grasses grow well in these areas the persistence of perennial legumes is still a problem.

Soil nutrition

The red-yellow soils are prone to leaching causing serious plant nutritional deficiencies. To counteract these deficiencies additions of fertilizer are necessary. The application of P has been shown to increase plant growth and in some areas trace element deficiencies need to be overcome. In Xiangfan, for instance, foliar sprays of boron have increased seed yields of white clover and red clover by 20–40% and sprays of molybdenum have increased seed yields of red clover by 15–22% (Xiao Yiman 1985).

In Yichang a lack of selenium in the soil has caused white muscle disease in lambs which was remedied with an injection of sodium selenite.

The red-yellow soils are also deficient in nitrogen and organic matter. The application of nitrogen fertilizers is not recommended because of its high cost. A more economical means of supplying N is by establishing pastures based on nitrogen-fixing legumes. Once robust, grass–legume, pastures are established, organic matter is steadily accumulated in the soil, which in turn improves N supply.

In Hubei Province multi-species pastures are more successful than single, or two, species pastures. Bao Jianying et al. (1986) found that when pastures consisting of two species (red clover and perennial ryegrass) or four species (red clover, white clover, perennial ryegrass and phalaris) were sown in western Hubei, the mix of four species yielded 37% more than that of two (7890 kg dry matter/ha compared with 5755 kg dry matter/ha).

Sown pastures have also been found to reduce soil loss by as much as 89% in mountainous regions when compared with crops and by 74% on the low mountains and hillocks when compared with native pastures and peanuts. Nie Zhongnan et al. (1991) showed that sowing pastures under trees can improve timber yield. In a 50 ha forestry plot the growth rate of trees with and without undersown pastures was measured over a period of two years. Mean growth rates of trees in the undersown area were 65% greater than in the control (6.6×10^{-2}/cu m/tree/year compared with 4.0×10^{-2}/cu m/tree/year.

Economic benefits

In Hubei about 37 000 ha of sown pasture have been established. Dry matter yields have been increased from 1800 kg/ha to 7500 kg/ha allowing for substantially increased stocking capacities (Liu Chuanqui et al. 1989.).

Studies conducted at the Animal Sciences Institute of the Chinese Academy of Agricultural Sciences have shown that stocking rates of sown pastures in Yichang, western Hubei, can reach 7.5 sheep per hectare with wool production per sheep of 5 kg. At present the wool price is $A3.00/kg giving a potential value of wool from sown pasture of $A112.50 per hectare. This is more than ten times the value of production from native pasture in the Province.

Problems and Strategies

The major impediments to forage development of the red-yellow soils of Hubei Province are a difficult environment for pasture establishment, a lack of agronomic skills and poor marketing infrastructure for animal products.

Environmental constraints

The mean daily temperature of the hilly areas of the Province reaches 27–28 °C in July–August with a maximum of >40 °C. The red-yellow soils have a low water-holding capacity and this combined with the high temperatures leads to water stress, wilting and even death of plants.

Management constraints

The peasant farmers of these regions have little experience with grassland agriculture. They raise cattle as draught animals and goats, rabbits and geese for their own consumption. On natural grasslands their grazing management is primitive and they often conserve insufficient forage for their animals in winter. As a consequence stock losses are high in winter and spring. On the sown pastures animal production is not being maximised and hence economic returns are comparatively low.

Marketing

Production units pay little attention to marketing. As a result beef, lamb and fresh milk are not sold in an organised way. Wholesale marketing and forward trading need to be developed. Consumer preferences need to be diversified. Diets are simple, based on rice and pork.

In 1987 the per capita consumption of meat was 22.7 kg of which the majority was pork. Beef and lamb consumption was a mere 0.3 kg and fresh milk 0.8 kg.

The Future

The productivity of the hilly, red-yellow, soils regions of Hubei Province can be increased through the sowing of pastures for animal production. In the past, forestry plantations have proved uneconomic because of high costs and difficult soil and climatic conditions. Grassland agriculture has a shorter cycle and hence yields economic returns more rapidly.

To overcome the problems limiting grassland development there is a need for selection programs to identify new heat and drought tolerant forage cultivars; a need to improve the level of management applied to grasslands, and a need to improve marketing systems to increase the consumption of red meats and dairy products.

The development of grassland agriculture will restore stability to the red-yellow soils and raise the standard of living of people living in the hilly and mountainous areas. In Bailihuang and Yichang counties, for example, the living standards of local peasants have already been improved through better grassland management. Average yearly family incomes have increased from $A 25.00 to $A 145.00 in five years as a consequence of raising sheep and cattle. Earnings from the improved grassland accounts for more than 50% of gross income (Huang Wenhui et al. 1989).

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Developing the Pastoral Industry of the Red Soils Region of Jiangxi Province

Xie Wei-min*

JIANGXI Province is located in the middle of the subtropics — latitude 24°9′–30°5′N and longitude 113°34′–118°29′E. About 64% (10.8 million ha) consists of red soil hills. The mean daily temperature is 16.2 to 19.7 °C and the number of degree days > 10 °C is 5040–6340 per annum. Annual precipitation is 1341–1939 mm and cumulative solar radiation is 405.7–479.4 kJ/sq cm. There are 1470–2088 hours of sunshine per year and 241–305 frost-free days per year. On account of the favourable climate the potential for developing animal husbandry in Jiangxi is high.

Livestock Production

Traditionally in Jiangxi animals have been of secondary importance to cropping. Cattle were raised for draught power not meat. Pigs were raised for special occasion feasts and chickens for home consumption and a means of bartering for cooking oil and salt. This situation is now changing with animal husbandry forming a major part of the rural economy.

As a consequence of considerable effort over the past 40 years Jiangxi has become one of the major meat producing areas of China. The production of meat from pigs, cattle and sheep, on a per capita basis, is 30 kg higher than for the rest of China. Output from livestock is 6.8 times higher than in 1949 and the number of domestic animals is increasing at the rate of 5.4% per annum.

Pig raising forms the main part of the livestock industry and Jiangxi is one of the ten main pig producing provinces. The total number of pigs in 1988 was 5.6 times higher than in 1949; adult pigs for slaughter and pork production also increased by factors of 4.5 and 7.3 respectively. Domestic fowl production has also increased 5.9 times during this period. Jiangxi produces 70% of one of China's speciality ducks. Down processing is one of the province's 20 main industries and has an annual value of $A150 million.

Overall the value of animal products increased from $A195 million in 1978 to $A555 million in 1988. Increases in various sectors of the livestock industry are summarised in Table 1.

Impediments to Pastoral Development

Although much progress has been made in livestock husbandry there are still urgent problems. This is reflected in the fact that only 20.5% of the province's total agricultural production is derived from livestock. This is 2% below the national average (Table 1). The major factors hindering development are:

Unbalanced production. Table 2 demonstrates the emphasis on pig production within the province. The demand for other commodities, particularly beef, mutton and milk is not being met. Likewise there is an unsatisfied demand for wool and rabbit fur.

Efficiency of production. Efficiency of pig production in Jiangxi is low in comparison to that of the other main pig producing provinces. For example in Jiangxi it frequently requires 15 months for a pig to reach 70 kg body weight; this compares with a weight of 90 to 100 kg achieved after 5–6 months in other regions. This low growth weight is reflected in the comparatively small proportion of Jiangxi-bred pigs slaughtered compared with the number being reared (Table 3). The slow adoption of improved breeds is considered to be a major contributing factor. Egg and milk production are also considered to be less efficient.

Development and utilisation of forage resources. A second reason for low efficiency of animal production in Jiangxi is the inferior protein content of feed. About 20% of protein comes from cotton and rape seed meal. It is considered uneconomic to use rice — the dominant cereal in Jiangxi — for feed. Techniques for using crop

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Table 1. Increases in livestock production in Jiangxi 1978-1988.

Year	Pigs Total (million)	Pigs Adult (million)	Cattle (million)	Sheep (million)	Domestic fowl (million)	Meat production ('000 t)	Milk ('000 t)	Eggs ('000 t)
1978	9.443	6.111	2.098	0.066	29.980	342.5	4.85	53.97
1988	14.545	11.685	2.955	0.129	83.030	978.0	22.82	150.76
% increase	54.0	91.2	40.8	101.6	176.9	185.5	370.0	179.4

Table 2. The components of livestock production in Jiangxi (1989).

Type	Meat production		Economic value	
	('000 t)	% of total	$A of total	% of total
Pigs	889.3	90.9	395.4	70.4
Cattle & sheep	15.8	1.6	35.1	6.3
Domestic fowl	73.0	7.5	124.4	22.2
Other	0.26	0.03	6.5	1.1
Total	978.3		561.5	

residues more efficiently for feed have not been developed. On the other hand, vast tracts of red hill soil are suitable for growing forages. Unfortunately this potential source of feed has not been developed.

Forage Development

The climatic and socio-economic conditions in Jiangxi Province provide the potential for increasing livestock production. It has been estimated that it is possible to increase meat production from the present 30 kg to 41 kg, on a per capita basis, by the year 2000. Similarly egg production could be increased from 5.5 to 13.1 kg and milk production from 0.1 to 3.8 kg. These increases depend upon improving the quantity and quality of livestock feed.

Better use has to be made of grain resources. In 1988 it was estimated that 2.61 million t of grain from the province's total production of 15.35 million t could have been used for feed: only 2.2 million t was used.

Less than 10% of the 3 million t of blighted rice grain was fed to livestock. Likewise, out of the total production of seed cake (mainly rape and cotton — 0.23 million, and bran — 4.5 million t) the proportions used for feed were 20% and 80% respectively.

Although greater use could be made of these feed sources, the contribution of grain to increasing livestock production will be limited by competing demand from the province's rising human population. Increases can only be achieved by making better use of forages and crop residues. There are three aspects to this:

Greater use of existing resources. Currently there are 207 000 t of peanut leaf and stem, 12 000 t of bean straw and 54 000 t of sugar cane leaf produced annually which is currently not utilised. In addition only 5% of the 18 million t of forage legume planted in winter for green manure over an area of 930 000 ha is consumed by livestock. The area of hill land growing grass is 2.72 million ha. Of the 513 species identified, 64% are grasses, 18% legumes and 18% weeds. Livestock feed on about 130 of these. It has been estimated that 7.85 million t of forage is available each year but only 0.5 million t (6.4%) is utilised.

Increased sowing of forages. The province has some 1.55 million ha of land with the potential for sowing forages. Of this, 660 000 ha is fallowed cropland, 500 000 ha is orchard and young plantation forest where undersowing is possible, and 270 000 ha is wasteland.

Introduction of improved species. Since the mid 1970s, 520 forage species have been introduced from other parts of China or abroad. The species have been evaluated at Nanchang, Ani and Chongren. Those showing the greatest promise are broadleaf ryegrass, rough cocksfoot, Nandi green brittlegrass, meadow fescue, blue grass, broadleaf shamrock white clover, common alfalfa Zhongshan No.1 and blue lupin. The feed composition of some other valuable species that have been identified is shown in Table 4.

Table 3. A comparison of livestock production in Jiangxi with other major livestock producing regions (1989).

Province or City	Pigs slaughtered		Meat production ('000 t)			Milk	Eggs
	million	% of pigs reared	Total	Pork	Beef	('000 t)	('000 t)
Jiangxi	12.381	85.2	1040	947	10	22	156
Beijing	2.291	157.8	233	156	8	200	247
Tianjing	1.123	155.8	107	81	4	68	174
Shanghai	3.613	178.0	321	202	1	200	152
Jiangshu	20.419	114.7	1837	1430	16	86	785
Hunan	28.665	106.4	1788	1399	13	10	263
Shandong	18.454	104.4	1971	1456	138	272	1094

Table 4. The composition of selected forages, expressed as % of DW.

Species	Moisture	Crude protein	Crude fibre	Fat	Soluble materials except N	Ash	Ca	P
Kummerowia striata	4.08	16.68	3.31	28.44	41.30	6.19	0.55	0.194
Desmodium heterocarpum	9.06	8.65	5.05	35.55	37.78	3.73	0.25	0.06
Arundinella hirta	7.39	3.88	1.43	36.74	40.11	5.45		
Ischaenum ciliare	7.17	3.55	3.46	38.76	43.77	3.29	0.16	0.04

Livestock Development

The dominance of poultry and pig production in the past has been a major reason for the forage potential of the hill lands being under utilised. The trend therefore, and a trend which must continue, is to diversify livestock production by increasing the numbers of cattle, sheep, rabbits and geese, which can make better use of forages. By doing this the production of meat and milk will be increased to meet increasing demand and the benefits of by-products such as down and hides will be gained.

Cattle

Throughout the province cattle have been traditionally used for draught power and this need will continue. Therefore a concerted effort is needed to generally improve the quality of animals and to develop draught–meat and draught–milk types. Extension services should be established to encourage the adoption of improved forages and cattle breeds. Realistic targets for meat and milk production levels by the year 2000 are 100 000 t and 350 000 t respectively.

Sheep

Sheep were originally introduced to Jiangxi from northern China. Conditions in the Province proved suitable for sheep raising and fine wool sheep were introduced in 1955. The average annual yield of fleece from sheep producing a 20 micron mean diameter fibre is 7.88 kg greasy with a yield of 49%. In 1986 strong-wool sheep were introduced. These sheep have micron measures of 30 and greater, produce an average 8.27 kg of greasy wool per head, with a yield of 50%.

Rabbits

Rabbits possess the advantages of feeding mainly on grass, they are prolific breeders and reach maturity quickly. They therefore have a relatively low cost of production. These features, together with the value of their meat, skin and fur, give the rabbit a prominent place in livestock development.

Geese

Geese are a valuable component of livestock production and are ideally incorporated with water fowl in an integrated management system. The major breeds of white geese are Guanfeng, Lianhua and Fengcheng. The most popular grey goose is the Xingou.

Forage Development

There are four categories of grassland which are presently under utilised:

High hill grassland occurs at an elevation of 300–1000 m above sea level and is characterised by sparse forest growing on mountain meadow soils.

Hilly grassland is found below 300 m. Grasses sometimes grow in association with shrubs.

River banks and alluvial gravels.

Grassland patches within cropped areas.

As stated previously, 513 plant species have been identified in the native grasslands of which about 130 are useful for feed. However, the feed value of the native herbage in all these grasslands types is poor in comparison with that possible from introduced species. Field trials have shown that yields from introduced species can be as much as five times those from native species, with protein contents as high as 20% and growing periods 60 to 90 days longer.

An experiment at Jiangxi Red Soil Research Institute compared yields from different grass and crop rotations. The highest DM yields were obtained from the rye grass–napier grass rotation due to the good tolerance of the napier grass to drought. In this respect Sudan grass was much inferior (Table 5). The *Vicia sativa* — mexican corn rotation also performed well with high yields of mexican corn being obtained in 1989. The alfalfa–pearl millet rotation had by far the lowest yield. The composition of the components of the rotations is given in Table 6.

In summary, the key to increasing livestock production in Jiangxi Province will be the development of pasture in crop rotations matched to the potential of the various landscape types to increase both the quantity and quality of feed available to livestock.

Table 5. Yield of grass and crop rotations. Yields for winter 1987 and summer and winter 1988 refer to the first part of the rotations; yields for summer 1988 refer to the second part.

Rotation	Yield per plot (kg per 10 sq m)				Annual Yield (t/ha.)		
	Winter 1987	Summer 1988	Winter 1988	Summer 1989	1987	1988	Average
Rye grass–Napier grass	94	192.2	92.9	432.9	143.1	262.9	203.0
Oat grass–Sudan grass	102.7	132.4	105.7	215.5	117.6	160.6	139.1
Alfalfa–pearl millet	31	117.8	36.6	147.8	74.4	92.2	83.3
Vicia sativa–Mexican corn	49.2	175.5	65.2	314.7	112.4	189.9	151.1

Table 6. Composition of the components of the rotations from Table 5 expressed as % DM.

Varieties	N	P	K	C	Crude protein	Fat	Crude fibre	Soluble material except N	Ash	Ca	Moisture
Rye grass	2.90	0.73	2.86	55.8	15.8	4.50	29.08	40.05	13.83	0.38	7.50
Napier grass	1.96	0.90	2.76	40.9	11.6	1.03	26.79	47.60	9.31	0.35	3.00
Oat grass	2.26	0.66	5.05	49.4	17.2	4.46	25.62	42.44	12.73	0.66	8.71
Sudan grass	2.94	0.75	2.09	41.7	17.3	5.81	23.01	46.65	8.50	0.65	3.07
Alfalfa	2.96	0.81	1.75	43.5	21.9	4.78	21.00	43.76	8.45	1.36	3.66
Pearl millet	2.57	1.19	3.61	40.3	13.3	4.81	28.47	43.93	9.30	0.49	4.18
Vicia sativa	4.21	0.75	3.91	55.1	27.0	4.13	23.81	40.90	9.03	0.62	8.20
Mexican corn	3.22	0.65	2.75	40.8	19.4	6.12	26.47	37.70	10.34	0.25	5.54

Current and Potential Development of Agricultural and Animal Husbandry Enterprises in Zhejiang Province

Lin Yuanwen*

ZHEJIANG Province is located on the southeast coast of China with Jiangsu adjoining to the north, Anhui and Jiangxi to the west, and Fujian to the south. The latitude ranges from 27° to 31°N and the land area covers 105 300 sq km. Of this total area, approximately 70% is mountainous or hilly, 23% is level and 7% is taken up by rivers and lakes. In the red soil region of the province, the altitude ranges from 50 to 350 m a.s.l.

The climate is sub-tropical with a strong monsoonal influence (including frequent typhoons which bring torrential rain). Originally, the land supported evergreen, broadleafed forests. The average monthly temperature varies from 4.6°C in January to 27.7°C in July. The annual accumulated degree days heat units (> 10°C) range from 4800 in the north to 5800 in the south whilst the average frost-free period varies from 225 to 280 days.

Average rainfall also increases from 1000 mm in the northeast to 2200 mm in the southwest of the province. Similarly, annual sunshine hours range from 1800 hours in the north to 2300 hours in the south.

Of the total soil area of some 9.7 million ha, approximately 40% is classed as red and 11% as yellow soils. The red soils are mostly distributed on the low hills of the eastern, southern, and northwestern parts of the province and in the central Jinhua-Quzhou basin.

The red soil area is generally located in a transition zone between the cropping and forestry zones. Historically, the red soils were covered with a dense canopy of trees and bushes. Following clearing of the forest, the soil has been reclaimed to support cropping, oil camellia, tea tree, fruit trees and forestry plantations. The gently rolling hills make water storage difficult and expensive to develop.

The productivity of the red soils tends to be somewhat restricted by their shallow profile which is generally between 30–70 cm deep. Soil chemical properities also limit productivity as they are usually acid with a pH in the range of 4.5 to 5.5, a cation exchange capacity of 30–35 meq/100g and a base saturation of less than 35%.

Current cropping enterprises

The area of land currently used for agricultural purposes in the red soils region of Zhejiang Province is 2.1 million ha (54% of the red soils region). Of this 68% consists of wetlands, 16% of dryland (42% of which is irrigated), 11% fruit orchards, 4% mulberry trees and 1% tea plantations.

Cereal production. The area sown, total production and average yield of cereal grains in the red soil area of Zhejiang is provided in Table 1. Also shown are the total areas and productivity for the entire province. In general, more than 50% of the cereal grain produced in Zhejiang comes from the red soil area.

Cash crops. Table 2 presents data showing the types of crop grown and their productivity, both in the red soil area and in the provinces. The dominant cash crops are tea and rapeseed, followed by mulberry trees, cotton, herbs and a range of minor crops. As shown in the table the vast majority of tea, day lily, sugarcane and sesame seed production within Zhejiang Province is carried out on the red soil area.

Fruit production. The red soil area of Zhejiang has 178 000 ha of fruit orchards, this represents about 75% of all such orchards in Zhejiang. Of this area, more than half is devoted to citrus, with much of this area having been developed as recently as 1987. Apart from citrus, the other fruits grown include peaches, loquats, pears, Chinese dates, apricots and persimmons. In general, the fruit yields range from 2 to 2.5 t/ha.

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Table 1. Grain yield of the red soil region of Zhejiang (a) and the total grain yield in Zhejiang Province (b).

		Area (ha)	%	Output (million t)	%	Yield (t/ha)	%
Winter sown cereal	a	364 400	58.4	0.83	47.5	2.3	81.3
	b	623 600	100	1.75	100	2.8	100
Early, early-mid rice	a	588 400	56.9	3.00	55.5	5.1	97.13
	b	1 032 800	100	5.40	100	5.2	100
Summer sown cereal	a	935 400	60.2	4.75	56.7	5.1	94.05
	b	1 553 480	100	8.38	100	5.4	100

Table 2. Production outline of the cash crops in the red soil area of Zhejiang (a) and the entire Zhejiang Province (b).

		Area (ha)	%	Total output (t)	%	Yield (t/ha)
Cotton	a	20 060	29	16 537	37.8	0.82
	b	68 980	100	43 665	100	0.63
Rape*	a	74 800	28.7	76 996	18.6	10.2
	b	260 690	100	413 926	100	15.9
Peanut	a	5 190	59	6 395	47	12.3
	b	8 810	100	13 590	100	15.5
Sesame	a	3 180	81	2 191	70.8	0.69
	b	3 920	100	3 091	100	0.79
Sugar cane	a	3 770	100	227 792	100	61.0
	b	3 770	100	227 792	100	61.0
Yellow day lily	a	4 567	99.5	2 198.5	99	0.4
	b	4 587	100	2 223	100	0.5
Tobacco	a	1 310	56.4	2 376	63.7	1.8
	b	2 330	100	3 749	100	1.6
Medical herbs	a	5 360	59	—	—	—
	b	9 080	100	—	—	—
Mulberry tree**	a	30 500	37	23 386	21	0.8
	b	82 340	100	105 636	100	1.2
Tea	a	137 400	81.3	83 978	65.5	0.6
	b	168 900	100	128 211	100	0.8
Camellia oil	a	n.a.	n.a.	22 007.8	98.5	n.a.
	b	n.a.	n.a.	22 335.8	100	n.a.

* The output and yield is for rapeseed
** The output and yield is for the mulberry leaf

Animal husbandry enterprises. The red soil area of Zhejiang supports an extremely diverse range of animal enterprises including pigs, cattle, sheep, rabbits, chickens, ducks, geese, honeybees as well as a number of animals raised for their skins or medicinal products. Among these, numerous specialist breeds have been developed notably the Jiaxing black and Jinwa pigs, Hu Yang sheep, Xiaoshan chicken, Wenling cattle and many others.

The number of animals in the major animal enterprises and their annual production are summarised in Table 3. The red soil area produces the major portion of the production of pigs, cattle, rabbits and honeybees in Zhejiang.

Table 3. Animal production in Zhejiang Province (a) and the red soil area of Zhejiang (b).

	Number of animals raised per year '000 head or birds or hives		Output of products '000 t	
	a	b	a	b*
Pigs	25 452.2	16 034.8 (63)	797.5	534.3 (67)
Sheep	2 359.9	1 576 (67)	8.03	3.8 (47)
Cattle	759.3	645.3 (85)	5.6	3.5 (62.6)
Rabbits	5 281.5	3 100.2 (59)	1.8	1.1 (59)
Poultry, eggs	155 020	68 984 (45)	109	38.1 (35)
Hives	1 269.3	1 205.8 (95)	n.a.	n.a.
Honey	n.a.	n.a.	72.4	48.3 (66.6)

* Figures in parentheses are the percentage of b/a

Productivity of Zhejiang red soils

The data presented in Tables 1–3 show that the productivity per unit area and per animal in the red soil area is generally somewhat less than that for the province as a whole. Exceptions to this trend are found with the cotton and tobacco crops which produce higher yields in this area than in the province overall. Pig production is also somewhat higher than the provincial average.

For livestock such as cattle and sheep, which rely heavily on the productivity of the grasslands areas, productivity is again lower than the provincial average. The proportion of the number of cattle which are marketed each year is only 6% reflecting low reproductive rates. The weight gain of cattle and sheep is also low with carcase weights of 18 month old stock being only 108 kg and 15 kg respectively.

Potential for increased production

Increases in crop production in the red soil area are possible through greater water storage for irrigation, through increased use of fertilizers and by improving crop varieties and cultivation techniques.

In the case of animal production in the area, the grassland resources have not been fully utilised nor developed. The area of grassland in the red soil area is 1.9 million ha which is 90% of the grassland of the province. Calculations based on the average fresh yield of the grassland (6990 kg/ha/yr) and the requirements of one cattle equivalent (9490 kg fresh material/yr) indicate that the stocking capacity of this area could be 1.4 million cattle equivalents. As the actual stocking rate is 0.9 million cattle equivalents, there is considerable potential for increased animal production.

In addition to the above areas of grassland, there are large areas of orchards which can be successfully undersown with forage species such as *Lolium multiflorum* and *Phaseolus aureus*. Also, land which is fallow in winter, such as paddy fields (up to 13 million ha) could be sown with forages such as *Astragalus sinicus* and *Lolium multiflorum* to support animals. It has been estimated that the utilisation by animals of green manure crops being grown on large areas of farmland (up to 29 million ha) could be increased by 30–50%.

If these areas described above could have 50% of the forage they produce utilised by animals, then a further 0.8 million cattle equivalents could be supported in the red soil area of Zhejiang.

At present, the utilisation of grasslands in the hilly region is only 30% whilst in the more mountainous regions, utilisation of the resources is only 5%. Current utilisation of forage resources in the cereal and fruit production areas is even less than 5%. Hence there is great potential for large increases in animal production.

Further evidence supporting this proposition that there is great potential for such increases is provided by studies of animal productivity from introduced forage species. From initial screenings of almost 1000 plant accessions, 27 grasses and 12 legumes have been identified as having great potential. These include species such as *Lolium perenne*, *Dactylis glomerata*, *Poa annua*, *Trifolium repens*, *Trifolium subterraneum*, and *Lotus corniculatus*.

Species which have been found to be well adapted to the low hills of the red soil area are *Paspalum wettsteinii*, *Lolium multiflorum*, *Euchlaena mexicana*, *Cynodon dactylon*, *Silphium perfoliatum* and *Trifolium pratense*. The yield of these species has generally been found to be 3–4 times greater whilst their crude protein content is 2–3 times greater than those of native forage species.

Results of sowings over 20 000 ha between 1985 and 1988 showed that *Lolium perenne* produced 1.2 million t of fresh weight of herbage containing 14% crude protein. This production was valued directly at 75 million yuan and resulted in 2600 million yuan from animal production. The forage area also increased the soil's organic matter leading firstly, to increased chemical and physical fertility of the soil and, secondly, to better yields of the subsequent crop.

To date, the only large areas of introduced forages sown have been with *Lolium multiflorum*, *Sorghum sudanense*, *Euchlaena mexicana*, and *Phaseolus aureus*. There remain great opportunities for other species in productive combinations.

Through the past decade there have been large advances made in extending the results of such agronomic research to farmers. Much of the research has been published in various forms and is now being implemented in extension programs.

Introduction and Establishment of Forages on the Red Soils of South Central China

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THE red soils zone of south central China extends over 2 million sq km, with red earths (Hapludults) being the most common soil group. They occur mostly in the hill regions (altitudes of 400–800 m) which generally have a local relief of no more than 100 m and are widespread throughout the north of the zone.

Until the early 1950s, most of these hill regions were forested but in the thirty years that followed, the forests were cut to support China's economic leap forward. The extent of this deforestation is illustrated by Lingling prefecture in Hunan Province, in which the area of forest decreased from 54 to 5% between 1950 and 1985. In the southern parts of the region, where the climate is less extreme, the hills have regenerated naturally with volunteer pasture species and soil erosion has not been as severe as in the north. In the latter, the most erosive rainfall events occur in April and May, which is too early after winter for the native grasses to establish and provide effective ground cover. This has resulted in widespread and severe erosion. Lost with the topsoil are most of the soil nutrient reserves resulting in exposed landscapes which native vegetation is unable to recolonise. In Lingling prefecture, such land degradation has resulted in 12% of the total land area being classified as wasteland.

In recent years the Chinese Government has promoted the development of these degraded lands. Widespread plantings of forests and citrus orchards have met with some success. In Lingling prefecture, for example, 49% of the total land area has been classified as reforested. However, in many cases, without adequate inputs of fertilizer, growth of the forests has been very poor and the soils remain exposed to continuing erosion.

An alternative and potentially complementary form of development of the red soils region is the establishment of silvopastoral systems on the eroded hills and incorporation of forages with upland cropping systems. Forage plants provide the quickest, cheapest and most effective method of controlling soil erosion. In addition they have the potential to provide forage for livestock in a region where forage quality year-round is poor and forage availability in the winter months is low. Inclusion of fast-growing tree species could also provide fuelwood for cooking and heating and supplementary forage for animals.

At present, in many areas, the major source of fuel and fodder for the winter months is rice straw. The native forages are limited by very low yields and poor quality. Therefore, experiments were conducted to evaluate better quality introduced forages and to find ways of improving establishment.

Materials and Methods

Forage introduction

One hundred and fifty accessions of temperate and tropical forage species from China and Australia were sown in nurseries at two sites in Hunan Province. At the Qiyang Red Soils Experiment Station (26.8 °N 115.9 °E) the nurseries were sown in May and October, 1987 and at the nearby Menggongshan Red Soils Experiment Station in March and September, 1990. The two sites were used to compare the results on soil that had never been cultivated (Menggongshan) with those from a soil that had been used in recent times for cropping (Guanshanping). Soils at both sites are acid red earths (pH [1:5 H_2O] 4.2–4.5) and the region receives 1250 mm rainfall annually. At Menggongshan, the nursery was fertilised with 40 kg P/ha, 25 kg Mg/ha and 50 kg K/ha, and limed to bring the top 10 cm of soil up to pH 5.6. At Guanshanping, the nursery was fertilised with manure and the soil limed to pH 5.6. The accessions were sown in rows 2m long at Guanshanping and 1m long at Menggongshan and replicated three times. The

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legumes were inoculated with appropriate strains of rhizobia. The number of plants surviving, colour, relative forage yield, plant height and width, drought resistance, frost and cold resistance, heat resistance, occurrence of disease and insect pests, flowering and relative seed yield have been recorded once a month since sowing and this will continue for two years. The species were aggregated into groups with similar performance characteristics using the pattern analysis program, PATN (Belbin 1987).

Sowing time and surface mulch

This experiment was conducted at Menggongshan in 1990–1991. Four forage species were sown at eight times (March, April, May, September, October, November, December, February) with or without a surface mulch of rice straw (64 plots). Each plot, representing one species/sowing time/mulch treatment, was replicated 3 times and sown with 4 rows of 100 seeds, 1 m long and 15 cm apart. The four species used were a tropical grass (*Digitaria smutsii* cv Premier), a tropical legume (*Macroptilium atropurpureum* cv Siratro), a temperate grass (*Dactylis glomerata* cv Porto) and a temperate legume (*Trifolium repens* cv Haifa). These species were selected because of their promising performance in the nursery at Guangshanping. The number of emerged seedlings at 2, 4 and 8 weeks was recorded. All plots were harvested when the best yielding plots became self-shading.

Results

Promising accessions

Of the 150 accessions evaluated, 29 were found to be well suited to the soil and climatic conditions of the region. These consisted of 3 legumes and 9 grasses of temperate origin and 6 legumes and 11 grasses of tropical origin. The measured attributes of these species are summarised in Table 1.

Seasonal variations of forage yields

The seasonal variations in the yield rating of four grasses are presented in Figure 1. A rating of 10 is the highest yield of all species in the nursery at that time. Relatively high yields were recorded for the grasses of tropical origin from July to December (Sabi grass) and from April to December (Premier finger grass). By contrast, both temperate grasses (cocksfoot and ryegrass) gave higher yields between December and June. Figure 2 shows the seasonal variation in the yield rating of four legumes. The tropical legumes (lablab and Wynn cassia) gave relatively high yields between July and December while the temperate legumes (maku lotus and white clover) performed well between November and June.

These results indicate that a full year forage supply is possible if a mixture of forages can be well established and different sowing times are adopted.

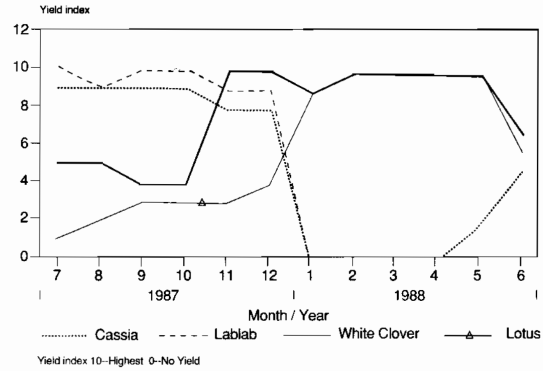

Figure 1. Seasonal variation of legume yield.

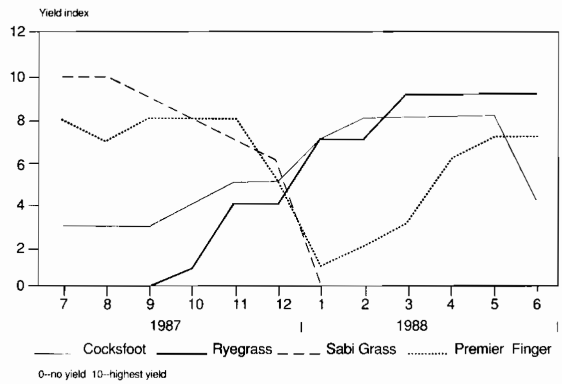

Figure 2. Seasonal variation of grass yield.

Effect of sowing times and mulch on establishment

Mean numbers of seedlings in the establishment experiment eight weeks after sowing are presented in Table 2. The best results were observed in March for the temperate species (Haifa white clover and Porto cocksfoot) and in May for the tropical legume (Siratro). The numbers of Premier finger grass seedlings were low at all sowings but establishment was better in the spring and summer. Apart from cocksfoot, the autumn sowings were unsuccessful, partly because of predation of seeds by mice (Siratro) and because of the unusually dry period prior to and following sowing. There was no significant effect of mulch on seedling numbers.

The March sowing was harvested on 22 July; the results of which are presented in Table 3. Mulch had a significant effect, increasing the dry matter yields

Table 1. Summary of the attributes of 29 promising forage species aggregated into 7 groups with similar attributes.

Species	Common name	Group	Attributes
Cassia rotundifolia	Wynn Cassia	1	Tropical perennial legume, high leaf and seed yield, fast growth from July to December, poor frost tolerance, winter dormant, regrows in May from seed.
Trifolium repens	White clover cv Haifa	2	Temperate perennial legume, increasing yield from year 2, frost and cold tolerant, poor persistence in summer, best growth from Dec. to June, moderate seed yield.
Lotus pedunculatus	Maku lotus		
Medicago sativa	Lucerne cv 516	3	Temperate perennial legume, grows throughout the year, heat, cold, frost and drought tolerant, moderate yield.
Panicum maximum	Petrie panic	4	Tropical perennial grasses, high leaf yields, very high seed yields except for Elephant grass, heat and drought tolerant, rapid growth from April to Dec., moderate cold and frost tolerance.
Digitaria smutsii	Finger grass cv Premier		
Chloris gayana	Rhodes grass		
Pennisetum purpureum	Elephant grass		
Paspalum wettsteinii	Broadleaf paspalum		
Paspalum dilatatum	Paspalum		
Setaria sphacelata	Setaria cv Wandi		
Dactylis glomerata	Cocksfoot cv Porto	5	Temperate, perennial grasses, moderate yields, good performance in spring, autumn and winter; frost and cold tolerant, but heat and drought susceptible. Moderate seed yields.
Dactylis glomerata	Currie cocksfoot		
Eragrostis curvula	Lovegrass cv Consol		
Festuca arundinacea	Tall fescue cv Demeter Tall fescue cv Epic		
Lablab purpureus	Lablab cv Highworth	6	Annuals, very poor cold and frost tolerance (died in winter), but heat and drought tolerant. Very high yield, best growth from May to Dec. Very high seed yields.
Macroptilium atropurpureum	Siratro		
Macroptilium lathyroides	Phasey bean		Species persisting for less than one year.
Aeschynomene elegans	Crown vetch		
A. falcata	Bargoo vetch		
Urochloa mozambicensis	Sabi grass		
Cenchrus ciliaris	Buffel grass		
Panicum maximum	Gatton panic		
Digitaria eriantha	Finger grass		
Lolium perenne	Ryegrasses: cv Atlas cv Tetila cv NZ Nui cv Kangaroo Valley	7	Temperate grasses lasting one season, moderate yields, poor heat and drought tolerance (died in early summer), very good cold and frost tolerance, grow from Nov. to late May. Best growth from March to May, high seed yields.

Table 2. Seedling recruitment eight weeks after sowing in an establishment with and without mulch.

Date	White clover		Cocksfoot		Siratro		Finger grass	
	Mulch		Mulch		Mulch		Mulch	
	+	−	+	−	+	−	+	−
	% of seeds sown							
12 Mar.	16	5	21	24	8	6	1	2
12 April	6	14	1	1	9	4	3	9
19 May	7	0	0	0	50	34	2	1
26 Sept	0	0	12	7	26	17	1	1
20 Oct	0	0	9	11	0	0	5	4
18 Nov	0	0	17	25	0	0	0	0
15 Dec	0	0	8	13	0	0	0	0
5 Feb	0	0	11	8	0	0	0	0

of all species except Premier finger grass. In particular, yields of Siratro increased sixfold as a result of surface mulch. The pattern of these results has also been evident in the later sowings. The decreased yields of Premier finger grass in the + mulch treatment might be explained as being the result of toxic residue leachates.

Table 3. Dry matter yields from July harvest of the March sowing in the establishment experiment.

Species/treatment	g DM/plot	
	+ mulch	− mulch
Haifa white clover	11.8	0.0
Porto cocksfoot	15.0	9.5
Siratro	87.2	14.3
Premier finger grass	3.4	16.2

Discussion

The nursery trials have shown that there is a large number of promising species for forage rehabilitation of the eroded red soils of south central China. As a result of these nursery evaluations a smaller selection of the most promising species is to be studied in greater detail to evaluate performance and persistence in small swards.

No single species is going to provide a year-round forage supply and maintain adequate cover to protect the soil from erosion. Mixtures of species will not only provide a better spread of forage yields throughout the year, but will also stabilise the soil more effectively. In the areas where extensive grazing is possible (such as higher altitude areas in Hunan), sown legume/grass pastures have proven to be successful (see, for example, Gao Chengshi and Lin Yan, these Proceedings). In the lower altitude, hilly areas however, interest is focussed on the integration of forages with cropping and trees for fuel and food production. One possible model is the sowing of forages (both tropical and temperate) and trees in contour strips around the hillside (with or without terraces) and interplanting these strips with crops. Research is being conducted on such systems at Menggongshan to identify useful tree species and the factors controlling persistence of forages on these soils.

The results of the establishment experiment have highlighted the large yield increases that are possible for some forage species by the simple addition of a surface mulch of rice straw. The beneficial effects of a mulch can include improved soil moisture conditions, moderated temperature fluctuations and increased organic matter in the soil (improving soil structural stability and reducing the effects of toxic aluminium). The results also highlight the low percentages of successful establishment from viable seed. Further experimentation is being conducted to investigate the causes and techniques that may be used to improve establishment (including the effects of higher seeding rates and seed-applied fungicides).

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The Effects of Lime and Nutrients on the Growth of Forages on the Red Soils of South Central China

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ULTISOLS and Oxisols are the most common soil types in south central China, covering an area of more than 2 million km^2. These soils are acid, infertile and often have lost all or part of their surface horizons due to erosion. The value of forages for rehabilitating these soils has been discussed in other papers in this workshop. This potential can only be realised when the significant problems associated with forage establishment and management have been solved.

The main chemical factors limiting long-term productivity of forages on these soils are high levels of exchangeable Al (often more than 20% of CEC) and multiple mineral deficiencies associated with low soil pH. Lime is commonly used to overcome these problems through the combined effects of additional Ca, alleviation of Al toxicity and improved availability of nutrients with increased pH (Adams 1981). The response of soil pH and plant yield to lime varies markedly according to the chemistry of the soil, type of liming material and the tolerance of individual forage species to the various aspects of soil acidity.

Liming an acid soil usually (but not invariably) results in significant increases in plant yields and uptake of minerals, especially P, Mg and Ca (Adams 1978, Kunishi 1982, Holford 1985). This improved availability and uptake of minerals is often not sufficient to overcome deficiencies, particularly of P, and fertilizer applications are often necessary in combination with liming. This paper describes experiments that are being conducted to quantify the limitations to forage production arising from mineral deficiencies and aluminium toxicity of the red soils.

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Materials and Methods

Mineral deficiencies

A nutrient omission pot trial was conducted at the Qiyang Red Soils Research Station near Hengyang in Hunan Province using a red earth (Typic Hapludult) with a pH(1:5H_2O) of 4.5 and exchangeable Al of 20%. The soil is typical of the red earth extensively developed on Quaternary clay in Hunan Province. The experiment consisted of seven treatments (+ All nutrients, −P, −K, −Mg, −Mo, −B and −All nutrients) in a completely randomised design with three replicates. Prior to potting, the soils were limed to a pH of 5.6. Nutrients were added in solution to the appropriate treatments at the following rates per kilogram of soil; N(0.210 g), P(0.093 g), K(0.234 g), Ca(0.180 g), Mg(0.027 g), S(0.036 g), Fe(12.57 mg), Mn(1.24 mg), Zn(0.147 mg), Cu(0.095 mg), B(0.008 mg) and Mo(0.001 mg). Five cocksfoot (*Dactylis glomerata* cv. Porto) plants were established in each pot. They were harvested 53 days after sowing and the dry matter yields of each pot recorded.

A long-term field experiment is also being conducted at the nearby Menggongshan Research Station. The aim of the experiment, which was established in 1988 on the same soil as used in the previous experiment, was to look at the initial and longer-term residual effects of a range of nutrient additions and liming rates on the growth of temperate forages. The experiment is based on a split-plot design with 3 lime treatments (0, limed to pH5.6 and limed to pH6.5) as the main plots and fertilizer treatments as the sub-plots. The sub-plots consist of 3 rates of P (0, 20, 100 kg/ha) × 2 rates of combined K + Mg (with and without K 50kg/ha + Mg 25 kg/ha) × 2 rates of complete microelements (with and without Fe + Cu + Mn + Zn + B + Mo applied as 'Librel BMX') replicated 3 times. The experiment was initially sown to a mixture of tall fescue (*Festuca arundinaceae* cv. Demeter), phalaris (*Phalaris aquatica* cv. Sirosa), white clover (*Trifolium repens* cv. Haifa) and red clover (*Trifolium pratense* cv. Redquin). It was subsequently resown in 1990 because of poor persistence following a severe summer drought. Dry-matter yields of all plots were measured for the first time seven months after sowing.

Lime response

A pot experiment was conducted to determine the pH response of the Menggongshan red earth to liming and the consequent changes in yields of Haifa white clover. A subsoil (pH(1:5H_2O) of 4.5) and a topsoil (pH(1:5H_2O) of 4.8) were treated with impure quicklime (the commonly-used local liming material consisting of a mixture of CaO and $Ca(OH)_2$) at seven rates (0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 g/kg soil) in a completely randomised design with four replicates. Using a mean bulk density for the red earths of 1300 kg/m^3 in the top 10 cm, 3.0 g lime/kg soil was equivalent to 3900 kg lime/ha. The nutrients used in the omission trial, except Ca, were added in solution to the pots at the start of the experiment, at the same rates as in the omission trial. The indicator species (Haifa white clover) was sown and harvested after two months. Soil pH and dry matter yields of each pot were measured.

Results and Discussion

The dry-matter yields of Porto cocksfoot from the omission experiment are presented in Table 1. Total dry matter yields were not significantly different between the Control (−All) treatment and the −P treatment (2% and 4% of the yields from the +All treatment respectively), highlighting the severity of P deficiency in this soil.

Total dry matter yields of the −K, −Mg, −Mo and −B treatments were 63%, 40%, 65% and 58% of the + All treatment yields respectively. Similar results were reflected in the root and shoot dry matter yields. The shoot:root ratio was significantly lower in the −All treatment than in all other treatments. The shoot:root ratios of the −Mg, −B and −Mo treatments were significantly higher than in the +All treatment.

Yield data from the field experiment show the interaction between applications of lime, P and K+Mg (Fig. 1). Significant increases in forage dry-matter yields from applications of P were only expressed in the presence of K and Mg and, with the exception of the 100 kg/ha P treatment, in the presence of lime. The dry matter yields without fertilizer and lime of 142 kg/ha increased to 635 kg/ha when 100 kg P/ha and lime (to pH 6.5) were applied and further increased to 2138 kg/ha with the addition of K and Mg.

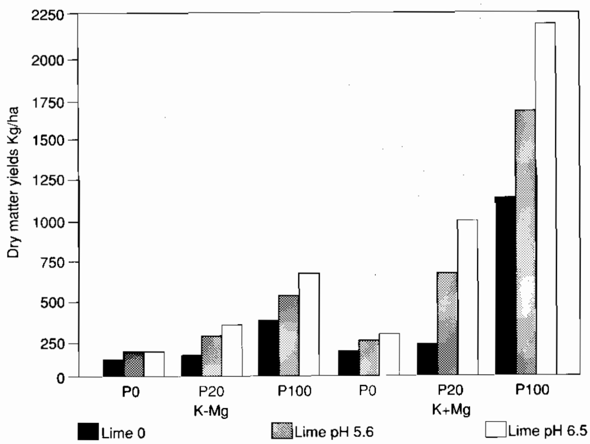

Figure 1. The interaction between applications of lime, P and K + Mg.

The dry matter yields of white clover in the lime response experiment were maximised at pH 6.0 (equivalent to 2 g lime/kg soil or 2600 kg lime/ha based on the previous assumptions) for both the topsoil and subsoil. The maximum yield in the topsoil (3.3 g/pot) was more than twice that for the subsoil (1.6 g/pot), probably due to the higher organic matter content and mineralisation of N in the topsoil. Yields decreased significantly above pH 6.0 in

Table 1. Dry matter yields of Porto cocksfoot in the nutrient omission trial.

	−All	+All	−P	−K	−Mg	−Mo	−B
Total dry matter	0.17[a]	7.87[d]	0.30[a]	4.93[c]	3.15[b]	5.16[c]	4.47[c]
Shoot dry matter	0.11[a]	5.76[d]	0.22[a]	3.62[c]	2.48[b]	3.94[c]	3.47[c]
Root dry matter	0.06[a]	2.11[c]	0.08[a]	1.31[d]	0.67[b]	1.22[d]	1.00[c]
Shoot:Root ratio	1.73[a]	2.73[b]	2.77[b]	2.80[b]	3.75[d]	3.20[c]	3.45[c]

Numbers within rows with the same superscript are not significantly different (lsd = 0.05)

Table 2. pH and dry matter yields of white clover in response to pH.

lime added (g/kg soil)	0	0.5	1.0	1.5	2.0	2.5	3.0
pH response (topsoil)	4.8	5.5	5.8	6.3	6.6	6.8	7.3
pH response (subsoil)	4.5	5.3	5.5	5.6	6.1	6.4	7.0
DM yields/pot of topsoil (% of max)	24	49	59	83	100	68	33
DM yields/pot of subsoil (% of max)	4	9	19	47	100	56	64

both soils. The addition of micro-nutrients did not significantly affect dry matter yields.

The results of the field experiment and nutrient omission trial support the general findings of Jiang et al. (1986) and Xie (1986) demonstrating the severity of deficiency of P and to a lesser extent Mg and K in these soils. As liming does not greatly increase the availability of these nutrients, fertilizer applications are essential for successful forage production. Field experiments are now being conducted to examine the initial and residual effects of a range of initial P application rates (up to 120 kg P/ha) with and without annual maintenance applications of 15 kg P/ha. The results for the micro-nutrients B and Mo are less clear. The results of the pot trial support the findings of Liu et al. (1986) that the red earths of this region are deficient in Mo and B. However, these deficiencies were not detected in the first harvest of the field experiment. Deficiencies of Mo and B are common in highly weathered acid soils but may only be expressed in the field by sensitive species (Kerridge 1978). It is possible that the test species in the pot experiment was sensitive to Mo and B deficiency whereas the species in the field are tolerant. Deficiencies in the field may appear in the yield results after several years.

The results of the lime response experiment show that large increases in yield can be expected from additions of lime, especially on the exposed subsoils. Due to the dominance of kaolinite in the clay fraction, the red earths have a relatively low buffering capacity. Thus only 2.8 t lime/ha is needed to achieve maximum yield. If only 80% of maximum yield is acceptable, a level often aimed for in low-input soil management, then less than 2 t lime/ha would be needed. The indicator species, white clover, is moderately tolerant of aluminium in the soil up to 20% of CEC. Larger responses to liming would be expected from sensitive species such as red clover, phalaris, lucerne (*Medicago sativa*), lotus (*Lotus corniculatus*) and perennial ryegrass (*Lolium perenne*). Lesser responses would be expected from generally more-tolerant species such as cocksfoot, Maku lotus (*Lotus pedunculatus*) and subterranean clover (*Trifolium subterraneum*) (Helyar and Anderson 1971, Andrew 1976, Edmeades et al. 1991). Indeed, negative responses have been observed to liming in Wynn cassia (*Cassia rotundifolia*) on an acid red earth, with significantly higher root and shoot yields at pH ($CaCl_2$) 3.8 (5.0 ppm Al) than at pH 4.5 (4.1 ppm Al), pH 5.0 (3.7 ppm Al) or pH 6.0 (0.9 ppm Al) (Koch 1991). Field experiments are now being conducted to investigate the long-term residual effects of lime on the growth of a mixture of temperate forages compared with annual maintenance applications.

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The Effect of Liming on Boron Adsorption in a Red Soil from Hunan Province

D. Alter and D.A. MacLeod*

BORON deficiency has been widely reported for the red soils of south central China. At the Red Soil Research Station in Qiyang County, Hunan, boron deficiency symptoms have been observed in brassica crops and in pine plantations.

The adsorption of boron determines the distribution of boron between the liquid and solid phases of the soil. This distribution is important for plant growth on account of the relatively small range between levels causing deficiency and toxicity symptoms (Hingston 1964). Boron is mainly adsorbed on clay minerals and by hydrous oxides of aluminium and iron. Two boron species, $B(OH)_3$ and $B(OH)_4^-$, are believed to be involved in adsorption reactions. They have different affinities for adsorption sites and their proportions in solution vary with soil pH (Keren and Gast 1983).

Several investigations have suggested that most of the boron adsorption sites are located on the broken edges of clay particles (Keren and O'Connor 1982). Hydroxy aluminium groups exposed at clay mineral edges are not fully coordinated by oxygens within clay mineral structures and they possess pH-dependent charge. It could be expected that as pH increases and positive charge decreases the adsorption of negatively charged borate ions would decrease. Keren and O'Connor (1982) have also suggested that the negative electric field surrounding clay colloids is one of the main factors controlling boron adsorption as this field makes adsorption sites less accessible to approaching anions. Furthermore, if $B(OH)_3$, $B(OH)_4^-$ and OH^- compete for the same adsorption sites, the proportion of boron species adsorbed should decrease as OH^- activity increases.

The red soils of south China are acid and require liming to increase their productivity. Their clay minerals are dominantly of the variable charge type, so increasing soil pH by liming increases their net negative charge. For the reasons given above liming might therefore decrease the soil's ability to adsorb boron added as fertilizer and thus increase leaching losses. The aim of this study was to determine how liming affects boron adsorption.

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Methods

The topsoil (0–15 cm) of a red earth profile from Menggongshan Experimental Station, Hunan Province, was used in this study. The soil pH (1:5 $CaCl_2$) is 4.1 and its available boron content is less than 0.1 mg/kg (Table 1). Kaolinite is the dominant clay mineral with subordinate amounts of illite, chlorite and quartz (Fig. 1). The dominance of kaolinite and the low organic matter content result in an effective CEC of 4.0 $Cmol_c$/kg.

Table 1. Properties of the topsoil (0–15 cm) of a red earth at Menggongshan Experimental Station.

Particle size distribution (%)	
Coarse sand	0.8
Fine sand	11.0
Silt	23.5
Clay	64.7
pH (1:5 $CaCl_2$)	4.1
Effective CEC ($Cmol_c kg^{-1}$)	4.0
Organic carbon	1.2
Available boron (mg kg_{-1})	<0.1

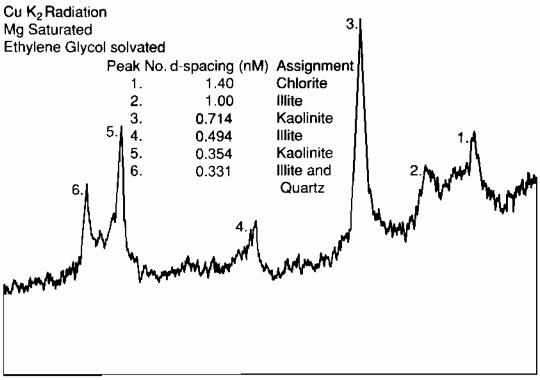

Figure 1. X-ray diffraction pattern of the clay fraction ($<2\ \mu m$).

Air dried 5 g samples of soil were weighed into centrifuge tubes and adjusted to pH 4.5 and 5.0 using Ca $(OH)_2$. Differing amounts of boric acid were added and the volume made up to 25 ml using 0.01 molar $CaCl_2$ to obtain constant ionic strength at a level commonly found in soils. These were then tumbled for 2 hours, centrifuged at 3000 rpm for 5 minutes and filtered through Whatman No. 41 filter paper. The amount of boron remaining in solution was determined as the Azomethine-H complex at 420 nM.

Results and Discussion

Figure 2 shows that increasing soil pH markedly increases boron adsorption, despite any increase in net negative charge that may have occurred on colloidal surfaces. Adsorption increases exponentially as pH $(CaCl_2)$ increases from 4.1 to 5.0. Clearly factors other than the development of negative charge are affecting boron adsorption.

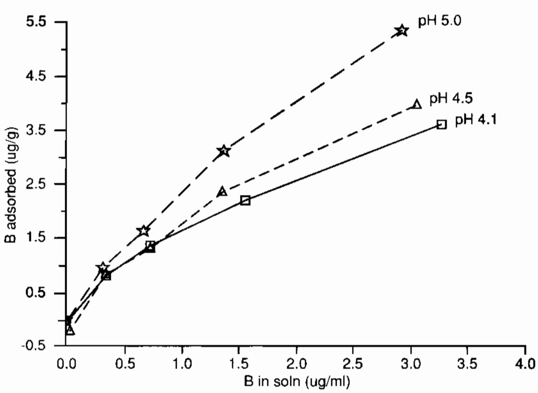

Figure 2. Effect of pH on boron adsorption.

Keren and Gast (1983) have shown that boron adsorption is very low below pH 3 and above pH 11. A sharp increase occurs between pH 3 and 5.5, followed by a gradual decline between 6.0 and 9.0. Maximum adsorption occurs at pH 6.0.

Boron adsorption differs from that of anions such as fluoride and sulphate, for which Hingston et al. (1972) found that no adsorption occurs at pH values above that of the point of zero charge (PZC). Boron adsorption can occur at pH levels higher than the PZC value and it seems that the pH at which maximum adsorption occurs depends on the affinity coefficients of $B(OH)_3$, $B(OH_4)^-$ and OH^- competing for the same adsorption sites (Keren and Gast 1983).

The two boron species occurring in the soil solution are boric acid H_3BO_3 and the borate anion $B(OH)_4^-$. Boric acid behaves as a weak acid and dissociates as follows:

$$H_3BO_3 + H_2O \leftrightarrow B(OH)_4^- + H^+$$

Below pH 7 the predominant form is H_3BO_3. Its adsorption at low pH, when most of the colloidal surfaces are positively charged, shows that boron can be adsorbed regardless of the sign of the surface charge.

Keren and Gast (1983) have suggested that the undissociated H_3BO_3 molecules can be adsorbed as long as they can dissociate at the surface to provide protons that react with surface OH^- to form water which is easily displaced by the anion. As pH increases this protonation due to H_3BO_3 increases. Between pH 3 and 6 the OH^- concentration in the soil solution is still low relative to that of boron and the amount of boron adsorbed increases rapidly. At higher pH levels OH^- concentration and competition between OH^- and $B(OH)_4^-$ for adsorption sites increase so that the amount of adsorbed boron declines.

The optimal rate of liming the red soils for forage production should raise pH within the range 5.5 to 6.5. In contrast to anions such as nitrate and sulphate, boron adsorption increases as pH increases. Liming should therefore increase the ability of the red soils to retain boron against leaching.

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Working Group Reports

Three working groups were formed to discuss issues of relevance to a) Forages, b) Soils and c) Farming Systems in the red soils region. The aims of the working groups were to identify constraints to the forage and animal husbandry development of the red soils region and outline priority areas for research. The recommendations of these discussion groups are presented below.

Forages

In southern China, agriculture is dominated by rice cropping. In this system, several rice crops are commonly followed either by a fallow period or the sowing of milk vetch. It may be better to replace the milk vetch component with an improved pasture which could increase animal production and subsequent crop production.

In some cases in southern China, especially in late winter and early spring, animal nutrition is so poor that some animals die because of shortages of forage. Farmers in these areas are finding it difficult to conserve sufficient forage. Maintaining a ruminant requires feed with a protein content of at least 7%; this level of protein is rarely achieved in winter, particularly with rice straw. By growing some legumes or pastures with a legume component it should be possible to supplement the very poor quality rice straw sufficiently to be able to maintain body weight.

Perceived problems constraining forage development in the Red Soil Region

There was widespread recognition among the group that there is a need for quality pastures if animal production is to be viable. The issues discussed were grouped under the headings of species selection, plant breeding, fodder conservation, and social constraints.

Selection of species

Tropical/temperate. It was noted that the species evaluations seen at Menggongshan in April indicated some of the temperate species were growing well, however, these may not persist over the summer period, especially when maximum temperatures of greater than 34 °C are experienced for periods of 10 days or more. One possible combination of pastures which may overcome the problems in those areas where high summer temperatures are experienced, such as in Hubei Province, may be the sowing of annual ryegrass for supplying winter forage combined with summer crops to supply summer forage. There was agreement that the various mixes of tropical and sub-tropical species still need to be explored to determine which combination of temperate, sub-tropical and tropical species will persist over the long term.

Short vs long-term productivity. The group agreed that species which are well suited for large-scale establishment of extensive grazing areas in upland systems will probably be different to those required for short-term pastures to fill gaps in the cropping cycles of the lowlands areas.

Perennial legumes. Mr Nie from Hubei Province advised the group there were two major problems: (i) the selection of perennial legumes for low-altitude areas with a hot climate, and (ii) the level of sheep disease found in the humid mountainous regions. Whilst the latter problem would need to be approached through a different, animal-oriented project, the selection of perennial legumes is a problem common to most grazing regions of the world.

Introducing persistent legumes is difficult for a number of reasons, especially their lower tolerance of drought stress compared to grasses, the competition which grasses impose, the fact that they are selectively grazed by animals, and the fact that little grazing management is possible under the Chinese system.

Plant breeding

The question was asked 'To what extent is pasture plant breeding or selection seen as important in China?' It appears there has been little, if any, coordinated forage breeding programs aimed at breeding forage species. As a consequence it is agreed that there is a need, across provinces of the red soil region, for a coordinated program of plant selection. Information transfer needs to be much better, especially in the area of supplying seed of pasture species.

Seed production. A viable seed-production industry is an essential foundation for a successful pasture establishment program. It may well be necessary to develop seed production in other specialist areas of the country where they have good supplies of irrigation water and also a reliable dry season during the maturation period of the seed. Mr Nie stated that there is a large seed-production area in Northern Hubei Province which has 800 mm of annual rainfall and experiences a dry summer.[1]

Fodder conservation

Silage. The question of fodder conservation was discussed at some length. Corn silage combined with Chinese milk vetch has proved to be quite successful in some areas. In Jiangxi Province, silage use is still relatively new to farmers, even though it is very successful. They cut the corn and fodder crops into very short pieces and store the silage in cement pits which have been built into the ground. Professor Ma Zhiguang stated that in inner Mongolia a small machine has been developed to facilitate the production of small packages of silage wrapped in plastic bags, each containing 50 kg of silage. Each bag can be used twice and this system is proving very successful.

It was noted that silage is a good way of conserving feed, particularly in the red soil area, because of the generally high rainfall during the spring and early summer season, the high quality of the fodder conserved and the long storage time possible with silage. However, it must be noted that the use of silage can result in substantial loss of nutrients from the soil. Farmers recognise this as they return organic manure to the cropping areas and those areas which are harvested for silage.

The use of small plastic bags of silage has also been very successful in pig breeding areas. Without supplementing their feed with silage, sows were giving birth to 8–10 piglets per litter but many of these were dying. With silage, the survival of the piglets was greatly increased. It is also possible to add nutrients to the silage to increase quality.

There were some comments that the silage made in plastic bags may be too acid and therefore unattractive to pigs, in some areas. It was thought that this may be because the legume content of the silage was too high; by including more grasses, the acidity of the silage would be adequately adjusted and yet more palatable to pigs.

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[1] Professor Jiang Chao Yu presented a short paper on forage germplasm resources in China which indicated the paucity of information on the adaption and potential utilisation of native forages in the red soils region. A collection at the Institute of Crop Germplasm Resources, CAAS, Beijing includes more than 1600 accessions of native forage plants (27 families, 184 genera and 567 species) and over 1100 accessions of introduced forage plants (10 families, 96 genera and 216 species). Regional evaluations of this native and introduced germplasm are essential to identify those accessions that are both well adapted to persist in the climatic and edaphic conditions of the region and also produce harvestable yields of high quality forage. In Yunnan, for example, the Bureau of Animal Husbandry has evaluated some 330 forage legumes and 130 forage grasses at multiple locations within the red soils region. Having identified a small group of useful species, it was then necessary to develop a large seed production facility before large-scale plantings were possible.

Whereas the making of silage is a relatively common practice, it is still conducted in a rather primitive manner. There is little attention to silage quality and farmers are quite unaware of the proper techniques. In Ireland, for example, farmers are advised through the media the appropriate time for making silage. It may be necessary for more research to be conducted on this topic, possibly through another project.

Social issues

Tradition. Farmers in the Red Soil region have very little tradition of growing pasture and raising animals, especially ruminants. It is therefore difficult to get farmers to adopt forage and animal technology as they do not see animals as a means of generating significant income. It was recognised that the two main problems are the development of an adequate market for meat products and getting sufficient price for the product. It was agreed that demonstration farms where the economic value of animal and crop production systems could be demonstrated might be of value.

Communication. It was agreed that communication might be improved across the Red Soils region if a journal could be published about soil and pasture issues related to the region. It was suggested that the inclusion of an English abstract with any papers published in such a journal would mean that the literature was then also available to other countries; this would mean the work of the Chinese scientists would not be isolated.

Research/extension links. It was agreed that the links between research and extension in China are poor. Researchers publish their data but extension workers are often unaware of the findings of research. This situation may be improved somewhat if the above suggestion of publishing a journal was achieved. The question of transferring information to farmers was also discussed and a suggestion made that television may be the most appropriate means of getting some of the messages through because many of the farmers are illiterate.

There was some feeling expressed by extension workers that research programs are somewhat irrelevant to the real problems of farmers. This problem may partly be solved if extension workers become more involved in determining research priorities.

Soils

Infiltration, retention and availability of moisture in the soil profile was considered to be of prime significance for forage production in the red soil region, where severe drought occurs in late summer and autumn. Although the red soils have a high clay content, their hydrological behaviour is similar to that of sandy soil on account of clay being present as stable micro-aggregates. Further research is needed on soil water regimes in relation to the establishment of forages and their survival during periods of water stress.

The scope for modifying soil water and temperature regimes by management practices should be investigated. In silvo-pastoral systems tree shade may reduce surface soil temperature and evapo-transpiration, but tree roots compete with forages for moisture. The fear was expressed that the productivity of orchards could be depressed through competition for moisture from forage understorey. However, temperate species such as white clover die down in summer and their litter could provide a mulch to reduce evaporation loss. Some legumes, such as *Cassia* and *Arachis*, have a spreading habit, which would act as a living mulch.

Because of the high temperatures generated at the surface of bare ground in summer the use of mulch to increase establishment and early growth was generally advocated. Sources of mulch is a problem as rice straw, the most abundant waste material, is used for fuel and feed in winter, particularly where fuel wood is scarce. Rye grass has been harvested for use as mulch. Mulch applied in winter would increase soil temperature and promote earlier germination. However, at Menggongshan Experimental Station mulch added in March, April and May reduced the germination of

Digitaria smutsii. By remaining a moist environment mulch may be inducing fungal disease, and the use of fungicide-coated seed should be evaluated.

In some areas crust formation and hardening of the topsoil reduce water infiltration leading to increased run-off and erosion. The use of appropriate polymeric soil conditions could alleviate these problems, but their high cost (40 yuan RMB per mu, as used in northern China) would restrict their use to highly intensive enterprises, such as horticultural nurseries. Their high cost is also compounded by their transient effect.

Establishment of forages and crops could be greatly increased by irrigation. Drip irrigation in the red soil region suffers from blocking of drippers due to the high amount of suspended clay in irrigation water.

Preliminary studies have been conducted at the Red Soil Research Station, Qiyang county, on means of controlling soil erosion in the plantations. These studies should be extended to farming systems in which forages are integrated with cropping. The Universal Soil Loss Equation (USLE) developed in the USA has many shortcomings when applied to China. This is due to erosion being generally more severe in the red soil region, with gully erosion being dominant. It was felt that this type of erosion is not adequately addressed in the USLE. Furthermore, none of the critical information needed to run the USLE is available for many Chinese crops and cropping systems. A mechanistic model, along the lines devised by Rose, et al. at Griffith University, Queensland, Australia, should be developed for the red soil region.

Soil chemistry and fertility

Soil acidity and P deficiency were perceived as the major chemical constraints to forage development on the red soils. The use of mycorrhizae to improve P uptake should be a high priority. Combining rhizobia with mycorrhizae in forage legumes may have considerable potential benefits. Deficiencies of K (particularly in sweet potato) and Mg are common, but little information is available for forages. The residual effects of P, Mg and K fertilizers has not been investigated.

Of the micro-nutrients B deficiency is the most widely recognised, particularly for brassica crops and also pine plantations. Zn and Mo deficiencies also occur; the implication of the latter for N fixation by forage legumes deserves attention. Se deficiency may be a problem for livestock.

The lime requirement to achieve economic forage production for different soil types in the red soil region has not been studied. Evaluation of liming materials in terms of their neutralising value, Mg content, and residual effects also requires research. The complexity of the Al chemistry of soils is well recognised. Critical Al levels for forage species should be established to aid selection of species and their lime requirements.

At present a wide variety of methods is being used to measure soil chemical properties and fertility, particularly for the assessment of available P. Often these are the same as used in lowland rice crop systems, where the relationships between yield and soil chemical properties are likely to differ from those in upland forage and cropping systems. Standardised methods of analysis should be developed for both cropping and forage production in the red soil region.

Within the subtropical region of China the fertility of the yellow earths, usually occurring above 800 m, is likely to be quite distinct from that of the lower lying red earths. Because they have developed under a cooler climate the organic matter content of the yellow earths is significantly higher but they are the subject to greater leaching because of higher rainfall and lower evaporation. The different climatic and soil conditions found at higher elevations means that the choice of forage species, their fertilizer requirements and management will differ from those of the red earths. A full understanding of these differences is needed for integrated land-use planning for whole catchments, as has been proposed in Fujian Province by the Fujian Academy of Agricultural Sciences.

The potential benefits of rotating forages with cropping were recognised and research is needed to quantify these benefits. In particular, information is required on nitrogen inputs from forage legumes and their residual effects, nutrient cycling and the dynamics of soil organic matter. The relationship of the latter to structural stability, infiltration and runoff is important for conserving soil and water resources of the red soil region.

Farming Systems

From the information presented at the workshop, it is clear that the red soils region covers a large range of agro-ecological zones, from the intensively cropped lowland rice fields to the higher altitude, remote grazing lands. No single farming system involving forages and animals will be appropriate across all these zones. The work group chose to define three broad agro-ecological zones and consider the constraints to development and priority areas for research within each:

1. Lowland, intensive cropping associated with double-cropping rice plus a winter crop (such as *Astragalus* for green manure or canola). This farming system is mostly associated with areas of high rural population density close to larger urban centres. The most common farm animals are pigs, geese, ducks and buffalo/cattle (for draught purposes).
2. Middle lands consisting of low red-soil hills and cropping on the terraced areas between the hills. Cropping varies from intensive rice farming, as in the lowland systems, to various combinations of rice, wheat, corn and sweet potato. The hillsides are mostly wasteland fringed by areas of dryland cropping. The soils on the hills are acid, infertile and subject to severe erosion. Rural population densities are relatively high but these areas are mostly distant from centres of urban development. Animals are kept largely in conjunction with the areas of intensive cropping and the hillsides remain mostly unutilised.
3. Upland areas consisting of mountainous land and higher-altitude, hilly grasslands. The mountainous lands are mostly used for forests of conifer and bamboo. The grasslands are used for grazing and dryland cropping. The soils are generally less acid and infertile than on the red soil hills in the lowlands. These areas are generally remote and population densities relatively low. Larger numbers of livestock (cattle and buffalo) are kept for extensive grazing.

Constraints to Development and Recommendations for Future Research

1. Lowland Intensive Cropping

The competition between cropping and the need for feed to support pig production is intense in these cropping-dominated systems. At present, significant amounts of valuable fuel are used to cook feed for pigs. Crop residues remain a substantially under-utilised feed resource. The group felt that the main priorities for research are:

1. To identify leguminous forages that can be used in rice-rice cropping systems to add nitrogen to the soil and provide higher yields of better quality forage for pigs than *Astragalus*.
2. To identify mixtures of such leguminous forages and grasses such that there is an adequate supply of both protein and energy in the diet of pigs. At present, utilisation of *Astragalus* by pigs is limited by shortages of energy in the diet.
3. To experiment with supplementation of crop residues with both symbiotic and inorganic nitrogen to make utilisation by ruminants more efficient. Low levels of nitrogen in the residues limit rumen microbial activity and hence intake.

2. Middle-land red soil hills and intensive cropping

The red soil hills represent the greatest opportunity for forage and animal husbandry development within the region. The work group agreed that of paramount importance was the control of soil erosion and the most promising way of achieving this was through integrated farming systems incorporating cropping, forages and trees for fuelwood, fruit and forage. Given the research that is already being conducted on the nutrient limitations of the red soils for growth of forages, the group listed the following priority areas for research and infrastructure development:

1. Further selection of tree, crop and forage species that are better adapted to the soil and local climatic conditions of the red soil hills.
2. Experimentation with various models of integrated farming/agroforestry systems that incorporate trees, crops, forages and animals (such as cattle, sheep, ducks, geese and fish), both in small scale research and at the level of demonstration farms.
3. At present, there are no groups within the research institutes in China that are conducting the multi-disciplinary research necessary to investigate the potential of integrated farming/agroforestry systems. There is a need for such groups to be established and therefore a need for both postgraduate training (possibly in other Asian countries) and short-term training courses in agroforestry systems research.
4. There is a need for quantitative research on methods of erosion control within these farming systems for the red soil hills.

3. Upland extensive grazing

The upland extensive grazing areas offer the potential for improved pastures on a large scale. Successful pasture improvement in areas of Hunan, Guangxi and Yunnan provinces has demonstrated the applicability of existing pasture technology to these upland areas. The work group agreed that the major priorities for research and infrastructure development are in the fields of land tenure and socio-economics:

1. Land tenure systems must be implemented that guarantee control of improved pastures to the production unit that developed it. A similar problem in Guangdong province facing foresters was solved by granting individual farmers leasehold title to areas of land for 50–100 years which then allowed them to obtain loans to buy tree seedlings and fertilizer.
2. Marketing and distribution of animal products from these more remote areas should be examined in detail.
3. The economics and availability of fertilizers for maintenance applications should be determined.
4. There is a need for more research on pasture management techniques (especially grazing management) at sites across the region. Combined with this is the need for training to produce skilled pasture managers within each production unit.

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