Tropical Legumes for Sustainable Farming Systems in Southern Africa and Australia

Editors: **Anthony M. Whitbread and Bruce C. Pengelly**

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Top row: farmers inspecting tropical legume, *Lablab purpureus*; preparing animal feed made from maize meal and lablab; farmers in crop of *Mucuna pruriens*. Middle row: farmers carrying straw used for animal feed, animal bedding and straw brooms; *Mucuna pruriens* (centre). Bottom row: preparing animal feed from maize meal; Obert Jiri with farming family collaborators; farmer and *Lablab purpureus*.

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Foreword

In much of southern Africa, large rural-based populations rely on subsistence and smallholder cropping and livestock enterprises. The productivity and sustainability of these livelihoods are threatened by various forms of land degradation. As well, both the quality and quantity of forage crops restrict animal production.

ACIAR funded a project in southern Africa to develop sustainable animal and cropping systems based on the integration of well-adapted forage plants and appropriate agronomic and animal-management practices. The project was carried out by CSIRO Sustainable Ecosystems and collaborating institutions in South Africa and Zimbabwe.

The project team identified legumes that can be used in rotation or intersown with crops to improve the nitrogen status of soils, and used the farming systems model APSIM to investigate these dynamics. In particular, they selected forage plants that could be introduced into the degraded grasslands of South Africa and Zimbabwe to improve animal production.

Through a participative action research approach, the project was very successful in obtaining farmer adoption of forage and dual-purpose legumes in several farming systems in southern Africa.

Most of the papers in these proceedings come from a final meeting and a successful review of the ACIAR project. They focus on aspects of forage and ley legumes and include the interactions with animal and crop production, and farmer evaluation and adoption of new technologies in the various farming systems found in South Africa and Zimbabwe.

There is currently little information available to scientists and extension workers, so this publication, which describes some of the recent developments in farming systems research for South Africa and Zimbabwe, will be a valuable resource.

Peter Core

Peter Core
Director
ACIAR

Contents

Tropical legumes for sustainable farming systems in southern Africa and Australia,
edited by A.M. Whitbread and B.C. Pengelly. ACIAR Proceedings No. 115.
(Printed version published in 2004)

Preface

'Tropical forage and ley legume technology for sustainable grazing and cropping systems in southern Africa', ACIAR project number AS2/96/149, originated from discussions held in South Africa and Zimbabwe from 1994 to 1996 and at a workshop held in Polokwane (formerly Pietersburg), Republic of South Africa (RSA) in June 1997.

Tropical regions of both countries support rural communities that depend on cereal and cash-cropping, and livestock production systems. These agricultural systems are under pressure because of the increasing population and, as a consequence, are often not sustainable. Forage-legume technology has the potential to improve the sustainability and productivity of some of these farming systems by providing a source of nitrogen (N). This can potentially be achieved by integrating forage legumes into the cropping components of mixed crop–livestock systems, intensive livestock systems such as dairying, and through the enhancement of the communal grazing lands.

These initial ideas were eventually formed into a four-year project that began on 1 January 1999 with Zimbabwean, South African and Australian partners. It was initially hoped that Mozambique could be considered as a potential partner during the early deliberations, but the difficulties in identifying appropriate in-country collaborators made this impossible.

The aims of the project were:

- to identify a range of ley legumes that can be used in rotation with crops, or as inter-row legumes with crops, to improve the N status of soils and to reduce soil erosion, resulting in sustainable and acceptable cropping practices
- to select forage germplasm that can be introduced into the degraded grasslands of northern South Africa, Zimbabwe and Mozambique to improve animal production using procedures appropriate to smallholder systems
- to develop grazing and cut-and-carry livestock-management systems, including dairying, that are sustainable and acceptable within the socioeconomic frameworks of the selected communities
- to demonstrably improve the decisions and practices of farmers managing forage-legume systems by collating research results from this project and from elsewhere and providing details of cost, benefits and management options to farmers and extension workers in an appropriate format
- to gain adequate understanding of seed production of the most-promising lines to enable the development of a local seed industry.

Several agencies have collaborated in this project. The Department of Research and Specialist Services (DR&SS) in Zimbabwe, the Department of Agriculture and Environment in the Limpopo Province of RSA and the Commonwealth Scientific and

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(Printed version published in 2004)

Industrial Research Organisation's (CSIRO) Division of Tropical Agriculture (now CSIRO Sustainable Ecosystems) in Australia have been the official partners in the project. In addition to these contracted agencies, AGRITEX and the University of Zimbabwe have been important and strongly committed collaborators in Zimbabwe, as have the University of the North and the Agricultural Research Council's (ARC) Range and Forage Institute in South Africa, and the Queensland Department of Primary Industries in Australia.

The project had two sites in Zimbabwe: at Zana II and Dendenyore, both of which are near to Wedza in Region IIB about 150 km southeast of Harare. There were several reasons for the selection of these sites. These included:

- the climate, which has sufficient rainfall for relatively reliable cropping
- enthusiastic farmers
- the reliance of communities on rangeland (veld) as a base for animal production
- animal production practices in which dairy and beef production were already established commercial enterprises for smallholders
- proximity to established extension and research teams
- the contrasting land tenure (Zana II is a resettlement area and Dendenyore a communal land community) provided a diverse farming system.

The project also operated at two sites in South Africa: Tarantaaldrai and Dan. Tarantaaldrai was chosen because:

- it was an existing dairy cooperative, already producing milk for local consumption
- it had what appeared to be an enthusiastic group of farmers/cooperative members
- dairy production in this semi-arid region was based on grazing unimproved veld
- there was a well-established infrastructure including arable land for forage cropping
- there were on-site extension staff

The Dan site was chosen as it:

- represented a typical maize-based, smallholder farming system in Limpopo Province, in which legume pulses, especially groundnut and cowpea, were important crops used in intercropping or in maize rotations
- was close to established extension and research teams
- had an enthusiastic farmer community.

The project operated in three sites in southeastern Queensland. The Queensland Department of Primary Industries' Brian Pastures Research Station near Gayndah offered an established grazing trial in which ley and phase legumes had been utilised for a number of years. This enabled the dynamics of soil nitrogen and organic matter in forage legume–cereal cropping production systems to be studied in some detail. Cinnabar and Broad Creek are both commercial beef-cattle properties in the Burnett region and were used in an experimental program to select new forage-legume genotypes that are adapted to the subtropical environment.

A participative model of research, in which farmers and extension and research professionals developed research priorities associated with one of the many legume technologies at their disposal, or at least could be associated with soil fertility issues, was used at all sites. The diversity of farming systems addressed in the project, resulted in a wide range of legume technologies being researched. These ranged from comparisons of new legume germplasm, to studies on the dynamics of soil N and carbon, the impact of ley, phase and green manuring on subsequent cereal crops to the impact of legume feeds on animal production. With the exception of the work at the Brian Pastures Research Station, all research was conducted on-farm.

The project included a number of formal training initiatives including the following:

- Mr Richard Clark of the Queensland Department of Primary Industries designed and conducted a workshop on participative research for the entire project team at Murewa, Zimbabwe at the start of the project in April 1999.
- University of Queensland accredited studies on action learning were successfully undertaken by several African team members over the course of the project.
- Team members Mrs Beatrice Chigariro, Mr Temba Elliot and Mr Brian Ndlovu undertook research within the project to meet requirements for undergraduate studies at the University of Zimbabwe.
- Several postgraduate students were supported by the project and Mr Jairus Nkgapele and Ms Gifty Mishiyi (through the University of the North, South Africa) and Mr Obert Jiri (through the University of Zimbabwe) successfully completed Master of Agricultural Science degrees or equivalent within the project.
- Team members Mr Owen Mabuku from Zimbabwe and Mr Terries Ndove from South Africa were awarded John Allwright Fellowships by ACIAR to undertake postgraduate studies at the University of Queensland.

The project has undertaken a wide range of legume-based research in the three countries. The outcomes of that research have led to new insights into legume adaptation and productivity, soil N/soil organic-matter dynamics and the impact of legume use on cereal and animal production. In some instances, particularly in Zimbabwe, the project has been able to achieve at least the first stages of the adoption of legume technologies by farmers. The project has also enabled formal and informal training of research and extension professionals to be undertaken, and the training here has subsequently resulted in further training and career opportunities for several of the African project team members. Importantly, the project activities have exposed all team members to a much wider range of biophysical and social issues and environments, developed better understanding of the farming systems, and fostered what we hope will be long-standing professional relationships.

Many of the papers in this publication were sourced from the final project meeting and review held at the Magoebaskloof Hotel in Limpopo Province, South Africa on 7–9 October 2002. The editors refereed the papers and Mr Dick Jones is acknowledged for his substantial contribution to the reviewing process. Drs Merv Probert, Michael Robertson and Bob McCown of CSIRO Sustainable Ecosystems are also acknowledged for reviewing various manuscripts. The paper by Pengelly et al. was reprinted with permission from the journal Tropical Grasslands, Volume 37, No. 4, pages 207–216.

The papers within this publication are presented under the following themes: The Environment; Evaluation of Legume Technologies; Farming Systems Research; and Participative Methodology and Adoption of Technologies. We hope that this publication will prove to be an excellent resource for many other research and development initiatives in progress in the Limpopo Province and for the wider R&D community of the tropics and subtropics.

Dr Bruce C. Pengelly (Project Leader)
Dr Anthony M. Whitbread (Principal Investigator)
Brisbane, Australia
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The Environment

Tropical legumes for sustainable farming systems in southern Africa and Australia,
edited by A.M. Whitbread and B.C. Pengelly. ACIAR Proceedings No. 115.
(Printed version published in 2004)

The Farming Systems of the Zimbabwean District of Wedza and the Role and Adoption of Forage Legumes in Small-scale Crop–Livestock Enterprises

B. Chigariro*

Abstract

An ACIAR project entitled “Tropical forage and ley legume technology for sustainable grazing and cropping systems in southern Africa” (Project no. AS2/96/149) conducted a farmer participatory research project with communal (Dendenyore ward) and resettlement (Zana ward) farmers in the District of Wedza in Zimbabwe from 1999 until 2002. The main aim of this project was to test and introduce a suite of legume technologies into the mixed crop–livestock systems that predominate in these regions. A range of constraints that include poor soil fertility, lack of dry season feed for livestock and variable rainfall, seriously limit production and food security in Wedza. Diversifying the range of crops, selling cash crops such as paprika and replacing weedy fallows with improved lablab or mucuna fallows, were all methods employed by farmers to improve production. Livestock farmers formed cooperative organisations to sell their products and build capacity in livestock production. Many farmers were able to substitute bought-in feed concentrates with home grown legume-based feed sources. This paper sets the scene for several subsequent papers that describe in detail the participative action research program based around the theme of using well-adapted legumes to improve the farming system.

Zimbabwe has a total land area of about 39,000 km^2. Five zones or ‘natural regions’ are recognised (Vincent and Thomas 1957). They are based largely on the mean annual rainfall, together with other physical parameters such as soil type (Table 1).

The country has a tropical continental climate in which rainfall is usually restricted to the period between November and March. The winter months between May and August are cool, because of the countries elevation (much of it above 1200 m altitude) and four distinctive seasons can be recognised:

- summer – rainy season (November to mid-March)
- autumn – post rainy season (mid-March to mid-May)
- winter – cool dry season (mid-May to mid-August)
- spring – hot dry season (mid-August to November).

Wedza District

Zimbabwe is comprised of nine provinces with the district of Wedza located in the Mashonaland East Province, about 120 km southeast of Harare. The district had a population of about 82,000 in 2001 and had a range of smallholder and commercial-scale farming operations, of which the communal farming systems and the large-scale commercial operations covered the largest land areas in 2001 (Table 2).

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* Agricultural Technical and Extension Services, PO Box 30, Wedza, Zimbabwe.

Tropical legumes for sustainable farming systems in southern Africa and Australia,
edited by A.M. Whitbread and B.C. Pengelly. ACIAR Proceedings No. 115.
(Printed version published in 2004)

The ACIAR project operated in two wards in Wedza District — Dendenyore and Zana. Descriptions of the communal and resettlement systems can be found in Maasdorp et al. (2004). Dendenyore covers an area of 14,028 ha and is part of the communal farming sector. In 2001, Dendenyore had about 3000 households and a population of about 15,000. Zana covers an area of 5187 ha and is within the resettlement sector. In 2001, it had 315 households and a population of about 1900. The two wards are located in natural region IIb between 18°15' and 19°15'S and 31°15' and 31°20'E, at an altitude of about 1400 masl. The temperature range in summer is usually 16°C to 30°C; in winter there is a moderate frost incidence.

The soils in the Wedza district are largely derived from granite, with categories on a typical catena recognised on the basis of soil moisture-holding capacity, waterlogging, weed burden and soil fertility. All these parameters increase down slope from the dry topland granitic sands of the upland ridges and valley slopes to the hydromorphic vlei-margin and valley bottom vlei soils. Size and texture of soil particles range from fine/medium grained sands over medium to coarse-grained sandy loams at the topland sites to medium to coarse-grained sandy loams in the vleis and vlei margins (J. Dimes, pers. comm.). Pockets of dolerite intrusions present in Dendenyore have led to the formation of red clay soils. The soils found in the topland, upland ridges and valley slopes are commonly used for crop production and are generally highly acidic, with the pH ($CaCl_2$) below 4.4 and very low in the status of base cations K^+, Ca^{++} and Mg^{++} (Jiri et al. 2004), reflecting very low soil organic matter ($C_T < 0.4\%$) and an associated low cation-exchange capacity. The combination of low waterholding capacity of the soils and the relatively impermeable nature of the underlying granite, renders such soils, even on the uplands, susceptible to high water tables for short periods during many rainy seasons (Thompson and Purves 1978).

The Smallholder Farming Systems in Wedza

In both Zana and Dendenyore, intensive mixed crop–livestock farming is practised. Maize is a major crop, while there are minor crops of sunflower, soybeans, groundnuts, cowpea millets, sorghum and sweet potatoes. The Dendenyore farmers have a subsistence agricultural focus and sell any surplus locally. The resettlement farmers of Zana, on the other hand, have a larger arable area available and employ that extra land in cash cropping. The two most important cash crops are tobacco and paprika.

Table 1. Mean annual rainfall for each of the five Natural Regions recognised in Zimbabwe. Source: Vincent and Thomas (1957).

Natural region		Mean annual rainfall range (mm)
Region I	Specialised and diversified farming region	> 1000
Region II	Intensive farming region	650–1000
Region III	Semi-intensive farming region	650–800
Region IV	Semi-extensive farming region	450–650
Region V	Extensive farming region	<650

Note. Region II is divided into two sub-regions. Sub-region IIa receives an average of 18 rainy pentads per year, and normally experiences reliable conditions. It rarely experiences dry spells in summer. Sub-region IIb receives an average of 16–18 rainy pentads per season and is subject to more severe dry spells during the rainy season, or to occurrences of relatively short rainy seasons (Vincent and Thomas 1957).

Table 2. Farming sectors, number of farmers and properties and the total area of each sector in Wedza District Zimbabwe in 2001.

Sector	No. of farmers	No. of properties	Total area (ha)
Large-scale commercial	76	76	8,0561
Small-scale commercial	475	486	45,900
Resettlement area	758	NA	NA
Communal area	22,036	NA	108,400

NA = data not available.

Tropical legumes for sustainable farming systems in southern Africa and Australia,
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(Printed version published in 2004)

Arable farming by resettlement farmers in Zana has been undertaken since 1986. Each farmer has a total arable area of 5 ha, of which, after 2001, 0.4 ha to 0.8 ha was typically being used to produce fodder for their dairy production, while crop production was being carried out on about 3 ha. Dendenyore has been under cultivation since the 1930s, and the typical ward holding of arable land ranges from 0.8 ha to 5 ha. Grazing in both farming sectors is communal.

The farming system of Zana does have the capacity to employ fallows and there is some crop rotation carried out, with a common crop sequence being maize–tobacco–maize or maize–paprika–maize. Fallows are seldom employed in Dendenyore where the smaller arable land parcels per farmer necessitate cropping on all land every summer. In more recent years, and since the inception of legume research with farmers in the district, the rotations being employed by dairy and beef farmers in Zana and Dendenyore are being modified to include a forage legume phase of lablab or mucuna, with the most prevalent rotations being lablab or mucuna followed by maize, maize–sunflower, tobacco or paprika.

Livestock Production in Wedza

Livestock and crop production in Zana and Dendenyore are integrated enterprises, with livestock being important sources of traction and manure, and crop residues and fodder crops providing important feed for both beef and dairy production. Cattle fattening in the Wedza district dates back to the 1950s, with the formation of the Wedza Feeders Association. The association has over >200 members, from almost every one of the 14 wards of the district. Dendenyore ward has about 2400 farmers who own cattle, of which 65 are pen fatteners and members of the Wedza Feeders Association and another 54 are aspiring dairy farmers who are members of the Wedza Dairy Association. Dairy farmers in Zana have been producing milk since 1992.

All dairy cows are milked manually, and usually only once per day, first thing in the morning following separation of the cow and calf overnight. A small number of farmers who have purebred or crossbred dairy cattle milk twice per day. The majority of established dairy farmers milk crossbred cows.

Marketing of livestock products is carried out within the ward, with beef farmers selling their animals through local butcheries and abattoirs. Milk from dairy enterprises is either marketed through the Wedza Dairy Association or sold locally. Direct selling in 2001 was realising prices of about \$75/L[1] compared with about \$50/L when sold through the Wedza milk centre which is managed by the Agricultural Rural Development Authority–Dairy Development Programme (ARDA–DDP) in collaboration with Agricultural Research and Extension (AREX).

Resources for Extension

An important part of the Wedza district farming systems is the presence and role of the agricultural extension team that operates at the ward level. The district extension arm is within the Zimbabwe Ministry of Lands, Agriculture and Rural Resettlement and has a staff of 45, with a ratio of extension officer to farmers of about 1 to 1200 in the communal areas and 1 to 400 in the resettlement areas.

The extension personnel play a key role in the dissemination of technologies to farmers. Their role is to facilitate agricultural activities and train farmers on all aspects of agriculture. Several extension strategies are employed to aid technology diffusion, with the ‘master farmer’ training program being amongst the most widely used. By 2002, 2059 farmers in the district had qualified as master farmer at ordinary and advanced level, with 125 farmers gaining these qualifications during the project period.

Advances in Feed Supply

The natural rangeland grazing is the major source of ruminant livestock feed in the smallholder and commercial sectors of farming in Zimbabwe. However, this source is particularly degraded in the smallholder sector because of a history of overgrazing, and it is unable to supply sufficient feed quantity and quality throughout the year. Crude protein levels in the dry season can fall to below 5%. Commercial feed supplements are used by both dairy and beef-fattening enterprises to partially overcome this protein shortage, but they are expensive (Murungweni et al. 2004).

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[1] These are Zimbabwe dollars (ZWD). The exchange rate in late 2002 was USD1 = ZWD55. Since then, hyperinflation has reduced the value of the ZWD and substantially increased the cost of inputs.

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Both the beef-fattening and dairy-production farmer groups have adopted fodder bank technologies during the period 1999 to 2002, using lablab and mucuna. Hay is produced from both legumes at the end of the growing season. Since the start of the ACIAR project, dairy farmers in Zana resettlement area and beef producers in Dendenyore are adopting the practice of growing legumes and bana/napier grass as fodder crops in their crop rotations in an attempt to reduce feed constraints. Over 70 farmers are now using lablab and mucuna as a feed source, and there has been a rapid increase in the number of farmers using planted cut-and-carry bana/napier grass which is fertilised with manure (Table 3). The use of this legume technology has spread to four resettlement villages neighbouring the participating community in Zana, to the Sengezi resettlement area, about 40 km from Zana, and to other nearby communal areas. Animal production has increased considerably, with milk yields almost doubling (Table 4). The farmers in the dairy sector have indicated that there has been a marked increase in the butterfat content of the milk. Dendenyore farmers have reduced their dependence on commercial feeds for pen-fattening by about 25%.

Conclusion

The Wedza communal and resettlement farming systems are complex. They produce maize and other crops for household consumption and, in the case of the Zana resettlement area, paprika and tobacco as cash crops. Many farmers also have commercially focused dairy and beef enterprises. There has been adoption by a large number of farmers within the farming communities originally participating in the project. The higher production and greater income being obtained by these farmers, and the enthusiasm and skills of the local extension staff, have resulted in the use of legumes being adopted in other Wedza wards. In all of these communities, the use of legumes in the farming system has enabled farmers to increase their incomes.

There remains a large number of issues that require further investigation. In the dairy enterprises for instance, the focus has been on feeding lactating cows, but measures to enable farmers to monitor the growth rate of the calves have not been implemented. Similarly, there have been no targeted measures of the changes in conception rate resulting from legume tech-

Table 3. Changes in the number of farmers employing various feed sources in dairy and beef production enterprises between 1999 and 2002 in Zana and Dendenyore wards, Wedza district, Zimbabwe.

Feed type	Zana (dairy producers)				Dendenyore (beef producers)			
	1998–99	1999–2000	2000–01	2001–02	1998–99	1999–2000	2000–2001	2001–2002
Lablab	Nil	4	11	23	nil	4	13	54
Mucuna	2	6	13	21	3	5	31	54
Bana/napier	0	8	12	12	2	2	38	38
Urea/stover	0	6	4	4	1	3	0	–
Native grass hay	2	5	8	9	3	4	13	36
Soybean/groundnut hay	2	6	12	12	2	11	26	26
Maize stover	13	23	28	38	2	4	13	153
Paprika calyx	6	17	23	23	–	–	–	–

Table 4. Average on-farm milk production (l/cow/day) trends between 1999 and 2002 at Zana resettlement area in Wedza District, Zimbabwe, as a result of incorporation of legume hay into the diet of cows.

Season and lactation stage	1999–2000	2000–01	2001–02[b]
Summer production			
Birth to 7 months	4–6	6–17[a]	5–10
7–8 months	1–3	2–8	4–6
Winter production	3 –4	5 –7	5 – 7
Birth to 7 months	1 – 2	2–6	2–6
7–8 months			

[a] Purebred cow; [b] drought year.

nology introductions or the role of legumes in increasing production in small stock such as goats. In the cropping systems, screening of new legumes has shown lablab and mucuna to be well-adapted, but their impact and options in rotations with crops such as paprika have not been documented, and even the impact on maize has not been widely demonstrated on a wide range of farmers' fields. These and many other issues still require further research on both the communal and resettlement areas of Wedza, and in adjacent districts.

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Description of the Biophysical Environment of Three Maize-producing Areas in the Limpopo Province of the Republic of South Africa and the Validation of APSIM to Simulate Maize Production

A.M. Whitbread*[*] and K.K. Ayisi[†]

Abstract

The focus of this paper is to provide background biophysical information and test the performance of the APSIM (Agricultural Production Systems sIMulator) maize model on several data sets collected at the field sites used in the Limpopo Province of South Africa during the ACIAR project AS2/96/149 described in these proceedings. The project targeted one community of smallholder farmers at Dan in the Mopani district of Limpopo, with the aim of improving their dryland cropping systems. A site called Syferkuil, located on the University of the North's experimental farm, and a nearby site called Dalmada, on a farmer's field, were also the location of several maize-intercropping/relay planting field trials. Using the data of the sole-maize control treatments from these trials, APSIM-Maize V3.2 predicted the biomass accumulation with a high degree of precision ($r^2 = 0.82$). Factors such as grazing damage, severe frost and striga infection that reduced the observed grain yield resulted in general over-prediction of simulated grain yield. Simulating maize production without N inputs under dryland conditions at Dan, using long-term weather records (1975–2002), indicates poor maize grain yields (<1000 kg/ha) and several crop failures. The application of 30 or 60 kg/ha N fertiliser increased maize yields to 1700 and 2600 kg/ha in 50% of seasons.

The Limpopo Province is in the northern part of South Africa, with an area of 12.3 million hectares and a population of 4.9 million in 1996 (Anon 2003). Although maize production accounts for only 4% of the province's gross agricultural income, maize is considered to be Limpopo's most important dryland crop in terms of the extent of production, the area utilised and the number of farmers involved (~519 000 farmers). Maize is the staple food of most of the rural population and the crop residues are a feed resource for animals. Despite the low and unreliably distributed rainfall in many parts of the province, maize will be an important crop for food security in the foreseeable future.

Most of the smallholder farming sector in Limpopo is located on infertile degraded soils, where nutrient deficiencies, predominantly of N (nitrogen) and P (phosphorus), limit crop production. As the cash reserves of these mainly subsistence farmers are limited, little or no inorganic fertiliser is applied to the maize crops and grain yields are commonly <500 kg/ha. The traditional farming practice of intercropping maize with grain legumes such as groundnuts (*Arachis* spp.) may help reduce the risk of crop failure of one of the species and add some N to the system through biological N fixation. Papers in these

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[*] CSIRO Sustainable Ecosystems, 306 Carmody Road, St Lucia, Queensland 4067, Australia.

[†] School of Agricultural and Environmental Sciences, Plant Production, University of the North, Private Bag X1106, Sovenga, 0727 Republic of South Africa.

Tropical legumes for sustainable farming systems in southern Africa and Australia,
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proceedings by Ayisi and Mpangane (2004), Maluleke et al. (2004) and Mpangane et al. (2004) describe various intercropping and relay-planting experiments using lablab (*Lablab purpureus)* and cowpea *(Vigna unguiculata).* The impact of the intercrops on maize production and their potential for N fixation were investigated with the aim of providing farmers with options for cash cropping, forage production and improvements in soil fertility.

The APSIM (Agricultural Production Systems sIMulator) software system provides a flexible structure for the simulation of climatic and soil management effects on the growth of crops and changes in the soil resource (Keating et al. 2003). Use of APSIM to investigate maize production systems in climatically risky environments has been extensively tested in Kenya and Zimbabwe (Keating et al. 1999; Shamudzarira and Robertson 2002).

The focus of this paper is to describe the biophysical environment and test the performance of the APSIM maize model on several field data sets from the sites used in the Limpopo Province during the ACIAR project AS2/96/149 described in these proceedings.

Materials and Methods

A range of experiments was conducted at the three sites described in this paper to investigate various aspects of maize–legume technologies. Most of these experiments included a sole maize control treatment that has been used to validate the APSIM model for the prediction of maize growth and grain yield. The control treatments are sourced from experiments described in Malueke et al. (2004) and Ayisi and Mpangane (2004), and unpublished data from Mishiyi (2003).

The experimental site at Syferkuil (23°85'S 29°67'E, 1250 masl) was on the University of the North's field station. The experimental site at Dalmada (23°87'S 29°53'E, 1334 masl) was 15 km from Polokwane (Pietersburg) and was rented from a local farmer. Irrigation was available at both these sites, and the experiments were entirely researcher managed. The on-farm site at Dan (23°90'S 30°27'E, 650 masl) was 13 km east of Tzaneen town in the Mopani district, on a 200 ha cropping area farmed by about 300 farmers. Each farmer had access to 0.5–1.0 ha of arable land under a 'permission to occupy' arrangement. Full details of this site and the community can be found in Ndove et al. (2004). The experiments conducted at Dan were also essentially researcher managed, although the farmers actively assisted in many field operations.

Field experiments

Syferkuil and Dalmada. All experimental areas were ploughed, disced and harrowed 1–2 weeks prior to planting. At planting, a basal P application of 30 kg/ha as single superphosphate and a K application of 30kg/ha as potassium chloride was applied. Maize (SNK2147) was planted by hand into 90 cm rows at 15 kg/ha in the first week of December in 2001 and 2002, and thinned to 3 plants/m^2 after emergence. N was applied as urea at 15 kg/ha at planting and at 30 days after planting (DAP). Supplementary irrigation was applied at both sites in 15 mm applications at planting, and at 30 and 45 DAP. The 2002–03 experiments at Syferkuil received 120 mm of irrigation in total, applied in eight 12–15 mm applications at 10 day intervals from planting. The 2002–03 experiments at Dalmada received 10–12 mm of irrigation at 40, 55, and 60 DAP. All treatments were replicated three times. There were six 5 m rows of maize. The plots were located in a different part of the field in each season.

Dry matter samples were taken at 54, 67 and 88 DAP at Syferkuil, and at 50, 71 and 95 DAP for all crops at Dalmada. At each of these samplings, three maize plants from each plot were cut at ground level and dried. At final harvest, maize cobs were harvested from the central four rows, with 1 m borders at each end of the plots. Stover yield was determined by taking 10 plants randomly from the harvested area.

Dan. At Dan during the 2000–01 season, an experiment was conducted on a farmer's field to determine the effects on maize production of applications of 0, 30 and 60 kg/ha of N. The experiment was arranged as a randomised complete block design, with three replicates and plot sizes of 5 × 8 m. No data were as recorded, because a herd of animals demolished the trial before harvest. After the construction of a sturdy fence, this experiment was continued in the 2001–02 season.

In both seasons, land preparation and basal fertilisation was as described for the Syferkuil and Dalmada sites. Due to the low pH (Table 1) an addition of 500 kg/ha of dolomitic lime was also applied during the land preparation activities. Maize (SNK2147) was planted as described above on 1 November 2001. In the 30 and 60 kg/ha N treatments, half the fertiliser was delivered as urea at planting and the other half at 30 DAP. No supplementary irrigation was available. The plots were harvested on 6 April 2002 using the same procedures as at Syferkuil and Dalmada.

Biophysical characterisation of the sites

Soil characterisation was undertaken for the soil profiles at Dan, Syferkuil and Dalmada. Measurements of drained upper limit (DUL), crop lower limit (CLL) and bulk density, and the calculation of plant available water capacity (PAWC), at the three field sites were undertaken using the methods described in Dalgleish and Foale (1998) (Table 2). This soils information, along with the chemical analyses for the specific experiments (Table 5), were used to parameterise the SOILWAT2 and SOILN2 modules that determine the dynamics of water, carbon and nitrogen within APSIM. The initialisation information (mineral N, starting soil water, residues and roots) is specific to each experiment and is described below.

Weather information was obtained through the Agricultural Research Council Institute for Soil, Climate and Water, the South African Bureau of Meteorology and via International Rainman V4.1 (Clewett et al. 2002).

Simulation of maize growth

Syferkuil and Dalmada. All simulations were started and initialised at day 182 in the same year that experiments were sown, using the data in Tables A2 and A3. Soil water and soil mineral N at sowing were therefore determined by APSIM. It was assumed that most surface plant residues from the previous season were removed, and the simulations were initialised at 400 kg/ha. The timing of tillage events, sowing, N fertilisation, and irrigation were as for the field experiments described above. The SC401 short-season variety available in APSIM was found to best represent the growth of SNK2147. Harvesting of the modelled data took place when the simulated crop

Table 1. Soil chemical analysis for the soil profiles at Dan, Syferkuil and Dalmada.

	Depth	pH	P[a]	Ca[b]	Mg[b]	K[b]	Na[b]	Mn	Zn[c]
	(cm)		mg/kg	cmol(+)/kg				mg/kg	mg/kg
Dan	0–15	4.8	6	2.42	1.27	0.09	0.03	174.1	2.5
	15–30	5.5	2	3.56	1.73	0.05	0.04	41.8	2.2
	30–60	5.6	2	3.70	2.02	0.05	0.08	30.4	13.1
	60–90	5.8	2	3.12	2.02	0.04	0.10	17.1	15.9
Syferkuil	0–15	6.6	30	2.86	2.82	0.28	0.26	n.d.	n.d.
	15–30	7.0	22	2.51	2.43	0.19	0.20	n.d.	n.d.
Dalmada	0–15	7.6	43	4.08	4.18	1.02	0.02	n.d.	n.d.
	15–30	7.9	27	4.49	4.51	0.95	0.04	n.d.	n.d.
	30–60	7.5	8	4.86	5.02	0.73	0.14	n.d.	n.d.

n.d. = not determined
[a] 1:7.5 extractant Bray 2
[b] 1:10 extractant ammonium acetate 1 mol pH7
[c] 1:4 extractant 0.1 mol HCl

Table 2. Soil water characteristics and mineral N of the soil profiles at Dan, Syferkuil and Dalmada.

	Depth (cm)	DUL (mm)	CLL (maize) (mm)	PAWC (mm)	Mineral N (kg/ha)
Dan	120	330	206	124	28
Syferkuil	90	137	85	52	44
Syferkuil – deep	120	184	118	66	48
Dalmada	90	158	83	75	10

CLL = crop lower limit; DUL = drained upper limit; PAWC = plant available water capacity.

reached physiological maturity. All simulations assumed that P was not limiting. This is a reasonable assumption because basal applications of P fertiliser were applied to all field experiments.

Dan. Maize in the 2001–02 season was simulated for the treatments that received N fertiliser at 0, 30 and 60 kg/ha. The soil mineral N measured prior to sowing (Table A1) was initialised in the model at day 300. Soil water was also initialised to the DUL at this time. It was assumed that most surface plant residues from the sorghum crop season had been grazed, and surface residue was initialised at 400 kg/ha. Fertiliser N was added as described for the field experiment. Harvesting of the modelled data took place when the simulated crop reached physiological maturity.

Long-term simulation of dryland maize at Dan. Using the soil characterisation for Dan (Table A1) and weather data (Letaba Letsitele station 19935) that contained daily records from 1975 until April 2002, the production of sole maize was simulated each season. While the soil nitrate and soil water were initialised in the first year of the simulation as in Table A1, the model subsequently determined these parameters. A soil tillage event took place on Julian day 304 each year. Maize (SC401) was sown on a yearly basis using a rainfall-based sowing rule. In order to trigger the sowing event within the sowing window from 15 November to 15 January, rainfall of at least 20 mm over five days was required before planting would take place. Maize was planted at 3 plants/m into 90 cm rows. A grass weed (a short-season annual grass) was also sown at 25 plants/m at the same time as the maize, to mimic the effect of weeds on the maize crop. The weeds were removed by tillage at 33 DAP. Separate simulations received 0, 30 or 60 kg/ha N fertiliser as urea in a split application at sowing and 33 DAP. Maize was harvested when it reached physiological maturity. Grain weight is expressed at 12% moisture.

Table 3. Rainfall (mm) at Dan, 1998–2002, and the long-term average (1975–2001).

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Year
1998–99	25	0	21	43	180	283	150	159	202	16	30	7	1114
1999–00	25	2	0	67	92	272	248	554	300	170	9	9	1749
2000–01	1	0	16	52	133	142	18	247	57	10	9	8	692
2001–02	1	0	6	86	252	202	46	7	n.a.	n.a.	n.a.	n.a.	601
Average	9	10	21	52	99	142	141	117	106	40	16	6	759

n.a. = data not available at this time.

Table 4. Rainfall (mm) at Pietersburg since 1998 and the long-term average (1904–1996).

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Year
1998–99	0	0	8	66	119	124	100	3	40	5	11	1	477
1999–00	5	0	4	40	90	75	105	188	40	74	20	24	667
2000–01	0	0	1	43	67	82	12	69	74	17	10	3	377
2001–02	0	0	0	55	215	46	102	21	4	23	20	4	488
Average[a]	3	3	12	41	79	89	87	73	61	29	11	5	493

[a] Long-term average calculated from 87 years of records sourced from Rainman International (Clewett et al. 2002).

Table 5. Rainfall (mm) at Syferkuil, 1998–2002, and the long-term average (1984–2002).

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Year
1998–99	5	0	6	56	64	72	77	6	54	2	12	0	353
1999–00	2	0	4	31	106	85	120	238	42	127	15	52	822
2000–01	0	0	6	42	94	62	0	72	11	30	15	4	336
2001–02	0	0	0	65	239	77	136	15	33	21	14	0	600
2002–03	0	0	6	14	0	113	73	58	44	0	0	0	308
Average	7	4	7	41	91	76	84	72	52	29	12	7	480

Source: University of the North experimental station records.

Results and Discussion

Biophysical environment

Dan. Based on the 1975–2001 weather files from the nearby Letaba Letsitele 19935 weather station, the annual average rainfall at Dan is 759 mm. The rainfall pattern is strongly summer dominant, with 86% of the rainfall received from October to the end of March (Table 3). The amount and distribution of rainfall is critical, as agricultural production at Dan is rain fed. Minimum temperatures of 6.5°C are reached in June and July, and maximums of 32°C are reached in December and January (data not shown).

Dalmada. Weather at Dalmada, which is approximately 30 km from Pietersburg, is based on the weather records obtained from the Pietersburg station. At Pietersburg, there is an annual average rainfall of 493 mm, received mainly from October to March (Table 4). Maximum temperatures of 28°C occur during January, with minimums of 4.4°C during July (data not shown). Supplementary irrigation was available to the field experiments at this site.

Syferkuil. The minimum and maximum temperature data obtained from the University of the North's experimental site at Syferkuil were similar to those described from the Pietersburg weather station. Frost occurs rarely, but caused the death of all legume experiments in May 2002. While the long-term rainfall averages were similar to those of Pietersburg, the amount of rainfall received was lower in the October–January period and higher in the February–April period (Table 5). The Syferkuil site is closer to a mountain range and its weather is obviously influenced by this.

Soils

Dan. The main soils used for crop production at Dan range from coarse-grained sandy soils to sandy loams derived from granitic parent materials. The depth of these soils, which overlie clay, varies from 60 cm to >150 cm. Much of the cropping land is susceptible to waterlogging during heavy rains, and subsoil drainage is poor because of the underlying dense clay layer. The sandy nature of the soil results in high bulk density and PAWC is 124 mm to the rooting depth of 120 cm (Table 2).

Available phosphorus concentrations are below 6 mg/kg, which is severely limiting to plant growth (Table 1). These soils are acidic, with pH values below 5.8. The basic cations Ca, Mg and K are in the adequate range for most grain crops. High concentrations of Mn in the surface soils at Dan indicate possible toxicity under waterlogged conditions.

Syferkuil. The soil at Syferkuil is a sandy loam (77–81% sand in the 0–60 cm depth). Soil depth varies from 90 to 120 cm, resulting in a PAWC that varies from 52 to 66 mm for maize (Table 2). The soils at the Syferkuil site are described as part of the Hutton series (Soil Classification Working group, 1991) with an orthic A horizon and red apedal B horizon overlying unspecified material (Boye Mashotole, pers. comm.). Apedal is defined as materials that are well aggregated, but well-formed peds cannot be detected macroscopically. Regular superphosphate fertiliser applications have resulted in adequate to high available P (Table 1). The basic cations Ca, Mg and K are in the adequate range for most grain crops.

Dalmada. The soils at the Dalmada site are described as part of the Bainsvlei Form (Soil Classification Working group, 1991) with an orthic A horizon and red apedal B horizon overlying a hard plinthic B horizon at a depth of 80–90 cm. This consists of an indurated zone of accumulation of iron and manganese, which could not be cut with a spade even when wet and which limits rooting to this depth. The PAWC for maize is 75 mm (Table 1). Impeded drainage through this layer could result in waterlogging, although this did not occur during our experimental program. Adequate to high available P was also measured at this site and the basic cations Ca, Mg and K are in the adequate range for most grain crops (Table 2). This site had been commercially farmed and probably received fertiliser applications in the past.

Specification of the APSIM SOILWAT2, SOILN2 and RESIDUE2 modules

The inputs required to specify the SOILWAT2 and SOILN2 modules are given in Appendix 1, Tables A1, A2 and A3. Other parameters that relate to evaporation and run-off are found in Table A4, and parameters that relate to the initialisation of residue are in Table A5. These parameters were largely based on the measured values described above. Other parameters that are not measurable, but required by the model, were estimated by consulting a range of literature.

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Sole maize field experiments

Dalmada and Syferkuil. Biomass accumulation is presented for the Dalmada experiment in 2002–03 and shows a slow accumulation until 50 DAP, followed by a rapid growth phase until maturity (Figure 1).

The simulated and observed data for all biomass measurements made at intervals during the growth of maize in the 2001–02 and 2002–03 seasons at both sites were combined (Figure 2). The simulated biomass accumulation was generally underestimated later in the season (i.e. when biomass values were largest), but the overall $r^2 = 0.83$ is high.

Grain yield was similar at the two sites in 2001–02 and increased considerably at Syferkuil in 2002–03 in response to more irrigation (Table 6). A severe frost late in the season at Syferkuil in 2001–02 reduced the harvested yield and may account for the overestimation of the simulated grain yield. At Dalmada in the 2002–03 season, uncontrolled wild animals damaged the plots by grazing and reduced harvested yield. This explains much of the variation between the observed and simulated data.

Dan. After maize was planted across all treatments in 2001–02, 252 mm of rain fell during November with a further 202 mm during December, resulting in good vegetative maize growth. Very hot and dry conditions corresponded with floral initiation around 8 January 2002, with temperatures above 35°C around flowering time in late January. With the exception of 42 mm of rain in the last two days of January, drought conditions prevailed throughout January and February. These hot and dry conditions resulted in a nearly complete failure in grain filling and very low grain yield in all treatments (Table 7). According to the simulations, N stress affected all treatments from 10 January 2002 until maturity and water stress was limiting maize yield from February 5 until maturity.

Table 6. The observed and simulated maize grain yield (kg/ha) of the sole maize treatments.

Year	Site	Observed	Simulated
2001–02	Syferkuil	1238	1627
	Dalmada	1185	1200
2002–03	Syferkuil	5181	3843
	Dalmada	1674	3733

There was no significant difference in grain yield or stover + husk yield between treatments. The most grain was produced in the treatment that received 60 kg N/ha, while no grain was produced in the treatment that received no N fertiliser (Table 7). The simulations predicted the biomass production well but overestimated the grain produced on the fertilised N treatments. The effects of *Striga hermonthica* (witchweed), theft of green cobs (mealies) and losses due to late harvesting were all factors that may have contributed to this discrepancy in the treatments that received N fertiliser.

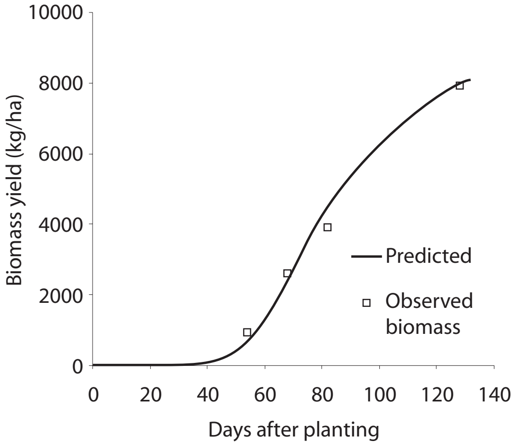

Figure 1. The measured values of biomass at 54, 68, 82 and 128 days after planting and the simulated biomass accumulation of maize at Dalmada in 2002–03

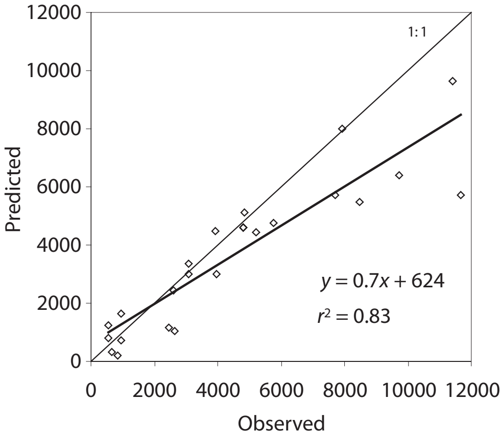

Figure 2. The relationship between the observed and predicted data for all biomass measurements (kg/ha) made during experiments at the Dalmada and Syferkuil sites.

Table 7. The observed and simulated grain and biomass (kg/ha) at final harvest at Dan in 2001–02.

	Grain		Biomass	
	Observed	Predicted	Observed	Predicted
M0	153	0	2735	2345
M30	320	888	3763	4547
M60	591	1300	4621	5403
Significance	n.s.		n.s.	

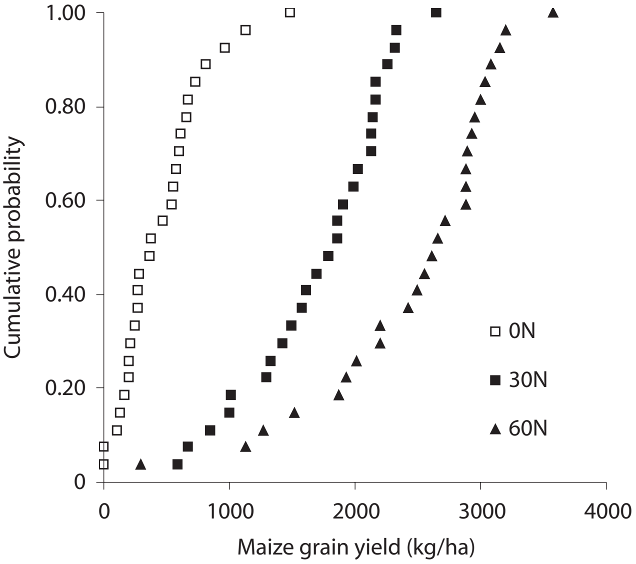

Figure 3. Cumulative distribution functions for maize production with 0, 30 or 60 kg/ha N applied (1975–2002) at Dan.

Long-term simulated performance of maize production at Dan

The simulation of maize production without N inputs under dryland conditions at Dan, using the weather data for the period 1975–2002, indicates extremely poor maize grain yields (<1000 kg/ha) in most seasons, and two crop failures (Figure 3).

With the application of 30 kg/ha of N, the poorest season yielded 587 kg/ha and 50% of the seasons yielded >1700 kg/ha. The application of 60 kg/ha of N resulted in maize yielding >2600 kg/ha in 50% of seasons (Figure 3).

Nitrogen use efficiency (NUE) was in the range 16–59 kg grain/kg N for applications of 30 kg/ha, and 18–44 kg grain/kg N for applications of 60 kg/ha (data not presented). These generally high NUE figures result from the model's assumption that there was no limitation caused by deficiencies of other nutrients, or by the other factors described above that affected the field trials.

Conclusion

The APSIM maize model was able to simulate biomass production with a high degree of precision. The observed grain yields were often affected by factors that are unmodellable (e.g. theft, damage by game) and factors that are now becoming modellable (e.g. parasitic weeds). A new version of the maize model that is responsive to P is being tested in the

ACIAR Risk Management Project (LRW2/2001/028) in Zimbabwe, and will be applicable to the low-P soils of South Africa.

The soil characterisations presented in this paper are common to large areas of arable land in the Limpopo Province. Utilising the characterisation information presented in this paper and modifying it to suit other sites will help expedite other model applications in the region.

The production of maize at Dan in the absence of N input resulted in a high risk of crop failure and a very low potential yield target. This matches the experiences of farmers from the community, presented by Ndove et al. (2004). The application of moderate amounts of fertiliser N (30 and 60 kg/ha) resulted in lower risk and higher yield potential. Although the reason for not applying fertiliser is said to a lack of available cash, the costs of ploughing large and often unused tracts of land are readily paid by the farmers. Efforts by the agricultural department extension officers to help farmers reprioritise their crop inputs could be rewarded by better food security.

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Appendix 1

Specification of APSIM SOILWAT2 and SOILN2 modules

The parameter *swcon* determines the proportion of water above the DUL that will be drained each day. In a well-drained sandy soil that becomes saturated, it could be expected that the soil water content will return to the DUL over 2–3 days. In Probert et al. (1998), swcon = 0.2 for the 'Warra' vertisol soil indicating much slower drainage than swcon = 0.7 for the sandy soils described here.

Finert describes the proportion of initial organic carbon assumed to be inert. Assuming that all organic C measured at depth is essentially inert, this quantity is assumed to remain the same at all depths.

Fbiom describes the initial biom as a proportion of non-inert C. These values are based on Probert et al. 1998 and other published data sets.

Table A1. Soil properties and initial values at the Dan site, by layer

Layer number	1	2	3	4	5
Layer depth (mm)	150	150	300	300	300
Air_dry weight (mm/mm)	0.03	0.03	0.03	0.03	0.03
ll15 (mm/mm)	0.120	0.120	0.180	0.200	0.200
Dul (mm/mm)	0.230	0.230	0.290	0.290	0.290
Sat (mm/mm)	0.400	0.400	0.400	0.400	0.400
swcon	0.7	0.7	0.7	0.7	0.7
Bulk density (g/cm^3)	1.47	1.46	1.46	1.46	1.46
Organic carbon (%)	0.70	0.60	0.50	0.40	0.40
pH	5.0	5.6	5.6	5.8	6.0
nh4 (µg/g)	0.50	0.50	0.50	0.40	0.40
no3 (µg/g)	0.9	0.7	1.5	1.0	1.0
Finert	0.57	0.66	0.80	0.99	0.99
Fbiom	0.03	0.02	0.015	0.010	0.010

Table A2. Soil properties and initial values at the Syferkuil site, by layer.

Layer number	1	2	3	4	5
Layer depth (mm)	150	150	300	300	300
Air–dry weight (mm/mm)	0.03	0.03	0.03	0.03	0.03
ll15 (mm/mm)	0.054	0.072	0.110	0.110	0.110
Dul (mm/mm)	0.130	0.156	0.157	0.157	0.157
Sat (mm/mm)	0.403	0.403	0.403	0.403	0.403
swcon	0.7	0.7	0.7	0.7	0.7
Bulk density (g/cm^3)	1.45	1.45	1.45	1.45	1.45
Organic carbon (%)	0.87	0.87	0.70	0.60	0.50
pH	7.0	7.0	6.9	6.9	6.9
nh4 (µg/g)	0.50	0.50	0.50	0.40	0.40
no3 (µg/g)	11.0	9.0	5.0	5.0	3.0
Finert	0.46	0.46	0.57	0.67	0.80
Fbiom	0.03	0.02	0.015	0.010	0.010

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Table A3. Soil properties and initial values at the Dalmada site, by layer.

Layer number	**1**	**2**	**3**	**4**
Layer depth (mm)	150	150	300	300
Air_dry weight (mm/mm)	0.03	0.03	0.03	0.03
ll15 (mm/mm)	0.068	0.100	0.100	0.100
Dul (mm/mm)	0.182	0.171	0.175	0.175
Sat (mm/mm)	0.432	0.436	0.428	0.428
swcon[a]	0.7	0.7	0.7	0.7
Bulk density (g/cm^3)	1.37	1.36	1.38	1.38
Organic carbon (%)	0.87	0.87	0.70	0.60
pH	6.9	7.0	6.9	6.9
nh4 (μg/g)	0.50	0.50	0.50	0.40
no3 (μg/g)	3.00	2.00	1.00	0.50
Finert[b]	0.46	0.46	0.57	0.67
Fbiom[c]	0.03	0.02	0.015	0.010

Table A4. Soil water parameters for the experimental sites at Dan, Syferkuil and Dalmada.

APSIM code	Definition	Values
u	Stage 1 soil evaporation coefficient (mm)	3.0
cona	Coefficient for stage 2 soil evaporation (mm day $^{-0.5}$)	3.5
cn2	Run-off curve number	80[a]
cn_red	Maximum reduction in cn2 due to presence of surface residues	20
cn_cv	Percentage residue cover at which maximum reduction in cn2 occurs	80
salb	Bare soil albedo	0.1
diffus_const	Coefficient defining diffusivity	88
diff_slope	Coefficient defining diffusivity	35.4

[a] The curve number at Syferkuil and Dalmada was set as 72 to represent lower potential run-off from these very flat sites than from the sloping and hard-setting Dan site.

Table A5. Soil nitrogen parameters for experimental sites at Dan, Syferkuil and Dalmada.

APSIM code	Definition	Values
soil_cn	C:N ratio of soil	14.5
root_wt	Initial root residues (kg/ha)	400
root_cnr	C:N ratio of root residues	45
residue_wt	Initial surface residues (kg/ha)	100
residue_cnr	C:N ratio of surface residues	80
residue_type	Type of surface residues, which determines the specific area and contact factor used by the residue module	maize
pot_decomp_rate	Potential decomposition rate of surface residues under optimal conditions (day^{-1})	0.05

Evaluation of Forage Technologies

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Tropical Forage Research for the Future — Better Use of Research Resources to Deliver Adoption and Benefits to Farmers[1]

B.C. Pengelly,* A. Whitbread,* P.R. Mazaiwana† and N. Mukombe†

Abstract

Successful adoption of forage technology is frequently associated with a need to increase production and income generation. Farmers might be expected to ‘demand’ new forages only when they can see a financial benefit in the short to medium term. Opportunities for farmers to generate income from livestock production are increasing dramatically as demand for animal products increases across Asia and Africa. Most of this increased demand will be met from mixed cropping–livestock enterprises, in which most tropical livestock are currently raised and production usually depends on low-quality crop residues. Forage research in the future will need to provide farmers with the means to meet the increased demand for livestock products. The challenge will be to develop research strategies that identify well-adapted forages that can improve livestock production and can be grown within the spatial and temporal constraints of complex and resource-limited mixed cropping–livestock farming systems; in addition, it will be necessary to provide appropriate information on the management and economic benefits of these forages. This paper presents two possible approaches.

In a participatory action research program on the use of forage legumes in cropping systems in Zimbabwe, the keys to successful forage adoption in rural communities are seen as: the emerging market for livestock products; a motivated and educated extension service working with a range of research specialists; and opportunities for beneficial synergies to be exploited from a mixed livestock–maize production system. Focused benchmarking of the communities identified farmers with sufficient resources and appropriate livestock systems to benefit from improved forage.

In a rice-based Indonesian farming system, simulation of forage growth and livestock production before on-farm research begins is being used to examine the possible whole-of-farm impacts of using planted forages. Identifying the most likely spatial and temporal opportunities for growing forages and incorporating them into the feed calendar can potentially avoid costly on-farm research on practices that have doubtful economic impact; moreover, this approach enables a wide range of options to be compared rapidly.

To avoid the mistakes of the past, researchers need to provide supporting evidence that investment in new forages makes a difference not only to livestock production but also to household income. They will need to focus on farming systems, such as mixed crop– livestock systems, where farmers have total control over the forage they produce and where adoption can be shown to be economically sustainable. Researchers also need to identify and target those farmers within rural communities with the resource capacity to invest in new farming practices.

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* CSIRO Sustainable Ecosystems, Queensland Biosciences Precinct, St Lucia, Queensland 4067, Australia.

† AGRITEX, Wedza, Zimbabwe.

Tropical legumes for sustainable farming systems in southern Africa and Australia,
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Livestock production is an important component of many smallholder farming systems throughout the tropics. As well as providing food, such as fish, meat, milk and eggs, livestock are also critical in providing draft power and manure for fertiliser and/or fuel; moreover, livestock often have wider socioeconomic roles within the community, such as providing financial security. The feed sources for animals in smallholder farming systems are extremely variable but usually comprise a mixture of grazing on communally owned grasslands, cut-and-carry forages from off-farm, and crop residues.

Without substantial additions to the diet in the form of mineral, protein and energy supplements, both reproductive rates and animal production are almost universally poor within these systems. Despite this low level of animal production, dietary supplements including sown forages have seldom been used until recently because of farmers' perceptions that they were not needed, the lack of capital or planting materials, or the absence of a financial incentive to invest labour and capital in forage production. For many years, the lack of incentive for forage investment resulted in poor adoption of almost all new forage technologies in smallholder systems in tropical Africa and Asia. This is despite many decades of pasture and forage research, and development in these regions. As noted by Squires et al. (1992) and Thomas and Sumberg (1995), the adoption of planted forages by farmers in sub-Saharan Africa has, in the main, been limited. Before considering any further commitment to new tropical forage science in smallholder farming systems, researchers need to address the following three key questions:

- Given the history of forage adoption, why should an increase occur *now* in the use of improved forages in smallholder systems?
- If such an increase is to occur, what farmers are most likely to adopt forage technology and in what farming systems?
- What have been the constraints to forage adoption and utilisation by *these* farmers?

This paper attempts to answer these questions in the light of international and regional trends in livestock production and consumption, socioeconomic constraints on farmers, and the large body of information already available on forage species adaptation and forage management.

International Demand for Livestock Products

The past 10 years have seen remarkable changes in demand for livestock products across the tropical world, and the increased demand is predicted to become even more obvious in the future. It has been estimated that milk consumption across the tropics will increase by about 3.2% per year until 2020 (Delgado et al. 1999). Similarly, beef and pork consumption is expected to double in developing countries between 1993 and 2020. This increase in demand is already having, and will continue to have, major impacts on household, farm and even regional economies throughout the tropics. The mixed crop–livestock farming systems of the tropics will be most affected by this increase in demand for livestock products. These systems already produce more than half the meat and most of the world's milk supply (Blackburn 1998; CAST 1999); more than 85% of the world's cattle, sheep and goats are held in these mixed systems in the tropics (Gardiner and Devendra 1995).

In several regions of Africa, Asia and the Americas, dairying has become an important and economically attractive enterprise for smallholder farmers. For example, by 1996, more than 400 000 smallholder dairy farmers in Kenya produced about 70% of the country's market milk (Reynolds et al. 1996). In Thailand, dairy cattle numbers increased fourfold during the 1990s to meet the increase in demand for milk; by 1999, there were >19 000 smallholder dairy farms in existence (Hare et al. 1999). Similar increases in demand for milk have been recorded in Colombia, South America (Rivas and Holmann 2000). With these rapid increases in livestock production comes demand for new sources of livestock feed.

The increase in demand for livestock products is also having major effects on regional economies and even government policy. The increase in demand for beef in Java, the most populous Indonesian island, has resulted in a rapid decline in local herd sizes on the Indonesian islands of Lombok and Sulawesi. High beef prices have encouraged farmers to market a significant proportion of the breeding herd for slaughter. Consequently, beef cattle numbers in South Sulawesi have declined from 1.23 million in 1991 to only 0.84 million in 1997 (FAO 1999). The decline in herd size has had various effects. A number of provincial governments in Indonesia have

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embarked on research and development programs to improve reproduction and livestock production in Bali cattle, with emphasis on developing a better forage basis for the industry. Some provincial governments have also imposed restrictions on livestock exports from their islands.

The rapid increase in demand for livestock products is providing opportunities for farmers to derive income from livestock production and improve the economic sustainability of their farming enterprises. However, it is also providing threats as farmers overstretch their dependence on limited resources such as communally grazed grasslands, manure and their breeding herds. Improved planted forages have the capacity to provide better quality feed for livestock. How then should the research community prioritise the limited forage research budget to assist farmers to take full advantage of the changing marketplace?

Avenues available to improve livestock production

Smallholder livestock systems throughout the tropics have traditionally been based on low-quality roughage sources from communally owned grasslands and/or crop residues (Ranjhan 1986; Moog 1986; Dzowela 1993). With both of these sources, total forage available and forage quality are usually limiting for considerable periods of the year. For example, crude protein concentrations in grass and maize stover can be as little as 3% and 6%, respectively (Ndlovu and Sibanda 1996; Makembe and Ndlovu 1996). Consequently, peak milk yields of indigenous animals in Zimbabwe can be as little as 3–5 kg/d (Mutukumira et al. 1996; Pedersen and Madsen 1998). Improving animal production will necessitate additional forage and/or some method of improving diet quality at strategic times throughout the year.

As potential economic benefits from improved animal nutrition become apparent, farmers are becoming far more interested in their feeding options and are making larger investments in animal feed. In Thailand, the purchase of animal feed constitutes almost 60% of a dairy farmer's direct costs and still productivity is largely limited by feed supply (Hare et al. 1999). Farmers have a number of options for improving diet quality. Feeding concentrates such as urea, phosphorus and molasses can greatly improve overall diet quality and improve livestock production. Such technology has been widely adopted throughout much of the tropics where low-quality crop residues are in abundance and form a significant part of the diet. In Zimbabwe, many livestock producers already feed concentrates, while in many parts of Asia, urea–molasses blocks are commonly used.

Over 40 years of research has clearly demonstrated that animal performance can also be improved by providing better nutrition via higher quality grasses, such as fertilised cut-and-carry grasses, or by the inclusion of legumes in the diet (e.g. Humphreys 1991). Despite the well-known benefits of improved forages, adoption in smallholder systems, and indeed in extensive production systems in developed countries, has frequently been poor. However, a number of success stories do exist.

In formulating policy on where forage research might be directed, it is important to consider factors that might affect adoption and at least attempt to characterise the farmers most likely to adopt new forage technologies, and their farming systems.

Farming Systems and Control of Utilisation

Given their restricted resources, smallholder farmers are necessarily cautious about new investments; they would probably invest in new forages only when they have control over the resultant utilisation. Consequently, investment in new forages for communally grazed grasslands is unlikely until pastoral communities develop strategies for grazing management (Squires et al. 1992). Rather, improved forages are more likely to be planted in mixed cropping–livestock systems where grazing control is usually practised, at least for part of the year. In these farming systems, the challenge for farmers, extension specialists and forage scientists is to identify suitable forage species/cultivars, and to identify the spatial and temporal opportunities to grow those forages.

Which Farmers Might Invest in Forage Technology?

The availability of well-adapted species and sound scientific evidence that improved forages improve livestock production has been insufficient to encourage farmers to make significant investment in forages. Thomas and Sumberg (1995) attributed some part of this reluctance to grow forages to producers being unfamiliar with the concept of investing labour and capital in forages rather than staple crops. Farmers have not been accustomed to considering forage production as a part of subsistence agriculture.

Horne and Stür (1997) argued that, in Asia, the lack of adoption of what are clearly well-adapted pasture plants was, in the main, the result of researchers not addressing farmers' requirements. They stressed the need for farmers to be partners in forage research and development, so that researchers can understand better the complexities and forage priorities within farming systems.

Over the past decade, there have been two significant changes that affect these views. The first was the already described development of smallholder livestock enterprises that have income generation, rather than wealth, social status or food security as a cornerstone. The second has been the use of a participatory process in agricultural research, particularly in agricultural research targeting smallholders in developing countries. In fact, participatory action research (PAR) has become commonplace and almost a prerequisite of research programs. Appropriately applied PAR is, by definition, inclusive of the farming community and enables all research partners to be part of the process of developing project aims. Farmers can then see first hand the impact of various experimental treatments on the production of *their own* crops and livestock.

Despite the increase in income-generating livestock enterprises and the use of PAR, investment in forage technology would not be appropriate for all smallholder livestock farmers. To adopt forage technology, it might be expected that farmers would meet at least the majority of the following criteria:

- They would already have a relatively stable food source. Farmers who struggle to support their families' needs for rice or maize or other staple food would almost certainly see investment in forage as a high-risk strategy. If these subsistence farmers had available capital for on-farm investment, it would most likely be targeted at improving food production through the purchase of fertiliser, labour for weeding etc.
- They would already have expertise in livestock production and would be in the position to recognise the potential benefits of increased animal production.
- They would have capital available for the investment.
- They would have land available for growing the forage and could envisage a management system that could fit the forages into a cropping cycle. Farmers who perceive that they already have insufficient land for crop production would not be in a position to consider using valuable land for new forages, unless totally new scenarios of land use became available.
- They would already have available to them an established or emerging market system for livestock products.

Forage Research for Smallholders — Where to from Here?

Identifying new well-adapted forages?

Farmers can produce higher quality forage through the use of improved grass species, such as napier grass, in conjunction with fertiliser or manure use, or provide high-quality forage through the incorporation of legumes into animal diets. Both strategies have a role and are being used in a range of environments throughout the tropics.

For instance, in Kenya, rapid advancement in the dairy industry has been largely based on the use of napier grass (*Pennisetum purpureum*) or other *Pennisetum* spp. Throughout Asia and the Americas, *Pennisetum* hybrids also form a major component of improved forages, but several other species such as *Paspalum atratum, Panicum maximum* and *Brachiaria* spp. are also used in various farming systems in the tropics (Horne and Stür 1999).

Legumes to supplement crop residues and grasses are also being adopted much more widely; again, a range of species is already being used. In West Africa, *Stylosanthes scabra* has been adopted as a supplementary feed and *S. guianensis* is being used widely in Southeast Asia. In sub-Saharan Africa, velvet bean (*Mucuna pruriens*) and lablab (*Lablab purpureus*) are being used, while in the Americas, *Arachis pintoi* and *Desmodium ovalifolium* have been adopted by smallholder farmers. Horne and Stür (1999) list a range of other legume species that are being used or have potential as forage in smallholder systems in Southeast Asia.

In general, the large number of well-adapted species identified over many years of research and the range of planted forages being used in some way in diverse environments suggest that finding new forage species and cultivars is not a priority research activity, at least for now.

If the knowledge base for forage adoption can be considered at least adequate, what approaches might the research community take to enhance adoption?

Forage research — approaches to encourage adoption

Low adoption rates over the past 40 years indicate that many farmers do not see investment in forages as a priority. If farmers are to take advantage of forage technology to meet livestock market demands, new approaches need to be applied to targeting, designing and conducting research, and providing outcomes to farmers. These approaches include: better identification of those farmers for whom forage planting is a sustainable practice to enhance livestock production and farm income; and better delivery of information on which judgments on planted forages and changes in practice can be made. Two contrasting research projects, which address these approaches in southern Africa and Indonesia, are outlined below.

Forage Research Using Teams, Participatory Research and a Systems Approach: an Example from Southern Africa

This model of research has been widely used over the past 10 years (e.g. Horne and Stür 1997; Thorpe 1999) and so cannot be considered novel. Its key elements are its truly participatory approach and the use of a team of scientists and extension specialists who can evaluate the role, management, and biological and economic benefits and costs of new planted forages within the whole farm enterprise.

In 1999, a project was initiated to develop forage technology for mixed cropping– livestock systems in southern Africa. Aims of the project, funded by the Australian Centre for International Agricultural Research (ACIAR), included:

- the identification of well-adapted legumes for use in rotations with cropping
- the development of strategies for feeding legumes to supplement maize stover and other low-quality forage
- the development of strategies to make the best use of soil nitrogen accumulated during the forage legume phase of the rotation.

Although the project operates in the Limpopo Province of South Africa and near Wedza in Zimbabwe, only the results from Zimbabwe will be discussed here. Farmers have been partners in most aspects of the research program, all of which is taking place on-farm. Most importantly, the project team restricted its research program to groups of farmers who were perceived to have the capacity to change. Communities that might participate in the project were selected according to a number of criteria, the most important of which were:

- Farmers were already producing livestock or milk for marketing.
- It was believed that some members of the community had sufficient capital to consider including inputs in their farming systems.
- At least some farmers had sufficient land to enable them to fallow an area of cropping land each year.
- The community had access to experienced extension officers who understood their farming practices.

Two communities in close proximity to each other are participating in the project. The Zana II community is a ‘resettlement’ community and has been farming its land, over which the community has tenure, for more than 20 years. The Dendenyore community is on communal land, with none of the farmers having tenure over the land.

Experienced local extension officers who had a detailed knowledge of the local community undertook initial benchmarking of these communities at the beginning of the project. The aim of the benchmarking was to determine farming practices, production levels, and the consumption and/or sale of agricultural outputs. Several groups of farmers (about five farmers per group) were interviewed in each of the communities. Farmers on the communal area of Dendenyore produced maize and some other crops but also produced beef cattle for market. In contrast, farmers from Zana II produced a greater array of crops, were investing in cash crops (such as paprika) and were involved in livestock production that focused on milk production.

The farmers perceived their communities to consist of three distinct groups based on wealth. They were able to describe in detail how they saw measures of wealth, based on capital and farming equipment. For instance, farmers in ‘wealth group 1’ had cultivators, harrows and carts, while the poorest households (wealth group 3) had no farming implements. Crop yields varied across wealth groups. Most of the wealthy farmers had up to 1.2 ha of fallow land per year (see Tables 1 and 2). In Zana II, the number of cows per farmer ranged from two to four, while milk yields ranged from 3 L to 6 L/day. Off-farm labour was used in the resettlement community of Zana II but not in Dendenyore. In Dendenyore, there

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was a vast range in the age of finished bullocks (3–10 years) and sale price (Zim$2000–8000/animal).

The benchmarking provided a detailed overview of wealth and farming practice and the relationships between these two factors. It enabled the identification of smallholder farmers in each community who might be best situated to adopt new practices because of their greater wealth and access to inputs. It also provided baseline criteria, such as level of animal production, cropped area and grain yields. These baseline data are essential to assessment of project impact in terms of productivity changes; impact assessment will be made at the project's completion in 2003.

After three years of project implementation, research indicates that velvet bean and lablab are amongst the best-adapted legumes for use in rotation with maize on the acid, light-textured cropping soils; that there are large benefits to subsequent maize crops when legumes have been included in a rotation; and that both beef and milk production are increased by including legumes in feeds. While none of these results is new, importantly, they have been obtained on-farm, with farmers participating in most aspects of the work. Farmer response to these research results is promising. Farmers who have been part of the project since the beginning, and their neighbours, are sowing lablab or velvet bean in their fallow land at their own expense and initiative, i.e. in addition to planting as part of the research program (see Table 3). They are investing considerable labour into making and storing hay from these legumes in early autumn, and are feeding it to lactating cows and penned beef animals during the dry season. Supplementing maize stover with lablab hay has significantly increased milk yields (measured by the farmers) from 4–6 to 6–17 L/day. Similar improvements in liveweight gains have been recorded when

Table 1. Resources, crop yields and number of animals for each of three wealth groups within the Dendenyore communal farming community (*n* = 49 households).

Resource or crop	Wealth group 1 (wealthiest)	Wealth group 2	Wealth group 3 (poorest)
Bank account	>Zim$5000[a]	Zim$1–4000	<Zim$3000
Arable land	3–5 ha	2–4 ha	<2 ha
Maize yields	2.0 t/ha	1.5 t/ha	0.8 t/ha
Sweet potato yields	15 t/ha	2 t/ha	1 t/ha
Groundnuts	75 bags/ha	50 bags/ha	12 bags/ha
Oxen	4	2	Nil
Cattle	>10	5–9	<5

[a] US$1.00 = Zim$60, May 2001

Table 2. Resources, crop yields and number of animals for each of three wealth groups within the Zana II resettlement farming community (*n* = 75 households).

Resource or crop	Wealth group 1 (wealthiest)	Wealth group 2	Wealth group 3 (poorest)
Bank account	Zim$10,000–100,000[a]	Zim$1000–9000	<Zim$1000
Maize yields	3 t/ha	2 t/ha	2 t/ha
Tobacco	2 t/ha	1.5 t/ha	Nil
Paprika	2 t/ha	1.25 t/ha	1.0 t/ha
Farm labour	Up to 3 employed	Occasional	Nil
Oxen	>4	2	Nil
Dairy cows	>3	2	2

[a] US$1.00 = Zim$60, May 2001

low-quality forage has been supplemented with lablab hay. Changes in farmer practices, not directly associated with the forage research results per se, have also occurred because of farmers' perceptions of what can be achieved through better practice (see Table 4). These changes in practice are possibly more important than the research results themselves, because farmers are demonstrating that they are willing to make significant investment to achieve change and improve production.

We consider that several factors have been important in achieving the enthusiastic partnership with the farmers in this project and achieving change in practice. These include the use of a participatory approach, the success of well-adapted forages, and a focus on the more wealthy farmers who were exposed to existing dairy and beef marketing practices. Primarily, it is these farmers who have increased the areas sown to legumes outlined in Table 3. However, the teamwork of researchers and extension specialists has been equally important. The team of researchers with expertise in plant adaptation, soil nutrition, crop agronomy and livestock nutrition has enabled a range of issues to be addressed. The role of the extension specialists in the project has enabled researchers to better identify farmers' needs and priorities. Most importantly, the researchers and extension specialists have worked

Table 3. Changes in the number of farmers using lablab, velvet bean or bana grass and making legume hay for dairy or beef production in Zana II and Dendenyore communities in Zimbabwe since the beginning of the project in 1999.

Forage/practice	Zana II community			Dendenyore community		
	1998–99	1999–00	2000–01	1998–99	1999–00	2000–01
Lablab	Nil	4	11	Nil	4	13
Velvet bean	2	6	13	3	5	31
Bana/napier grass	0	8	12	2	2	38
Hay making	2	5	8	3	4	13

Table 4. Descriptive changes in practice as indicators of adoption of legume technology in the Zana II and Dendenyore farming communities in Zimbabwe.

Change in practice from 1999 to 2001	Comments
Thirty-eight farmers in the community now hold 'dairy production' certificates	The demand for dairy certificates has been farmer-driven and was not envisaged in the initial project design.
Three farmers from within the project have attended 'train the trainers' courses	This development has been encouraged both by the farmers and by the extension specialists
Fourteen fact sheets have been produced in relation to legumes in the cropping system; four of these have been produced by farmers in partnership with AGRITEX	Some key farmers are recognising their own expertise in certain areas of legume production and use, and have willingly provided key information for these fact sheets.
Some farmers are purchasing additional dairy animals as production increases	This is a strong indication of adoption: buying these animals requires substantial investment.
Farmers are replacing high-cost dairy concentrates with legume hay	Initially, the project aimed to improve production of dairy and beef animals by supplementing animals that produced milk primarily from veld grazing. However, more affluent dairy producers have taken the opportunity to reduce costs by replacing concentrates with legume hay while maintaining or increasing milk production.
Farmers in adjacent communities are adopting forage options without the project having any on-farm study in those communities	This is another strong indicator of adoption: the on-farm results are being communicated by farmers themselves.

with farmers to transform research results into on-farm practice.

At this early stage, there is still some doubt as to whether this initial adoption will be sustained, but evidence of new practice and farmer investment suggests that some of the changes will be.

Evaluation of Forage Value in Farming Systems Before On-farm Research: a Project in Sulawesi, Indonesia

The previously outlined decline in cattle numbers in Sulawesi will inevitably mean that this region will be unable to maintain its role as an exporter of cattle. This outcome will impact on the agricultural and overall economy in a region that is already one of the poorest of the 26 provinces of Indonesia. Based on cattle prices of about 3–4 million rupiah (Rp) per animal (US$1.00 = Rp11,200 at June 2001), the export industry has a gross worth of about US$75 million. For individual farmers, cattle sales are extremely important because they provide a means of obtaining a significant cash income in addition to income from crop production, which is often limited to subsistence production levels.

Previous research has provided considerable understanding of the complexities of forage and livestock production in rice-based farming systems in Southeast Asia (Perkins et al. 1986; Ranjhan 1986), particularly in Sulawesi (Rachmat et al. 1992). However, there has been no quantitative evaluation of the economic costs, benefits and risks of using improved forages to increase livestock production.

In this project, a farming systems analysis approach is being adopted to evaluate the potential impact of improved forages on production of cattle. A simulation modelling approach is being used to provide estimates of forage production, its impact on livestock production, and the possible biophysical interactions between livestock and crop production. Finally, a whole-of-farm economic analysis will be used to evaluate the economic benefits and risks of forage adoption. This combination of simulation and economic analysis provides information to the farmer on the possible on-farm consequences of forage adoption and also provides researchers and funding agencies with evidence on which to base decisions about research investment.

The project focuses on smallholder farmers operating mixed farming systems of: (a) rice, maize, groundnut and cattle; and (b) estate crops, rice and cattle. To date, farmers in these systems rely almost exclusively on cut-and-carry forage, and communal grazing of naturally occurring vegetation and crop residues, as feed for their animals. This is largely because of intensive cropping in the farming systems and limited opportunity for spatial and temporal placement of improved forages within the systems.

Nevertheless, there are various possible opportunities for placement of forages into these farming systems, including placement of forages in communally grazed areas, placement in estate cropping systems, use of herbaceous forages with field cropping (such as relay cropping), and even the placement of forages on bunds. Improving forages in communally grazed areas is notoriously difficult because of the absence of grazing or harvesting management; moreover, sowing forages on bunds in rice paddies offers little potential to provide substantial amounts of forage. The best opportunities for substantially increasing forage production are likely to be the use of herbaceous legumes and grasses in relay cropping (especially in those areas where only one or two crops of rice, peanuts, maize or soybean are grown annually) or in estate crops (especially newly established orchards). The project is concentrating on these two options.

The key questions being addressed are:

- What benefits, if any, to animal production and whole-farm income might be realised from the adoption of high-quality forages?
- What are the related costs of and constraints on that adoption?
- Is the use of planted forages ever a viable economic option, and, if so, when and where in the cropping systems might they be produced?
- If planted forages are a viable option, do farmers find the provision of information relating to adoption, in terms of potential economic costs and benefits, useful in decision making?

Providing answers to these questions should move the research and development of tropical forages in smallholder farming systems forward. The topic needs to progress from species evaluations and the description of farming systems, to a consideration of the broader issue of technology adoption by smallholders. In particular, it needs to concentrate on the potential use and impact of high-quality forages on livestock production and whole-farm income in rainfed cropping systems.

Conclusions

Despite almost 50 years of investment in forage research in the tropics, forage adoption has been relatively poor across all tropical farming systems, yet there is overwhelming evidence that planted forages can make a substantial impact on livestock production. When considered together, these two facts suggest serious flaws in the research community's understanding of smallholder farming systems and of how farmers perceive forages. The lack of adoption of well-adapted plants also demands that researchers and extension specialists themselves adopt a new paradigm — one that 'recognises' the socioeconomic factors affecting adoption and is also dominated by socioeconomic considerations. Forages are not a commodity in themselves but a means to providing livestock products. As such, they are not usually high on a farmer's list of priorities. It is now time for forage researchers to place more emphasis on providing evidence to farmers of the economic benefits and costs of forages.

As most livestock in the tropics are in mixed crop–livestock systems, research and development providers must prioritise these systems. Of course, this is not a new approach, and undoubtedly most forage research being conducted today is aimed at these farming systems. It is in these systems that forages have the potential to play a large role in supplementing the crop residues that in many cases form the bulk of feed resources. The major question is how much, if any, resources should be aimed at open grazing/communal land situations where, in the developing world at least, there is rarely any control over grazing. In such circumstances, any judicious farmer would be unwilling to invest resources, as the return on that investment would be shared with others. In these situations, until grazing can be controlled, further research and development on new forage plants or other management practices cannot be justified. Instead, investment to demonstrate to decision makers the benefits of implementing change, especially in grazing control, within the socioeconomic constraints of the community would be a potentially better use of research and development resources.

Given past difficulties in achieving adoption, research and development providers may need to relinquish their often-desired aim of introducing forage development amongst the most resource-poor farmers. These farmers, by definition, are the most sensitive to risk and are most unlikely to adopt new forage technologies. In most smallholder systems, these poorest farmers have little or no land in addition to their cropping land; they do not have land on which to grow forages and seldom have the cash reserves necessary for new initiatives. Instead, more receptive targets for adoption might be farmers who have access to resources for investment and who are more able to take risks.

The forage research environment has changed considerably over the past decade. Research funding for forage genetic resources, species evaluation and forage management has decreased greatly. At the same time, new forage research and development programs that consider socioeconomic factors are becoming more prevalent, as evidenced by several papers in these proceedings. An even more recent research theme has been the use of simulation modelling of forage and animal production. The judicious combination of research on socioeconomic factors, simulation modelling and economic analysis appears to offer the best hope for helping farmers to develop farming practices that enable them to take advantage of the rapid increase in consumption of livestock products, and of improved market conditions.

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Selecting Potential Fodder Bank Legumes in Semi-arid Northern South Africa

G. Rootman,* M. Mabistela† and B. Pengelly§

Abstract

Two experiments were conducted in Limpopo Province, northern South Africa, to determine the suitability of 54 tropical forage legume accessions for use in fodder banks. In a small-plot evaluation trial, accessions of *Stylosanthes scabra*, *Macroptilium bracteatum*, *M. atropurpureum* and *Desmanthus pubescens* persisted for three years and there was seedling recruitment in the annual legume *Chamaecrista rotundifolia*. In a second experiment, *S. scabra* cv. Seca was managed as a fodder bank to determine its yield and persistence in this semi-arid environment. Overall establishment was poor, but total dry-matter yield ranged from 1 to 1.5 t/ha, even in a very dry year. In contrast to the performance of cv. Seca in Australia, there was almost no seedling recruitment during the three-year experiment.

The species listed above may provide options for fodder banks in this region, although the combination of a semi-arid, unreliable climate, sandy soils, and continuous grazing by indigenous game is likely ensure that fodder bank technology is a relatively unreliable source of animal feed in this environment.

The Limpopo Province of northern South Africa has a semi-arid tropical climate, with 70% of the province receiving rainfall of less than 600 mm per year. Agriculture is the biggest provider of livelihoods, with large-scale commercial farming of cattle, maize and horticultural crops as well as smallholder farming of beef cattle and maize being important. In addition to large-scale commercial and smallholder farmers, recent provincial government programs to redistribute land have resulted in a growing number of medium-scale animal producers (emerging farmers) who grow beef cattle for market, primarily feedlot markets, rather than for home consumption. There are also a small number of dairy producers.

At all scales of enterprise, animal production is dependent on native forages and is severely constrained by low forage quality for much of the dry season (March to November). The integration of well-adapted legumes into animal production systems has improved forage quality in other tropical countries. In Australia, augmentation of native pastures with legumes such as stylos (*Stylosanthes hamata* and *S. scabra*) has been widely adopted by beef producers and has resulted in annual liveweight gains increasing by about 50% (Coates et al. 1997). Forage legumes such as *S. scabra* have also been successfully used as standing feed that can be strategically fed during the dry season. In West Africa, about 27 000 farmers have adopted stylo fodder banks for use in the dry season (Elbasha et al. 1999). The integration of forage legumes into livestock production systems in Limpopo has the potential to play a similarly pivotal role in reducing the impact of low forage quality on animal production.

The aim of the study described here was to identify forage legumes that could be used to provide high-

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* Towoomba ADC Private Bag X1615, Bela-Bela, Republic of South Africa.

† Department of Agriculture & Environment, Private Bag X9487, Polokwane 0700, Republic of South Africa.

§ CSIRO Sustainable Ecosystems, 306 Carmody Road, St Lucia, Queensland 4067, Australia.

quality forage in fodder banks grown on cultivated land adjacent to the natural pastures or veld. This fodder bank option for providing legume-based feed was seen as preferable to augmentation of native pastures in Limpopo Province because of the low rainfall of the region, and because it is much simpler to operate and is better suited to smallholder systems, partly because farmers have greater control of the use of the legume feed as a supplement throughout the year.

A second trial was sown to determine the potential yield and persistence of *S. scabra* cv. Seca when sown for a fodder bank in the Limpopo Province environment. This cultivar was selected on the basis of its performance in Australia in semi-arid environments; it was deemed the most likely to persist and produce significant yield.

Materials and Methods

Project site

An existing cooperative dairy scheme was selected as the experimental site. The Batlokwa dairy scheme at Tarentaaldraai was founded during the early 1980s and continues to produce milk for sale in nearby communities. Tarentaaldraai is in the northwest of Limpopo Province in the Matoks area (23°27'S 29°37'E), halfway between Polokwane (Pietersburg) and Machedo (Louis Trichardt), and is on the Tropic of Capricorn at an elevation of 1048 m. The native vegetation is locally described as arid sweet bushveld. Rainfall is about 500 mm per year; although accurate long-term data for the site are not available, long-term records from the nearby Mara Research Station are in Table 1. Soils are light-textured loamy sands (>1 m depth), neutral in reaction in the A horizon (0–10 cm) and have low phosphorus levels below 10 cm depth. The basic cations Ca, Mg and K are in the adequate range (Table 2).

Legume adaptation

Fifty-four legumes accessions (Table 3) were chosen for inclusion in this evaluation study based on their history of adaptation elsewhere in dry or semi-arid tropical and subtropical environments. Inoculated seed of all legumes was sown into a prepared seedbed to which 22 kg/ha P was applied as single superphosphate on 3 March 1999. Seeds were covered with soil using a rake. Each plot consisted of a single 4 m row with 1 m between rows. Sowing density depended on seed size with the aim being to obtain at least 20 plants per metre of row. Yield ratings were taken one month after establishment, and legume presence and absence was recorded each year for three years.

Stylosanthes fodder bank

Seca stylo seed was sown into a cultivated seedbed on 28 February 2000 at a rate of 4 kg/ha. Two sowing

Table 1. Mean (1960–1999) maximum and minimum temperature (°C) and mean (1936–1999) monthly rainfall (mm) for Mara Research Station (23°9'S 29°34'E, elevation 894 m), situated 40 km north of Tarentaaldraai.

Month	Maximum temperature (°C)	Minimum temperature (°C)	Rainfall (mm)
January	30.4	18.0	79.7
February	29.6	17.7	57.9
March	28.7	16.2	54.6
April	26.8	12.9	35.0
May	24.9	8.1	12.5
June	22.4	4.6	5.0
July	22.6	4.6	3.1
August	24.6	7.1	2.1
September	27.3	10.9	13.6
October	28.2	14.1	32.8
November	28.2	16.1	65.8
December	29.6	17.3	80.6
Mean temp/total rainfall	26.9	12.3	442.7

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treatments were used: seed was broadcast and either pressed or not pressed into the soil with a tractor wheel. Each treatment was replicated twice. The site was on the same soil type described in Table 2 and had a slight slope.

Table 2. Soil chemical properties at Tarentaaldraai.

Property	Soil depth (cm)	
	0–10	10–50
pH (H_2O) [a]	7.6	5.5
Phosphorus (mg/kg) [b]	22	10
Calcium (cmol(+)/kg) [c]	6.65	2.38
Magnesium (cmol(+)/kg) [c]	1.98	1.10
Potassium (cmol(+)/kg) [c]	0.97	0.56
Exchangeable acidity (me%)	0.09	0.06
Clay (%)[d]	14	18

[a] 1:5 soil:water
[b] 1:7.5 extractant Bray 2
[c] 1:10 extractant ammonium acetate 1N, pH7
[d] Near infrared determination

Plant density was recorded after establishment, after the first rainfall of the second summer, and again at the end of the third summer, using fifty 0.25 m × 0.25 m quadrats per replicate. Because of poor and uneven plant establishment and survival, biomass was only recorded in the higher density sections of the experiment in the second and third year, from cuts taken from about 20 quadrats.

Results and Discussion

Rainfall in March 2000 (approximately 150 mm) and following overcast conditions resulted in good emergence in both trials. Total rainfall in year 1 (1999–2000) and year 2 (2000–2001) was at or near the mean annual rainfall. However, in the third year of the trial there was a severe drought, with almost no rainfall recorded from December 2001 to late April 2002.

Legume adaptation

Most of the 54 legumes established well. The late sowing time and grazing by indigenous game meant that no species were high yielding, but one accession of *A. americana* (CPI 93624) and a number of *Vigna* and *Macroptilium* accessions had the highest yields (Table 3). Almost all legumes were heavily frosted in June 2000, with only *Lotononis bainesii* cv. Miles being unaffected, while *Desmanthus leptophyllus* cv. Bayamo and TQ 90 and *D. pubescens* cv. Uman made some growth during the dry season. Most accessions failed to persist into the second season; those that persisted and regrew in November 2000 are noted in Table 3. By March 2001, at the end of the second summer, only seven accessions (*Stylosanthes scabra*, *Macroptilium bracteatum*, *M. atropurpureum* and *Desmanthus pubescens*) had persisted under heavy grazing by indigenous game (Table 3), although seedlings of *Chamaecrista rotundifolia* had germinated and established. Most of these seven legumes survived the extremely dry summer of 2001–02, but production was minimal.

While the persistence of Seca stylo was expected, the persistence of *Desmanthus pubescens* cv. Uman on the light-textured soils suggests that this species might also have a role in this environment. Similarly, the production and persistence of the *Macroptilium* accessions suggest that *M. atropurpureum* and *M. bracteatum* might be considered as legumes for short-term pastures or fodder banks. *Macroptilium* accessions might have the advantage over some of the productive annual *Vigna* accessions, as they have the ability to persist for at least two years.

Seca fodder bank

Heavy rainfall soon after sowing resulted in considerable surface wash, loss of seed and uneven establishment. Establishment at the bottom of the slope was poorer than at the top. Nevertheless, there was a significant difference in plant density between pressed (32 plants/m^2) and unpressed (9 plants/m^2) treatments (Table 4). This may have been because of better contact between soil and seed, or because water concentrated at the bottom of the tractor wheel track, providing better soil moisture conditions for germination and establishment. While the differences in plant density between treatments remained through to years 2 and 3, those differences were not significant.

Only 22% and 16% of established seedlings in the rolled and unrolled treatments, respectively, survived into the second summer of the trial, but most of those that did were still present towards the end of the third summer (February 2002; Table 4). Although there was some seedling establishment at the beginning of the second summer (November 2000), this was probably from seed that had failed to germinate at sowing rather than from new seed set in the first year. No seedlings were observed after November 2000, but plants flowered and there was some seed set during the trial. In a number of observations, that seed was not well filled.

Table 3. Legume accessions sown in an adaptation trial at Tarentaaldraai in March 2000; ticks indicate the highest yielding accessions in year 1, and those persisting into the second summer and at the end of the third summer of the trial.

Species	Accession	No. plants established March 2000	High yield accessions Apr–May 2000	Regrowth or seedlings Nov 2000	Persistence Apr 2002
Aeschynomene americana	CPI 56282	Intermediate			
	CPI 93624	Intermediate	✔		
	cv Lee	Intermediate			
	cv Glenn	Intermediate			
Aeschynomene falcata	ATF 2194	Poor			
	ATF 2196	Poor			
	cv Bargoo	Poor			
Aeschynomene histrix	CPI 93599	Poor			
	CPI 93636	Poor			
	CPI 93638	Poor			
	ATF 2191	Poor			
	ATF 977	Very good			
Aeschynomene villosa	cv Reid	Very good			
	cv Kretschmer	Very good			
	TP 188	Very good			
Alysicarpus rugosus	CPI 30034	Very good			
	CPI 30187	Very good			
	CPI 51655	Very good			
	CPI 76978	Very good			
	CPI 94489	Very good			
Centrosema pascuorum	CPI 64950	Poor			
	cv Cavalcade	Poor			
	Q10050	Poor			
	CPI 55697	Very good			
Chamaecrista pilosa	CPI 57503	Very good			
Chamaecrista rotundifolia	CPI 93094	Very good		✔	✔
	cv Wynn	Very good		✔	✔
Clitoria ternatea	cv Milgarra	Intermediate			
Desmanthus pubescens	cv Uman	Poor		✔	✔
Desmanthus leptophyllus	cv Bayamo	Very good		✔	
	TQ 90	Very good		✔	
Lotononis bainesii	cv Miles	Very good		✔	
Macroptilium atropurpureum	cv Aztec	Very good	✔	✔	✔
Macroptilium bracteatum	CPI 27404	Very good	✔	✔	✔
	CPI 55769	Very good	✔	✔	✔
	CPI 68892	Very good	✔	✔	
Macroptilium gracile	CPI 84999	Very good		✔	
	CPI 93084	Very good		✔	
	cv Maldonado	Very good			

Table 3. (cont'd) Legume accessions sown in an adaptation trial at Tarentaaldraai in March 2000; ticks indicate the highest yielding accessions in year 1, and those persisting into the second summer and at the end of the third summer of the trial.

Species	Accession	No. plants established March 2000	High yield accessions Apr–May 2000	Regrowth or seedlings Nov 2000	Persistence Apr 2002
Macrotyloma daltonii	CPI 60303	Very good			
Stylosanthes guianensis	cv Oxley	Poor			
Stylosanthes hamata	cv Amiga cv Verano	Intermediate Intermediate			
Stylosanthes mexicana	CPI 87484 CPI 87847	Intermediate Intermediate			
Stylosanthes scabra	cv Seca	Intermediate		✓	✓
Vigna lasiocarpa	CPI 34436	Very good	✓	✓	
Vigna luteola	cv Dalrymple	Very good	✓	✓	
Vigna oblongifolia	Q 25362	Very good	✓	✓	
Vigna unguiculata var. *dekindtiana*	CPI 121688	Intermediate			

Because of the uneven density throughout the trial, dry matter yield was measured from only the highest density areas to give an estimate of 'potential' yield. The potential yield was 1.5 t/ha in March 2001, 0.8 t/ha in November 2001, 0.9 t/ha in December 2001 and 1.0 t/ha in January 2002.

Despite the uneven establishment and very dry environment, especially in the summer of 2001–2, this trial demonstrated that Seca stylo can establish, persist and produce at least 1–2 t/ha/annum of legume biomass in this environment, and that this can be expected to continue for at least three years. Although this suggests that Seca stylo may have a role in improving animal production as a fodder bank species, a major restriction could be the failure of Seca to produce significant amounts of seed and so allow for seedling recruitment to replace the original plants, which inevitably die. Perhaps, if fodder banks need to be resown every three or four years, higher yields may be necessary to make their use attractive. Failure to set seed might have several causes, such as frost (which can occur as early as May), drought and continuous grazing by game throughout the year (which seem unlikely, given the history of stylo in Australia), or disease (there was no sign of anthracnose in the experiment).

Conclusions

Macroptilium atropurpureum and *M. bracteatum* may have potential as fodder bank species in this region, although both species would probably need to be resown every two to three years. Although *S. scabra* persisted for three years, the failure to set seed, at least in this experiment, suggests that it has little advantage as a fodder bank species over the *Macroptilium* species, especially as its feed quality can be less than that of most other legumes (Jones et al. 2000). *Chamaecrista rotundifolia* seeded, and there was recruitment of new plants in the legume

Table 4. Seedling and plant density (/m^2) of *Stylosanthes scabra* cv. Seca in the rolled and unrolled treatments at Tarentaaldraai.

Planting method	Seedlings 25/3/00	Plants 28/11/00	Seedlings 28/11/00	Plants 15/2/02
Rolled	32.5 (15.5) [a]	7.0 (4)	3.5 (2.5)	5.5 (3.5)
Unrolled	9.0 (5)	1.5 (0.5)	1.0 (0)	2.5 (1.5)

[a] Standard error of the mean in parentheses

adaptation trial. While reliable regeneration from seed might negate the need to re-establish fodder banks every two to three years, *C. rotundifolia* has poor leaf retention (Jones et al. 2000), which might make it one of the least desirable legumes for a fodder bank.

Whichever species might be considered, however, continuous grazing by small indigenous game in the region is a major constraint on using fodder banks, and it will be necessary to use effective fencing to make the most of fodder bank technology. The annual occurrence of frost, often as early as May, suggests that farmers would need to cut and conserve forage at the end of April to gain the most benefit from the technology.

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Assessment of the Variation in Growth and Yield of Diverse Lablab (*Lablab purpureus*) Germplasm in Limpopo Province, South Africa

K.K. Ayisi,* M.P. Bopape* and B.C. Pengelly†

Abstract

Lablab (*Lablab purpureus*) is a dual-purpose legume with the potential to be incorporated into the smallholder maize monoculture system which predominates in the Limpopo Province of South Africa. Thirty-three introduced accessions and three local plant types were evaluated in a farmer's field near Polokwane during the 2002/03 growing season for agronomic characteristics, biomass production and grain yield. Days to 50% flowering ranged from 51 to over 150 days and days to maturity ranged from 90 to 197 days among the entries. Approximately 50% of the accessions produced between 1000 and 5000 kg/ha of total biomass at 87 days after planting (DAP), with two of the entries producing over 7000 kg/ha. The maximum grain yield obtained was between 500 and 600 kg/ha, produced by about 14% of the accessions. Generally, the early flowering and maturing types produced the highest grain yields. This diversity in growth characteristics suggests potential for lablab to be a multi-purpose crop for use in the smallholder systems of South Africa. Further on-farm evaluation in partnership with farmers is suggested as the next step in testing promising accessions of lablab.

Lablab (*Lablab purpureus*) is a legume that is presently grown in certain parts of Africa, namely, Cameroon, Sudan, Ethiopia, Uganda, Kenya, Tanzania, Swaziland and Zimbabwe, primarily as a food crop, with both the grain and the immature pods being consumed (Smartt 1985). Lablab is poorly known in South Africa but initial trials indicate that it can be successfully grown in the Limpopo Province, which is in the northern part of the country. Lablab is useful as a forage crop, a cover crop that can produce nitrogen through biological nitrogen fixation, improve soil nitrogen status, and suppress weeds (Schaafhausen 1963; Humphreys 1995). Recognised for its drought hardiness (Hendricksen and Minson 1985; Cameron 1988), lablab has the potential to be grown in semi-arid parts of the Limpopo Province where the mean annual rainfall is commonly < 650 mm. Following an initial study with smallholder farmers in rural communities, it was discovered that the fresh or dried lablab leaves could be cooked and consumed as leafy vegetables and as well as being used as a grain legume. Stimulating the interest in lablab as an alternative crop in these predominantly smallholder farming systems requires evaluation and an active promotion of the crop within the province. Currently, the only commercial lablab cultivar in the country is Rongai, which is a long-duration forage type (>150 days to maturity). There is an important need to identify other lablab types for integration into the rural farming systems of the Limpopo Province.

The objective of this research was to assess biomass production, yield performance and agro-

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* School of Agricultural and Environmental Sciences, Plant Production, University of the North, Private Bag X1106, Sovenga 0727, Republic of South Africa.

† CSIRO Sustainable Ecosystems, 306 Carmody Road, St Lucia, Queensland 4067, Australia.

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nomic characteristics of diverse lablab germplasm in the Limpopo Province relative to locally sourced material.

Materials and Methods

A field experiment was established on 10 December 2002 on a clay loam soil (Bainsvlei Form according to the Soil Classification Working Group, 1991) on a farmer's field at Dalmada, near Polokwane in the Limpopo Province. The soil at that location was neutral pH and low in both phosphorus and potassium (Table 1). Further details of the soil can be found in Whitbread and Ayisi (2004).

Table 1. The pH and phosphorus and potassium levels at three depths prior to sowing of the lablab evaluation trial at Dalmada in December 2002.

Soil depth (cm)	0–15	15–30	30–60
pH	6.8	6.9	6.8
Nitrogen (mg/kg)	3	1	1
Phosphorus (mg/kg)	26	14	7
Potassium (cmol(+)/kg)	1.00	0.84	0.64

The experiment was established as a randomised complete block design with three replications. Each experimental unit was 3 m × 3.6 m, consisting of four rows of lablab with an inter-row spacing of 90 cm and 22.5 cm between plants. Thirty-three lablab accessions were selected from a collection of the species held at the Australian Tropical Forage Genetic Resources Centre, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Brisbane, Australia, on the basis of their relatively early flowering or appropriate grain types as noted in a recent characterisation of the germplasm collection (Pengelly and Maass 2001). These accessions were CPI 29399, CPI 29400, CPI 29803, CPI 34777, CPI 34780, CPI 35771, CPI 35893, CPI 35894, CPI 36019, CPI 36093, CPI 30701, CPI 52504A, CPI 52504B, CPI 52506B, CPI 52508, CPI 52513, CPI 52514, CPI 52518B, CPI 52530, CPI 52533, CPI 52535, CPI 52551, CPI 52552, CPI 52554, CPI 57314, CPI 57315, CPI 60795, CPI 81364, CQ 3620, CQ 3621, Q 5427, Q 6880B, and Q 6988. Three local forage types that are locally known as 'Rongai black', 'Rongai brown', and 'Rongai white' were assigned as controls in each block. All seeds were inoculated with an appropriate commercial *Bradyrhizobium* inoculant before planting. The seeds were sown by hand at a depth of 4–6 cm, then thinned 2 weeks after emergence to the desired spacing. Weeds were controlled by hand-hoeing. A total of 297 mm of rainfall was received at the site and 178 mm of irrigation was applied (Table 2).

Data collected were emergence, mid-season dry-matter production, days to flowering, physiological maturity, grain yield and its components. Emergence percentage was recorded 3 days after seedling emergence. Dry matter was collected from two plants in the middle rows of each plot, at 0.5 m, 87 days after planting (DAP) and dried in an oven at 65°C to constant moisture content. Dried samples were weighed to determine biomass production. Flowering was scored when 50% of plants on a plot had flowered and physiological maturity was recorded when 90% of the pods within an experimental unit were brown. At harvest, two 2 m lengths of the middle rows of each experimental plot were harvested for the determination of grain yield, number of pods/plant and seed weight/pod.

The data were analysed using the Statistical Analysis System (SAS). Analysis of variance was used to test significance of treatment effect, and differences due to varieties were compared using Duncan's multiple range test (DMRT) procedure.

Results and Discussion

Weather

The total rainfall received at Dalmada from December 2002 to July 2003 when plants were growing was 297 mm, of which about 91% fell in December, January and February (Table 2). The total amount of irrigation applied was 178 mm. Maximum temperatures remained above 28°C during the period from December to April. The minimum temperature remained above 12°C during this period but fell to 4.4°C in June (Figure 1).

Agronomic characteristics

Emergence

All accessions had in excess of 80% establishment which was sufficient for excellent plot cover and reflected the favourable soil and weather conditions at sowing.

Flowering

There were significant differences in days to flowering among the lines. The earliest flowering accessions were CPI 35894, CPI 52508 and CPI 52513, which

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flowered before 60 DAP. Accessions CPI 30701, Q 5427, CPI 34780, CPI 29400, CPI 52518B, and Rongai white, Rongai black and Rongai brown, were late flowering (Table 3). The majority of the lines flowered between 60 and 100 DAP (Figure 2). The three types of the local Rongai cultivar flowered later than 150 DAP as did CPI 34780, CPI 30701 and Q 5427.

Table 2. Total monthly rainfall and irrigation water applied (mm) between December 2002 and July 2003 at Dalmada.

Months	Rainfall	Irrigation	Total
December	108	8	116
January	110	69	179
February	51	32	83
March	–	25	25
April	–	–	–
May	–	10	10
June	28	22	50
July	–	12	12
Total	297	178	475

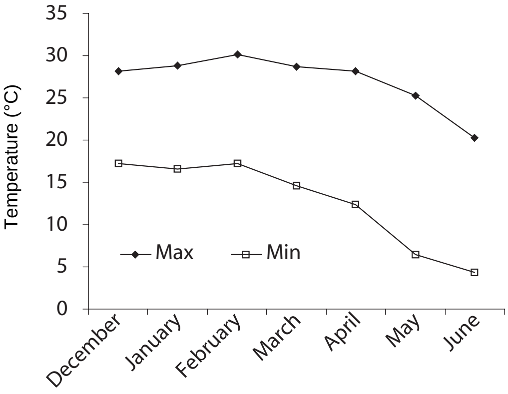

Figure 1. Minimum and maximum temperatures between December 2002 and July 2003 at Dalmada.

Physiological maturity

Days to physiological maturity ranged from 90 to 197 DAP. The accessions CPI 35771, CPI 35894, CPI 52504B, CPI 52508, CPI 52513, CPI 52533, CPI 52535, CPI 52552, CPI 60795 and CQ 3620 matured before 100 days and this constituted about 28% of the lines studied. The late-maturing genotypes were Rongai white, Rongai black and Rongai brown, CPI 34780, CPI 30701 and Q 5427 which all matured after 180 DAP. CPI 34780, CPI 30701 and Q 5427 are clearly long-duration types, comparable to the local cultivar, Rongai. Evaluation of maturity across the lablab entries indicated that the majority of the lines (72%) matured between 90 and 120 days, whilst 11.0% and 17% matured between 120 and 150 DAP and after 180 DAP, respectively (Figure 3).

Table 3. Flowering and physiological maturity (days after planting) of lablab accessions during the 2002/03 growing season at Dalmada.

Accession	Flowering	Maturity
CPI 29399	94.3 c	125.0 e
CPI 29400	101.7 b	138.3 b
CPI 29803	90.7 c	115.7 g
CPI 34777	81.7 d	121.3 e
CPI 34780	158.0 a	197.0 a
CPI 35771	63.3 g–k	90.3 r
CPI 35893	76.7 e	111.7 h
CPI 35894	59.7 k	99.7 o–q
CPI 36019	80.3 de	119.3 f
CPI 36903	83.0 d	111.0 h
CPI 30701	158.6 a	197.0 a
CPI 52504A	65.0 g–j	102.0 lm
CPI 52504B	65.7 g–i	99.7 o–q
CPI 52506B	76.0 e	107.0 j
CPI 52508	59.7 k	99.7 o–q
CPI 52513	51.7 l	99.0 q
CPI 52514	65.0 g–j	101.0 l–o
CPI 52518B	101.3 b	127.3 c
CPI 52530	66.7 fg	104.7 k
CPI 52533	61.7 h–k	99.3 pq
CPI 52535	64.7 g–j	99.7 o–q
CPI 52511	66.7 fg	101.7 l–n
CPI 52552	60.3 jk	99.3 pq
CPI 52554	67.0 fg	104.7 k
CPI 57314	61.3 i–k	101.3 l–n
CPI 57315	61.7 h–k	100.7 m–p
CPI 60795	60.7 jk	99.0 q
CPI 81364	60.7 jk	102.3 l
CQ 3620	63.0 g–k	99.0 q
CQ 3621	71.0 f	109.0 i
Q 5427	158.3 a	197.0 a
Q 6880B	64.7 g–j	101.7 l–n
Q 6988	66.3 gh	100.3 n–q
Rongai black	156.7 a	197.0 a
Rongai brown	157.7 a	197.0 a
Rongai white	158.7 a	197.0 a
Significance	**	**
CV (%)	2.9	0.6

Note: Numbers followed by the same letter or letters within a column are not significantly different from each other ($p < 0.01$); ** = highly significant, $p < 0.01$; CV = coefficient of variation.

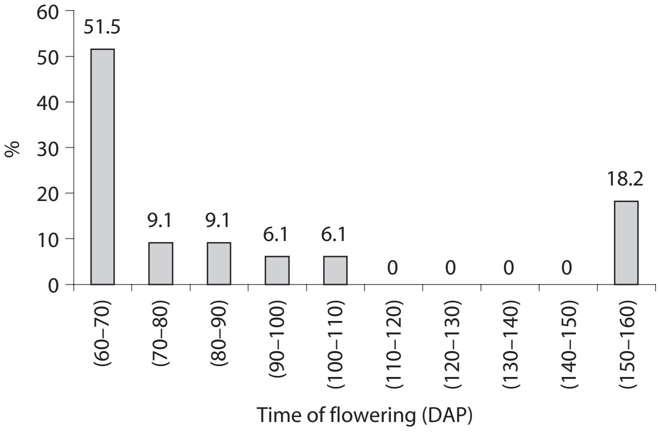

Figure 2. Frequency distribution of flowering in lablab accessions during the 2002/03 growing season at Dalmada.

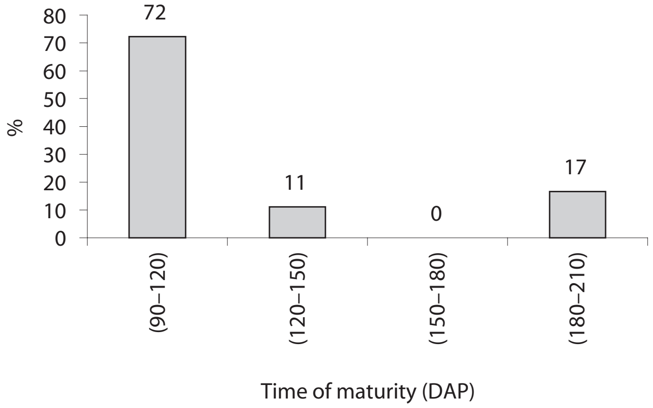

Figure 3. Frequency distribution of maturity in lablab accessions during the 2002/03 growing season at Dalmada.

Biomass accumulation

There were significant differences ($p < 0.01$) in total biomass accumulation of the plants as well as in the leaf, stem and root fractions at 87 DAP (Table 4). CPI 29399 produced more than 7000 kg/ha biomass, which was comparable to that of Rongai brown. The biomass yield of Rongai black, CPI 30701, CPI 52506B and CPI 81364 ranged form approximately 5000 to 7000 kg/ha. Forty-seven percent of accessions produced biomass between 1000 and 5000 kg/ha by 87 DAP. CPI 52513 accumulated the least total dry matter, which was less than 1000 kg/ha. Biomass production was generally related to flowering time. For instance CPI 29399 and Rongai brown were amongst the late-flowering, high-yielding types and CPI 52513 was the earliest to flower and had a low biomass yield.

Grain yield and yield components

There were significant differences ($p < 0.01$) in grain yield among the treatments studied. CPI 52514, CPI 52552, CPI 60795, CQ 3620 and Q 6880B produced yields of >500 kg/ha, whereas CPI 29399, CPI 29803, CPI 34780, CPI 35893, CPI 30701, CPI 52518B, Q 5427, Rongai black, Rongai brown and Rongai white produced grain yield of less than 50 kg/ha. The other lines were between the two yields (Table 5). The high-yielding lablabs were all early flowering. With the exception of CPI 60795, they also produced relatively lower total biomass indicating less investment in vegetative growth, and higher numbers of pods per plant and heavier seeds per pod (Table 5). The poor-yielding types generally flowered between 90 and about 100 DAP and matured late. The flowering date of the late types occurred in March, which exposed all reproductive stages of these lines to much lower minimum and maximum temperatures (Figure 1). This could have contributed to lower seed production in the late-maturing types.

Conclusions

There was considerable physiological variation amongst the lablab accessions studied here. The earliest-flowering types gave promising total grain

Table 4. Dry-matter production (kg/ha) at 87 days after planting of lablab accessions during the 2002/03 growing season at Dalmada.

Accession	Leaf	Stem	Root	Total
CPI 29399	3231 a	4440 a	325.9 a	7796 a
CPI 29400	1666 de	1229 i–o	155.8 h–k	3050 f–i
CPI 29803	499 mn	481 op	166.6 g–i	1146 op
CPI 34777	491 mn	584 n–p	233.7 c	1274 n–p
CPI 34780	835 g–j	3822 ab	226.3 c	4882 cd
CPI 35771	1349 f	1631 h–l	177.6 f–h	3158 f–h
CPI 35893	491 mn	864 k–p	229.8 c	1585 k–p
CPI 35894	640 i–m	1859 f–j	149.8 i–k	2583 g–k
CPI 36019	1013 g	1876 f–j	87.8 op	2977 f–i
CPI 36903	798 g–k	1315 h–m	118.5 k–m	1623 k–p
CPI 30701	2414 b	2563 d–f	277.9 b	5255 c
CPI 52504A	1345 f	2108 e–h	148.5 i–k	3601 e–g
CPI 52504B	517 i–n	747 m–p	71.5 pq	1335 m–p
CPI 52506B	2501 b	3937 ab	198.7 d–f	6637 b
CPI 52508	565 k–n	746 m–p	75.1 pq	1296 n–p
CPI 52513	339 n	271 p	174.5 f–i	784 p
CPI 52514	656 i–m	1201 i–o	92.2 op	1941 i–o
CPI 52518B	858 g–i	1394 h–n	93.9 n–p	2345 h–m
CPI 52530	699 h–m	1699 g–k	139.9 j–l	2538 g–l
CPI 52533	655 i–m	1003 k–p	161.2 h–j	1819 k–p
CPI 52535	765 g–l	1046 j–p	132.6 k–m	1939 i–o
CPI 52511	1597 e	2471 d–g	188.0 e–g	4257 c–e
CPI 52552	709 h–m	1116 i–o	95.5 n–p	1918 j–o
CPI 52554	1604 e	2657 c–f	171.5 g–i	4432 c–e
CPI 57314	866 g–l	1408 h–n	188.3 e–g	2462 h–m
CPI 57315	777 j–k	1524 h–m	74.1 pq	2608 g–k
CPI 60795	1647 de	3061 cd	210.2 c–e	4917 cd
CPI 81364	2144 c	2858 c–e	102.6 no	5045 c
CQ 3620	1855 d	2879 c–e	215.1 cd	3133 d–f
CQ 3621	942 gh	1488 h–m	111.4 m–o	2542 g–l
Q 5427	730 h–m	727 m–p	74.7 pq	1531 k–p
Q 6880B	588 j–m	771 m–p	70.30 pq	1429 l–p
Q 6988	730 h–m	802 i–p	49.3 q	1581 k–p
Rongai black	2075 c	2806 ce	227.4 c	5129 c
Rongai brown	3376 a	3393 bc	257.6 b	7117 ab
Rongai white	1548 ef	1916 f–i	130.8 k–m	3595 e–g
Significance	**	**	**	**
CV (%)	11.03	23.7	9.1	18.7

Note: Numbers followed by the same letter or letters within a column are not significantly different from each other ($p < 0.01$); ** = highly significant, $p < 0.01$; CV = coefficient of variation.

yields, sometimes in excess of 500 kg/ha in this very dry environment. The diversity in growth characteristics suggests potential for the crop in smallholder systems in South Africa, as a multi-purpose crop which might supply green pods as vegetables as well as grain, and where leaf and stem postharvest might offer improved forage to the small number of grazing animals in the farming systems. Further studies are required to confirm their adaptability and find suitable agronomic practices for cultivation. Equally important are further studies in partnership with farmers to assess lablab eating qualities.

Table 5. Grain yield and yield components of lablab accessions during the 2002/03 growing season at Dalmada.

Accession no.	Grain yield (kg/ha)	Number of pods/plant	Seed weight/pod (g)
CPI 29399	1.1 d	2.9 ef	0.3 fg
CPI 29400	79.1 a–d	8.8 c–f	1.6 b–g
CPI 29803	14.3 d	3.2 ef	0.6 d–g
CPI 34777	132.5 a–d	8.2 d–f	2.3 b–g
CPI 34780	5.0 d	1.4 f	0.3 fg
CPI 35771	106.6 a–d	12.5 b–f	2.9 b–d
CPI 35893	49.5 cd	2.3 ef	1.7 b–g
CPI 35894	187.2 a–d	8.1 d–f	2.5 b–f
CPI 36019	353.2 a–d	12.0 b–f	2.3 b–g
CPI 36903	92.3 a–d	5.1 d–f	2.3 b–g
CPI 30701	7.2 d	2.7 ef	0.3 fg
CPI 52504A	111.8 a–d	6.9 d–f	2.8 b–e
CPI 52504B	156.1 a–d	6.9 d–f	2.9 b–d
CPI 52506B	190.9 a–d	10.1 c–f	3.1 b
CPI 52508	412.2 a–d	13.4 b–f	2.7 b–e
CPI 52513	440.4 a–d	29.2 a	6.4 a
CPI 52514	518.7 a–c	24.9 ab	2.5 b–f
CPI 52518B	1.1 d	0.8 f	0.5 e–g
CPI 52530	185.3 a–d	6.8 d–f	2.1 b–g
CPI 52533	347.5 a–d	12.5 b–f	2.5 b–f
CPI 52535	359.5 a–d	8.9 c–f	1.8 b–g
CPI 52511	439.6 a–d	23.2 a–c	2.8 b–e
CPI 52552	576.2 a	18.6 a–d	3.0 bc
CPI 52554	382.2 a–d	15.1 b–f	2.6 b–f
CPI 57314	90.8 a–d	4.6 d–f	2.7 b–e
CPI 57315	112.7 a–d	9.1 c–f	2.6 b–f
CPI 60795	570.5 a–b	24.6 ab	3.2 b
CPI 81364	99.7 a–d	6.6 d–f	2.6 b–f
CQ 3620	574.2 ab	16.8 a–d	2.7 b–e
CQ 3621	53.0 cd	5.3 d–f	1.7 b–g
Q 5427	12.2 d	5.8 d–f	0.7 c–g
Q 6880B	531.9 a–c	12.9 b–f	3.5 b
Q 6988	71.2 b–d	8.1 d–f	2.3 b–g
Rongai black	2.6 d	14.6 b–f	0.1 g
Rongai brown	3.3 d	6.1 d–f	0.2 fg
Rongai white	7.4 d	7.0 d–f	0.2 g
CV (%)	125.1	73.1	56.5

Note: Numbers followed by the same letter or letters within a column are not significantly different from each other ($p < 0.01$); ** = highly significant, $p < 0.01$; CV = coefficient of variation.

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Evaluation of Herbaceous Forage Legumes Introduced into Communally Managed Rangelands in Zimbabwe

P.H. Mugabe,[1] D. Majee,[2] X. Poshiwa,[2] B. Chigariro,[3] B. Ndlovu,[1] F. Washayanyika[1] and N. Mukombe[3]

Abstract

Eighteen legume accessions were tested over three growing seasons on a previously controlled grazing site and a communal grazing management site. Within sites, there were two soil wetness blocks — namely, vlei and topland. Generally, the vleis produced better establishment in season 1. Most legume counts drastically declined in seasons 2 and 3 on all sites except for uncontrolled topland where some legume accessions increased significantly, including *Aeschynomene villosa* cv. Reid, *A. villosa* cv. Kretschmer, *Chamaecrista rotundifolia* cv. 93094 and *C. rotundifolia* cv. Wynn. Biomass production was very low for most legumes across all sites and the promising accessions were *C. rotundifolia* cv. 93094, *C. rotundifolia* cv. Wynn, *C. pilosa, A. villosa cv.* Reid and *A. villosa* cv. Kretschmer. While the results were not very encouraging, the *C. rotundifolia* accessions are worth pursuing on communal toplands, while the *A. villosa* accessions could be tried on the other sites.

The use of forage legumes for rangeland improvement in Zimbabwe has been researched for decades and has been shown to be an option for improving degraded rangelands. For instance, Clatworthy and Madakadze (1988) recommended *Desmodium uncinatum* cv. Silverleaf for reinforcing topland rangelands on heavy soils and *Macroptilium atropurpureum* cv. Siratro, *Stylosanthes guianensis* cv. Oxley and *Macrotyloma axillare* cv. Archer for sandy soils. Muchadeyi and Chakoma (1995) and Majee and Chikumba (1995) identified *Trifolium* spp., *Arachis pintoi* cv. Amarillo, *Chamaecrista rotundifolia* and *Aeshynomene americana*, among others, as potential legumes for use on sandy vlei sites.

Such research has been confined mainly to research stations and commercial farms with limited work on communally managed rangelands. The current research was done to evaluate the potential of a range of herbaceous tropical forage legumes for improving forage production on communally managed rangelands. Specific research objectives were to evaluate the establishment, persistence and biomass production of a range of herbaceous legumes on communal rangelands.

Materials and Methods

Site description

The study was carried out in Zana 2 Ward in Wedza district in the Mashonaland East Province of Zimbabwe, located 70 km west of Marondera. The

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[1] Animal Science, University of Zimbabwe, PO Box MP 167, Mount Pleasant, Harare, Zimbabwe.
[2] Grasslands Research Station, Agriculture Research and Extension Services (AREX), P. Bag 3701, Marondera, Zimbabwe.
[3] Agricultural Technical and Extension Services, PO Box 30 Wedza, Zimbabwe.

area receives 750–1000 mm of rainfall annually, and the soils are predominantly sandy. Monthly rainfall received in the years 1996/97 to 2001/02 is displayed in Figure 1.

Experimental design

Test legumes were sown in two sites: a fenced, 7 ha paddock, under controlled grazing by one bull (controlled); and an unfenced communally managed grazing area outside and adjacent to the 7 ha paddock (communal). Within each site, there were two soil wetness blocks — namely, topland (dry) and vlei (wetland). There was no replication of the soil wetness blocks within a site but the legume treatments were replicated three times per block. Eighteen legume accessions of *Aeschynomene, Chamaecrista, Lotononis, Desmodium, Macroptilium* and *Stylosanthes* species (Table 1) were sown on 26 November 1999 in plots measuring 2.7 × 2.8 m with 0.5 m between plots and 1m borders between replicates. Existing natural forage was burned and sowing rows prepared with an ox-drawn plough at 0.5 m spacing. Sowing rates varied between 1 and 5 kg/ha depending on seed size and seed availability. Dolomite lime and single superphosphate were applied at planting at 1000 kg/ha and 250 kg/ha, respectively, based on recommendations from soil analyses. The communal site was temporarily fenced and not grazed during the first two growing seasons to allow legumes establishment.

Establishment and persistence assessment

Plant counts for establishment and persistence assessments commenced on 17 December 1999 and were repeated fortnightly until the end of March in the first season and three times in each of the second and third seasons. Legume plants were counted along 1 m in each of the two middle rows per plot. Changes in plant counts both within and between seasons represented persistence.

Biomass assessment

Biomass production was assessed in two 0.5 × 0.5 m quadrats per plot. Herbage was clipped to 5 cm above the ground, separated into botanical components, oven-dried at 60°C for 72 hours and weighed to determine the dry matter yields. Biomass sampling was done over two rainfall seasons on 17/11/00, 15/12/00, 12/01/01, 26/01/01, 08/02/01, 11/12/01, 03/02/02 and 27/04/02.

Analysis of variance (ANOVA) on establishment, persistence and biomass was done using the General Linear Model procedures of SAS (1998).

Results

Establishment and persistence

Controlled vlei

All 18 legumes on the controlled vlei established and persisted to the end of season 1 (1999–2000),

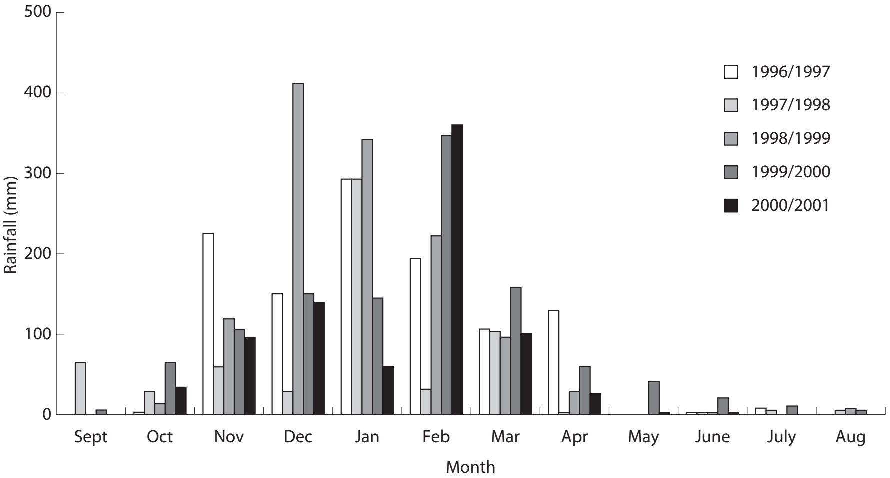

Figure 1. Rainfall data for Zana 2 Ward, Wedza district, Mashonaland East Province, Zimbabwe, for 1996–2001.

with *Stylosanthes scabra* cv. Seca, *S. hamata* cv. Verano, *Aeschynomene villosa* cv. Kretschmer, *A. falcata* TP 188, *S. mexicana* 87484 and *A. falcata* cv. Bargoo having more than 10 plants/m (Table 1). *A. villosa* cv. Reid had very poor establishment but had better plant counts at the end of season 2 than other legumes. All legume plant counts decreased drastically with zero counts for all in season 3 except for *A. villosa* cv. Reid and *Lotononis bainesii* cv. Miles.

Communal vlei

Establishment of legumes as shown by mean plant counts was similar to that on controlled vlei in season 1, with greater than 10 plants/m for *S. scabra* cv. Seca, *S. mexicana* 87484, *S. hamata* cv. Verano, *A. falcata* cv. Bargoo, *A. falcata* TPI 88, *A. villosa* cv. Kretschmer, *A. histrix* ATF 977 and *A. histrix* 93638. All legume counts had dropped by the end of seasons 2 and 3 except for *Lotononis bainesii* cv. Miles which increased from 1.7 plants/m in season 1 to 6.1 plants/m in season 3.

Controlled topland

All legumes except *L. bainesii* cv. Miles established and persisted to the end of season 1. No average counts greater than 10 plants/m were recorded. Most counts declined to zero counts in seasons 2 and 3, but *L. bainesii* cv. Miles increased from 0 plants/m in season 1 to 4 plants/m in season 3.

Communal topland

Again, no average plant counts of greater than 10 plants/m were recorded, although the majority established and persisted to the end of season 1. While plant counts in season 2 were generally low, most legume plant counts had significantly ($P < 0.05$) increased by the end of season 3. Greater than 10 plants/m were recorded for *A. villosa* cv. Reid, *Chamaecrista rotundifolia* cv. Wynn, *C. rotundifolia* 93094, *L. bainesii* cv. Miles and *Desmodium uncinatum* cv. Silverleaf at the end of season 3 (Table 1).

Biomass production

Controlled vlei

In season 2, the highest legume biomass of 492 kg/ha was recorded for *A. villosa* cv. Kretschmer. The other significantly higher ($P < 0.05$) biomass performances were for *A. villosa* cv. Reid, *L. bainesii* cv. Miles and *S. scabra* cv. Seca. Biomass production for all legumes was negligible in season 3 on the controlled vlei (Table 2).

Communal vlei

In season 2, the highest biomass production of 1191.6 kg/ha was recorded for *A. villosa* cv. Reid with *A. villosa* cv. Kretschmer, *S. scabra* cv. Seca, *Macroptilium atropurpureum* cv. Siratro and *L. bainesii* cv. Miles being the other significant ($P < 0.05$) top performers (Table 2). The rest of the legumes had negligible biomass production. All legumes had negligible biomass production in season 3.

Controlled topland

A. villosa cv. Reid had the highest biomass production of 111.2kg/ha followed by *L. bainesii* cv. Miles (72 kg/ha) and *S. scabra* cv. Seca (68.8 kg/ha) (Table 2). The rest of the legumes had negligible biomass in season 2. All legumes had negligible biomass in season 3 (Table 2).

Communal topland

In season 2, much higher biomass production was recorded for some legumes compared to the controlled topland. *C. rotundifolia* cv. 93094, *C. rotundifolia* cv. Wynn, M. atropurpureum cv. Siratro and *C. pilosa* had significantly ($P < 0.05$) higher total dry matter yields of 2094.2 kg/ha, 1700 kg/ha, 658.8 kg/ha and 517 kg/ha, respectively (Table 2). All legumes on communal topland had negligible biomass production in season 3.

Discussion

There was differential establishment of legumes depending on previous grazing management and soil wetness. Generally, higher establishment was achieved on the communal site. This could have been due to the difference in the native forage soil seedbanks of the two sites. The communal site would have had a smaller seed bank of the natural herbaceous vegetation because of the previous overgrazing, resulting in reduced seed production by the native species. The amount of litter and senescent herbage from previous seasons was obviously not a problem for legume germination since all sites were burnt before sowing.

Within grazing management sites, establishment was highest on vlei for most accessions — the highest establishments being for the communal vlei. This suggests an interaction of previous grazing management and soil wetness. The soil moisture in the sandy toplands was apparently not adequate to support the initial year establishment of most accessions.

Table 1. Average legume counts for the controlled and communal grazing sites from season 1 (1999–2000) to season 3 (2001–2002).

	Controlled						Communal					
	vlei			topland			vlei			topland		
Species Season	1999–2000	2000–01	2001–02	1999–2000	2000–01	2001–02	1999–2000	2000–01	2001–02	1999–2000	2000–01	2001–02
Aeschynomene falcata cv. Bargoo	10.7	2.5	0.06	2.3	0.2	0.5	21.7	1.5	0.6	4.0	4.2	6.2
A. falcata ATF 2196	1.0	0	0	5.0	1.2	1.1	7.7	0.8	0.9	3.3	2.3	8.2
A. falcata TPI 88	14.3	0	0	2.7	0.2	0.5	14.7	0	0.06	0.7	0	2.6
A. histrix 93638	3.0	0.5	0	0.3	0.3	0.3	10.3	0	0.3	1.0	0.2	1.3
A. histrix ATF 977	9.0	0.5	0.5	2.3	0	0.9	10.7	2.7	0.2	2.0	0.3	2.6
A. villosa cv. Reid	7.0	11.2	2.4	1.3	1.3	2.8	7.0	10.7	0.8	0.3	0	18.9
A. villosa cv. Kretschmer	16.3	3.6	0.7	4.0	3.2	3.2	12	2.2	2.9	2.3	0	5.7
Chamaecrista rotundifolia cv. Wynn	6.7	0.2	0.6	3.3	0.8	0.3	8.7	0.8	0.1	5.3	4.0	14.2
C. rotundifolia 93094	2.7	0.2	0.06	1.3	1.0	1.7	3.3	0.7	0.4	3.0	4.5	23.3
C. pilosa CPI 57503	3.3	0.2	0	3.3	0.2	0.2	4.0	0	0.1	4.7	4.5	9.8
Lotononis bainesii cv. Miles	5.7	5.3	2.0	0	0	4.1	1.7	0.8	6.1	0	0	12.0
Desmodium uncinatum cv. Silverleaf	1.0	0.3	0.4	0.3	0.3	2.2	0.3	0.5	1.1	0	0.3	19.2
Macroptilium atropurpureum cv. Siratro	1.3	0.5	0	0.3	0	1.4	0.3	0.3	0.2	0.3	0.3	0.5
Stylosanthes hamata cv. Verano	22.7	0.2	0	4.7	0.2	0	22.7	0	0.06	2.3	0	3.4
S. hippocampoides cv. Oxley	3.7	0	0.3	8.0	0.5	0.1	8	1.0	0.3	1.7	2.8	4.6
S. mexicana 87484	13.3	0	0.06	4.3	0.8	0.4	25	1.8	1.6	8.7	0.3	2.5
S. scabra cv. Seca	31.3	11.3	0.6	3.7	1.3	2.4	33.3	19.3	0.2	2.7	3.5	9.5
S. scabra cv. Fitzroy	7.0	2.3	0.3	1.7	1.0	0.4	9.7	5.0	0.1	3.3	1.8	3.2
LSD	5.08	1.41	7.75	5.08	1.41	7.75	5.08	1.41	7.75	5.08	1.41	7.75

Table 2. Legume biomass production (kg/ha) in controlled and communal grazing sites for season 2 (2000–2001) and season 3 (2001–2002).

	Controlled				Uncontrolled			
	vlei		topland		vlei		topland	
Species Season	2000–01	2001–02	2000–01	2001–02	2000–01	2001–02	2000–01	2001–02
Aeschynomene falcata cv. Bargoo	4.8	0	0	0	2	0	180	0.03
A. falcata ATF2196	0	0.01	2.8	0	0	0	47.2	0
A. falcata TPI 88	0	0	0	0	0	0	0	0
A. histrix 93638	0	0	25.2	0	0	0	3.6	0
A. histrix ATF 977	2	0	0	0	0	0	35.2	0
A. villosa cv. Reid	397.2	0	111.2	0	1191.6	0.5	27.6	0
A. villosa cv. Kretschmer	492	0	4	0.07	322.4	0.1	0	0
Chamaecrista rotundifolia cv. Wynn	0	0	5.2	0	6.9	0	1700	0
C. rotundifolia 93094	29.2	0	0	0	0	0.06	2094.2	0.02
C. pilosa	0	0	2.8	0.06	0	0	517.6	0
Lotononis bainesii cv. Miles	388.4	0	72	0.4	98.8	0.7	19.2	0
Desmodium uncinatum cv. Silverleaf	0	0	0	0	0	0	0	0
Macroptilium atropurpureum cv. Siratro	0	0	9.2	0.5	172	0	658.8	0
S. hamata cv. Verano	1.2	0	0	0	0	0.03	0	0
S. hippocampoides cv. Oxley	0	0	0	0	0	0.07	192.4	0.4
S. mexicana 87484	3.7	0	0	0	0	0	47.2	0
S. scabra cv. Seca	134.4	0.01	68.8	0.2	384.4	0	130.4	0
S. scabra cv. Fitzroy	2.8	0	0	0	14.4	0	96	0
LSD	18.13	0.23	18.13	0.23	18.13	0.23	18.13	0.23

The poor persistence of most accessions across all sites could have been due to competition from native vegetation. This has been documented for *Chamaecrista rotundifolia* and *Stylosanthes* accessions in semi-arid sites in Nigeria (Tarawali 1994), and for *Stylosanthes* spp. in Mozambique (Muir and Abrao 1999). According to Clatworthy and Muyotcha (1980), some legumes — especially those that have an erect growth habit — can die as a result of shading, and legumes such as the *Stylosanthes* species can be badly affected. *A. villosa* and *C. rotundifolia* accessions increased dramatically in plant counts in the third year on communal topland. While the reasons are not clear, it can be postulated that while these accessions are slow establishers on well-drained semi-arid sites, they can persist under intensive grazing and competition from native vegetation.

The biomass production was very poor for most accessions. This has also been the experience in other studies. In a 2-year study of nine accessions in three semi-arid sites in Nigeria, *C. rotundifolia* accessions yielded better in the second season, with yields of 0.3–1.7 t/ha, while *S. hamata* generally yielded better in the establishment year, with a yield range of 0.7–1.8 t/ha (Tarawali 1994). In Mozambique, Muir and Abrao (1999) observed poor yields of only 298 kg/ha which declined progressively over 5 years. They concluded that the quantity of *Stylosanthes* species forage produced may not compensate for the cost of establishing forage banks, although they argued that this forage contribution may be significant on a range site with very little dry-matter production in the dry season. The only ‘reasonable’ biomass production in this study was for *A. villosa* and *C. rotundifolia* accessions and even then, there was no consistency among the sites. Edye et al. (1998) argue that adequate plant densities for high dry-matter and seed yields must occur regularly to ensure the long-term persistence of legumes to ensure their colonising ability during favourable seasonal conditions can be realised. In this study, this argument may hold because of the poor establishment and persistence results obtained.

The legumes in this study were tested in single legume plots and not legume mixtures. Tarawali (1994) suggested that legumes could be considered in mixtures so as to exploit the good aspects of each species. This might give a spread of production in different seasonal conditions. Some legume seed, e.g. *L. bainesii* cv. Miles, seemed to survive in the soil across seasons only to germinate under more favourable conditions. This is a good attribute for any legume to be used on these climatically variable savannah rangelands.

The two grazing management systems tested could have been either too lenient or too excessive to permit sufficient legume growth. It is necessary to test intermediate grazing intensities for the communally managed rangelands with introduced forage legumes.

Conclusion

The establishment persistence and biomass production success of the 18 legumes being tested were affected by previous grazing management of the site and long-term soil wetness. These are realistic variables for communally managed rangelands, which vary from site to site.

At this point, it would seem that on the basis of establishment, persistence and biomass production, the following should be further observed and evaluated for improving communally managed rangelands with characteristics similar to the test sites: *A. villosa cv.* Reid, *A. villosa* cv. Kretschmer, *C. rotundifolia* cv. 93094, *C. rotundifolia* cv. Wynn and *C. pilosa* CPI 57503.

The minimal performances by the legumes should not be used to totally abandon legume evaluations on communally grazed rangelands because as per the argument of Muir and Abrao (1999), their contribution might still be of significance on these rangelands.

The research must be continued to evaluate various grazing management strategies’ effects on the persistence and biomass production. These strategies must not only include grazing intensity but must also encompass local farmer community dynamics and community institutional options for managing the rangelands common property.

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Evaluation and Screening of Forage Legumes for Sustainable Integration into Crop–Livestock Farming Systems of Wedza District

R. Nyoka,* N. Chikumba,* I Chakoma,* P Mazaiwana,† N. Mukombe† and N. Magwenzi†

Abstract

A forage-legume screening trial was carried out on 34 annual and perennial legumes during the period 1999 to 2001 in the Zana and Dendenyore wards of Wedza district in Zimbabwe. Performance of legumes was based on the assessment of establishment, resistance to pests and disease, and dry matter production. Based on research results and appraisal by the farmers, the legumes that appear to have potential for a variety of uses in the local farming systems and require further evaluation include the following: *Alysicarpus rugosus* CPI 76978, *Centrosema pascuorum* Q 10050, *Centrosema pascuorum* cv. Cavalcade, *Desmodium intortum* cv. Greenleaf, *Desmodium uncinatum* cv. Silverleaf, *Lablab purpureus* cv. Endurance, *Macroptilium atropurpureum* cv. Siratro, *Macroptilium bracteatum* CPI 27404, *Macroptilium gracile* cv. Maldonado, *Macroptilium gracile* CPI 93084, *Vigna lasiocarpa* CPI 34436, *Vigna unguiculata* CPI 121688 and *Macrotyloma axillare* cv. Archer.

Smallholder farming systems in Zimbabwe are characterised by a high degree of interdependence between crop and livestock activities at farm level. Crops such as maize, sorghum, finger millet and pearl millet are grown in association with livestock rearing (mostly cattle, goats, sheep and poultry). Crop production is most commonly on a subsistence basis and is severely limited by, among other factors, a shortage of inputs, lack of draught power and inherent poor soil fertility. Ruminant livestock depend largely on native pasture that is usually in short supply and of poor nutritive quality during the prolonged dry season. Crop stovers make up the bulk of livestock feed during the dry season. The dung from livestock is frequently used as manure in the arable lands.

Increasing rural resettlement has led to a rapid and general decline in the areas of grazing and arable lands available to each farm family. Therefore, the need to intensify and optimise both livestock and crop production is the major challenge being faced by smallholder farmers.

Legumes tend to have higher protein levels than grasses and have a low natural occurrence in most of the natural pastures. However, forage-legume technology has the potential to improve the sustainability and productivity of the smallholder farming systems by providing a protein source that can boost livestock production (through increased availability of high-quality forages) and crop production (through biological nitrogen-fixation). For the successful use of forage legumes, climatically and edaphically adapted accessions that produce reasonable quantities of quality forage need to be selected. This paper reports on the performance of 34 legume accessions evaluated in the Wedza district of Zimbabwe.

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* Grasslands Research Station, P. Bag 3701, Marondera, Zimbabwe.
† Agricultural Technical and Extension Services, PO Box 30, Wedza, Zimbabwe.

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Materials and Methods

Farmer group description

The group of farmers involved with the trials included households headed by both males and females. Their ages were in the range 40–65 years. Farming activities were maize-based (Table 1).

Legume accessions

Thirty-four perennial legume accessions were planted in November 1999, for agronomic and phenological evaluation in the Zana and Dendenyore wards of Wedza district during the period 1999 to 2001. Table 2 lists accessions and species.

Experimental sites

The trials were conducted at two and four sites, respectively, in the Zana and Dendenyore wards of Wedza district. Wedza lies in agro-ecological region IIb at an altitude of 1200 m. Mean annual rainfall is in the range 600–900mm with about 80% falling between November and March. Mean maximum temperatures of 31.1°C occur in October and mean minimums of 8.4°C in July. Soils in the district are predominantly acidic (pH 4.5) deep brown sands to sandy loams of low fertility derived from granite. The vegetation is wooded shrubland with *Terminalia sericea* and *Burkea africana,* in association with various *Combretum* and *Acacia* species, being prominent. *Brachystegia spiciformis, Julbernadia globiflora* and *Brachystegia boehmii* may occur in places. Grasslands are dominated by species of *Hyparrhenia.* Further details of the farming systems common to these areas can be found in Chigariro (2004).

Experimental design and layout

The accessions were planted during the 1999–2000 season in a randomised complete block with seven replications, with each replicate on a different farm. Each plot was a 6 m long row, with 1 m between rows.

Land preparation, sowing and seedling establishment

Seed of the 34 accessions was scarified using sand paper and inoculated with appropriate *Rhizobium* strains before planting. All sites were prepared to a fine tilth by using ox-drawn ploughs and discing. Before discing, the row plots received a basal application of 500 kg/ha of dolomitic lime and 250 kg/ha of single superphosphate. In November 1999, inoculated seed were drilled in rows and lightly covered with soil. Farmers were assisted by research and extension personnel during sowing and were responsible for the general upkeep of the experimental sites. The sites at Zana were kept almost weed free, while there was varying levels of weed competition at the other sites.

Data collection

A team comprising the farmer, researcher and extension personnel visited the plots fortnightly to monitor the performance of the accessions. Farmers were also encouraged to visit the plots on their own and write comments in the notebooks issued at the inception of the project and to provide feedback to other partners during the fortnightly visits. At the end of the evaluation period, farmers were asked to rank the legumes in terms of performance.

The establishment density was assessed at 12 weeks after planting, and monitoring of vigour and pest and disease incidence during the growing season. Establishment was rated visually on a one to five scale (1 – poor; 2 – fair; 3 – good; 4 – very good; 5 – excellent). Similarly, pest and disease incidence were rated on a one to five scale (1 – least severe; 2 – fairly severe; 3 – severe; 4 – very severe and 5 –

Table 1. Gender of household head, main agricultural activities and ages of farmers in the forage evaluation group in Zana and Dendenyore wards in Wedza District.

Farmer	Ward	Agricultural activities	Approximate age (years)	Household head
Chingwaru	Dendenyore	Maize	50–55	Male/female
Chingwa	Dendenyore	Maize	45	Male
Chiwanza	Dendenyore	Maize	50–60	Male/female
Makwarimba	Dendenyore	Maize and beef	45	Male
Mapfumo	Zana II	Maize, soya bean and paprika	55	Male/female
Makondo	Zana II	Maize and paprika	40	Male

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extremely severe). In May 2001, dry matter yield was measured by cutting two randomised 1 m^2 quadrants 5 cm above ground level from each plot. Cut material was oven dried at 60°C and weighed.

Statistical analysis

The general linear models (GLM) procedure within SAS (1994) was used to analyse data.

Results and Discussion

Plant density

Plant density at 12 weeks after planting differed significantly across sites ($P < 0.05$), with the counts on a red soil site at Dendenyore and the two sandy soils at Zana being higher than on the four sandy soil at Dendenyore (data not presented). The good establishment observed in Zana could be attributed to the fact that the farmers were generally more committed to the trial and kept their plots free of weeds at this critical stage in the growth of the legumes. Regular weeding significantly reduced competition between the test species and the weeds. At other sites where establishment was relatively poor, little attention was paid to the plots and the plants suffered from weed competition.

Considerable differences in plant density were also observed among the legume species ($P < 0.01$). Legumes in the genera *Aeschynomene, Alysicarpus* and *Macroptilium* generally exhibited good emergence compared with other genera, with scores ranging from 2.70 to 3.50. Accessions with the highest establishment rating were *Aeschynomene americana* cv. Lee, *Alysicarpus rugosus* CPI 76978 and *Macroptilium gracile* cv. Maldonado (Table 2).

Forage dry-matter yields

Forage dry-matter yields were taken only in year 2 of the trial, so the significant differences between accessions in yield (Table 2) would be expected to reflect a strong discrimination against annual species. Dry-matter yields greater than 1500 kg/ha were obtained from *Alysicarpus rugosus* CPI 51655, *Alysicarpus rugosus* CPI 94489, *Centrosema pascuorum* CPI 65950, *Desmodium intortum* cv. Greenleaf, *Macroptilium atropurpureum* cv. Siratro, *Vigna unguiculata* CPI 121688, *Macroptilium gracile* cv. Maldonado and *Macrotyloma axillare* cv. Archer (Table 2).

Intermediate forage dry-matter yields in the range 1000–1500 kg/ha were obtained from *Alysicarpus rugosus* CPI 30034, *Macroptilium bracteatum* CPI 55769 and *Neonotonia wightii* cv. Cooper.

The least amounts of forage material were harvested from *Desmodium uncinatum* cv. Silverleaf, which gave an average of 237 kg/ha over the 2000–2001 season. The yields were atypical of this usually high-yielding accession. Yields were low because harvesting was done during the dry season (May) when leaf loss was at its peak. Generally, competition from weeds prevented most species from realising their optimum yielding potentials.

Most of the accessions listed above are perennial species, although the results for *V. unguiculata* CPI 121688 are of special interest. This ‘wild’ form of the species has performed very differently to the annual domesticated cowpea, indicating that this form (probably *V. unguiculata* spp. *dekindtiana*) has potential in these systems, as material may be able to persist for more than one year.

Disease and pest tolerance

Legume species differed significantly ($P < 0.01$) in their tolerance to diseases. Stem and root rot, in addition to leaf sclerosis, were recorded in some cowpeas, particularly in cv. Gauche and the local strains (Table 2). The incidence of stem and root rot was particularly high between October and March when hot, wet and humid conditions prevailed. Fungicides were sprayed to curtail the disease but with little success. In view of the high cost of fungicides and other crop chemicals, it is unlikely that these cowpeas would be adopted for use as livestock forage, but might still be persevered with for human food production. *Desmodium intortum* cv. Greenleaf was severely affected by a disease causing numerous brown necrotic lesions on the leaves. The condition was particularly serious during flowering, and resulted in heavy loss of leaf material. Legumes from the other genera were generally less susceptible to fungal diseases. Species exhibiting impressive tolerance to diseases were *Macroptilium bracteatum* CPI 55769 and CPI 68892, *Macroptilium gracile* CPI 84999 and CPI 93084, and *Stylosanthes hamata* cv. Verano. Cheaper alternatives of controlling diseases by cultural methods, particularly within the genus *Vigna*, need to be sought.

Three accessions of *V. unguiculata* (cv. Gauche, and the local strains) were the most susceptible to aphids, followed by *Neonotonia wightii* cv. Cooper *and Macroptilium gracile* cv. Maldonado. Symptoms of nematode attack were also evident in cowpea cultivars. Problems of pests were generally high at sites where weed management of the plots was poor.

An appraisal by the farmers

At the end of the evaluation period, a group discussion involving the researchers, extension personnel and the participating farmers was held to consolidate feedback from the farmers and map out future strategies. At the end of the 2000–2001 growing season, each farmer was also invited to name their five best-performing legume accessions. The farmers' appraisals were based mainly on the visual assessment of the herbage yield, tolerance to diseases, pests and grazing by livestock (Table 3). The opinions of farmers tallied with observations made by researchers, but again their selections have probably discounted the performance of annual legumes in the first year of the evaluation trial. Consequently, both the research and farmer appraisals have to be seen as being useful in the

Table 2. Means ($n = 6$) of performance attributes of legume accessions planted in the Zana and Dendenyore wards of Wedza district.

Species	Establishment	Pest	Disease	Dry matter yield (kg/ha)
Aeschynomene americana CPI[a] 56282	2.2	3.8	3.5	–
Aeschynomene americana CPI 93624	2.0	3.4	3.4	–
Aeschynomene americana cv.[b] Glenn	2.5	3.8	3.7	–
Aeschynomene americana cv. Lee	2.7	4.2	4.2	–
Alysicarpus rugosus CPI 30034	2.0	6.1	3.9	1168
Alysicarpus rugosus CPI 30187	1.0	2.9	2.9	1493
Alysicarpus rugosus CPI 51655	1.7	4.1	4.1	1704
Alysicarpus rugosus CPI 76978	3.1	3.7	3.7	834
Alysicarpus rugosus CPI 94489	2.8	3.8	3.4	2233
Centrosema pascuorum CPI 65950	1.9	4.4	3.9	1807
Centrosema pascuorum Q[c] 10050	1.4	3.7	3.7	315
Centrosema pascuorum cv.Cavalcade	1.7	3.8	3.7	956
Clitoria ternatea cv. Milgarra	0.5	3.1	3.0	647
Desmodium intortum cv. Greenleaf	1.7	1.3	1.3	1717
Desmodium uncinatum cv. Silverleaf	1.9	2.9	2.7	237
Lablab purpureus cv. Endurance	1.9	2.5	2.6	–
Macroptilium atropurpureum cv. Siratro	1.8	4.0	3.6	1911
Vigna oblongifolia Q 25362	2.7	5.7	3.6	939
Macrotyloma daltonii cv. Ex-Odzi	1.3	2.9	2.7	734
Vigna unguiculata CPI 121688	0.4	3.8	3.4	2383
Macroptilium bracteatum CPI 55769	1.7	4.6	4.5	1116
Macroptilium bracteatum CPI 27404	1.0	4.2	4.2	835
Macroptilium gracile cv.Maldonado	2.7	3.8	3.8	1614
Macroptilium gracile CPI 84999	1.0	4.5	4.5	525
Macroptilium gracile CPI 93084	1.8	5.0	4.9	840
Macrotyloma daltonii CPI 60303	1.1	3.3	3.2	–
Neonotonia wightii cv. Cooper	0.7	2.5	2.8	1034
Stylosanthes hamata cv. Verano	2.8	4.9	4.8	–
Vigna lasiocarpa CPI 34436	1.4	3.7	3.6	613
Vigna luteola cv. Dalrymple	1.8	4.0	3.8	893
Vigna unguiculata Local 2	1.8	2.9	2.8	–
Vigna unguiculata Local 1	2.0	2.1	1.9	–
Vigna unguiculata cv. Gauche	1.6	2.5	2.5	–

[a] Australian Commonwealth Plant Introduction number.
[b] Commercial cultivar.
[c] Queensland Department of Primary Industries introduction number.

selection of legumes for use in a two-year legume fallow rather than a single-year legume rotation.

In addition to information on legume adaptation and attractiveness to farmers, the research project provided other benefits. Farmers considered that the forage-legume screening program had been instrumental in forming closer links between farmers, extension staff and researchers, and all participating farmers present at the evaluation meetings at the end of the experimental program reported that their contact with extension agents had improved substantially since the start of the project. They indicated that the project opened the way for more frequent visits by extension staff and other government officials from the district, as well as other stakeholders interested in rural development. The farmers also indicated that the project had a big impact on the way they now perceive and manage their pastures.

Despite the feedback from farmers, however, there remains a number of constraints to the use of forage legumes in these farming systems. These include shortage of seed, lack of adequate financial resources, and ownership patterns of grazing lands. Farmers agreed to consider establishing seed-production plots. They indicated that for this to be successful, some training on the basics of seed production and marketing was necessary. The aspirations of the farmers were incorporated into the activities of the 2001–2002 season. Seed plots of the best-bet legume species were established during this season by farmers, with minimum assistance from researchers and extension personnel. However, the dry conditions that persisted in the area in that summer adversely affected establishment and subsequent seed production. Despite the drought, farmers hoped to produce seed in the forthcoming season if conditions are favourable.

Conclusion

Evidence from the experiment has resulted in the farmers, extension staff and researchers agreeing on the selection of some legume species for further testing in Wedza district. The materials recommended for further testing under different farming systems are:

Table 3. The five top-performing legumes as appraised by the farmers.

Farmer	Ward	Legume species ranking
Mapfumo	Zana II	1. *Macroptilium atropurpureum* cv. Siratro 2. *Macroptilium bracteatum* CPI 68892 3. *Desmodium uncinatum* cv. Greenleaf 4. *Vigna* species 5. *Lablab purpureus* cv. Endurance
Makwarimba	Dendenyore	1. *Macroptilium bracteatum* CPI 68892 2. *Macrotyloma axillare* cv. Archer 3. *Macroptilium bracteatum* CPI 27404 4. *Macroptilium atropurpureum* cv. Siratro 5. *Desmodium uncinatum* cv. Greenleaf
Chingwa (loams)	Dendenyore	1. *Vigna* species 2. *Lablab purpureus* cv. Endurance 3. *Alysicarpus rugosus* CPI 76978 4. *Centrosema pascuorum* Q 10050 5. *Stylosanthes hamata* cv. Verano
Chingwa (red soils)	Dendenyore	1. *Vigna* species 2. *Macrotyloma axillare* cv. Archer 3. *Lablab purpureus* cv. Endurance 4. *Alysicarpus rugosus* CPI 76978 5. *Vigna lasiocarpa* CPI 34436
Makwarimba	Dendenyore	1. *Macroptilium bracteatum* CPI 68892 2. *Macrotyloma axillare* cv. Archer. 3. *Macroptillium atropurpureum* cv. Siratro 4. *Desmodium uncinatum* cv. Silverleaf 5. *Desmodium intortum* cv. Greenleaf

Aeschynomene americana cv. Glenn, *Aeschynomene americana c*v. Lee, *Alysicarpus rugosus* CPI 76978, *Centrosema pascuorum* CPI Q10050, *Centrosema pascuorum* cv. Cavalcade, *Desmodium intortum c*v. Greenleaf, *Desmodium uncinatum* cv. Silverleaf, *Lablab purpureus c*v. Endurance, *Macrotyloma axillare* cv. Archer, *Macroptilium atropurpureum* cv.Siratro, *Macroptilium bracteatum* CPI 68892*, Macroptilium bracteatum* CPI 27404, *Macroptilium gracile* cv. Maldonado, *Vigna lasiocarpa* CPI 34436, *Vigna unguiculata* CPI 121688, and the local cowpeas. While research is still needed to assess and quantify the impact of forage legumes on soil fertility and crop and livestock production, the concept of legume use in these systems is of considerable interest to smallholder farmers in Wedza district.

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Identification and Development of Forage Species for Long-Term Pasture Leys for the Southern Speargrass Region of Queensland

R.L. Clem and B.G. Cook*

Abstract

Well-managed pasture leys using species that are adapted to the climate and soils are an option for redressing pasture and soil degradation in areas of the speargrass region of southern Queensland. To identify the most promising pasture plants and compare them with current cultivars, some 180 legumes and 50 grasses were tested in small swards at two sites on farmers' properties at Cinnabar near Kilkivan and Broad Creek near Durong.

Since planting in February 2000, rainfall has been below average but most of the legumes and grasses established. Density of legumes has generally declined, but the grasses have improved to the extent that some are now covering 100% of the plots. Of the grasses, creeping bluegrasses (*Bothriochloa insculpta* cvv. Hatch, Bisset and CPI 69517) are well adapted to both sites as are digit grasses (*Digitaria eriantha* cv. Premier and *D. milanjiana* cv. Strickland and accessions such as *D. eriantha* ATF 605). There are also *Urochloa* spp. that are equally as well adapted and leafier than *U. mosambicensis* cv. Nixon.

The annual legumes, lablab and *Centrosema pascuorum* Q 10050 were the highest yielding in the first year at both sites and *Macroptilium bracteatum* cvv. Juanita and Cadarga have persisted at both sites, producing some forage in the third season. These could be effective short-term ley legumes in cropping programs. Legumes that are strongly perennial and could be used in longer-term leys and for grazing are *Stylosanthes scabra* cvv. Seca and Siran and *S. guianensis* var. *intermedia* cv. Oxley. *Desmanthus glandulosus* CPI 90319A is also promising at both sites but a range of *Desmanthus leptophyllus*, including CPI 38820, CPI 63453, CPI 92806, CPI 92809, CPI 92818 and TQ 90, while promising at Cinnabar, were less successful at Broad Creek. *Aeschynomene falcata* ATF 2194 is a low-growing but promising long-term legume for grazing that has persisted and produced more forage than *A. falcata* cv. Bargoo at Broad Creek.

The southern speargrass region of Queensland comprises an area of some 6.2 million hectares south of 24°S latitude in coastal and near-coastal areas with annual rainfall of 700 to 1000 mm (Weston *et al.* 1981). The main land use is grazing of native and sown pastures with some 1.5 to 2 million beef cattle. Beef cattle breeding, cattle finishing and mixed farming (cattle/cropping) are the main rural enterprises, with a smaller area of the more fertile soils being used for annual crops. Sorghum, maize, barley, soybeans, navy beans and peanuts are the main crops, while forage crops of oats, forage sorghum and lablab are common in cattle finishing and mixed-farming enterprises.

Pasture and soil degradation is widespread, with 20% of the southern black speargrass area assessed as degraded and some 60% deteriorating and requiring some change in management to prevent further degradation (Tothill and Gillies 1992).

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* Queensland Department of Primary Industries, PO Box 395, Gympie, Queensland 4570, Australia.

Tropical legumes for sustainable farming systems in southern Africa and Australia,
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Cropping practice varies greatly depending on economic circumstances, land and soil suitability, and farmer preference, and is constantly under review. Deeper, more-fertile soils with minimal slope might be cropped each year, whereas some of the shallower, less-fertile soils are cropped irregularly and many are being resown to pasture. A successful cropping phase can increase a farmer's per-hectare returns, but at a cost. Each cultivation reduces soil structure and fertility, and largely destroys existing pasture and ground cover. Well-managed pasture leys using species that are adapted to the climate, soils and farmer's need are an option for redressing these adverse consequences.

Legumes for short-term pasture leys in areas subject to frequent cultivation have been evaluated in southern areas of Queensland (Lloyd *et al*. 1991; Weston *et al*. 2000) and northern Australia (Jones *et al.* 1991). These were often species that had been rejected from evaluations that sought persistent pasture plants. Since the sown ley was only required to persist for 2 to 3 years, these less persistent species, which were often very productive, were more acceptable. In the southern speargrass lands, cropping is opportunistic and, on many properties, old cropping lands are being returned to pasture. For many farmers, unless there is a change in commodity prices in favour of grain, future cropping is unlikely. For this reason, plants that can persist for the medium to long term are more desirable than higher-producing short-term plants. Further, it may also be important to incorporate a grass into the ley, in the interest of suppressing weeds, improving ground cover, enhancing organic-matter accretion, and generally providing greater stability to the system.

Species investigated in this project were drawn from the most promising of the short-term group, pasture cultivars recommended for the area, and other productive accessions that are likely to persist in the longer term.

Our specific objectives were to assess the potential of a range of sown legumes and grasses to fulfil a role in longer-term pasture leys in farming systems in the region and to encourage farmers to develop and evaluate pasture systems based on the more promising species.

Materials and Methods

Sites and sowing procedures

Paddocks with soils and land-types representative of the district were selected on farmers' properties at Broad Creek via Durong and Cinnabar via Kilkivan. These areas had previously been used for cropping but had been sown to, or recolonised with, a range of pasture grasses and legumes, and in more recent years had been grazed with beef cattle. The main pasture species included *Heteropogon contortus, Bothriochloa bladhii, Bothriochloa decipiens, Chloris gayana,* other *Chloris* spp. and *Eragrostis* spp. Soils were clay loams that varied in colour and fertility (Table 1).

Areas of about 2 ha at each site were fenced to exclude grazing stock and cultivated before sowing. In February 2000, 139 legume and 50 grass accessions and in February 2002, 45 legumes and 5 grasses including controls (Appendixes I and II) were sown by hand into the surface of dry soil. The exceptions were the larger-seeded *Arachis* and *Lablab* spp., which were sown into furrows and covered. All legumes were inoculated with appropriate strains of either *Rhizobium* or *Bradyrhizobium* spp. and seed was mixed with a small quantity of dampened sawdust to

Table 1. Location, rainfall and some soil characteristics of the experimental sites.

Datum	Broad Creek	Cinnabar
Latitude and longitude	26°27'S, 151°27'E	26°07'S, 152°09'E
Average annual rainfall (mm)	780	880
Soils (0–10 cm)	Brown sandy clay loam	Dark clay loam
pH (1:5 H_2O)	6.3	6.6
Available P (bicarbonate) (ppm)	18	36
Exchangeable K (ppm)	0.73	1.1
Available S (ppm)	6.8	7.2
Organic C (%)	1.5	2.6

aid spreading. At the Cinnabar site, plots were rolled using a rubber tyred roller to firm the coarse seedbed and improve soil–seed contact. At Broad Creek, the lighter textured soil surface was loose and dusty and no post-sowing treatment was undertaken.

Plots were 5 × 2m with a 1 m border between the rows to allow access and demarcation. To make recognition of plots easier, the grasses and legumes were allocated rather than randomised so that accessions of the same genus were not sown in adjoining plots. Two replicates were sown.

In the 2002 planting, as well as the small plots, some 20 accessions, including commercial cultivars, were sown in larger (100 m^2) plots. At both sites, the legume plots in this series were oversown with digit grass (*Digitaria eriantha* cv. Premier) at 2 kg/ha.

Management and sampling procedure

2000 planting

Establishment was determined by counting emerged seedlings in two quadrats of 0.25 m^2/plot at Cinnabar and Broad Creek in March 2000. Plot yield, composition, frequency and vigour of the sown accessions was measured in May 2000. Plot yield was assessed by ranking all plots on a scale of 1 to 5 and then calculating yields (kg/ha) from regression equations derived by cutting, drying and weighing 10 selected plots across the range of yields and plotting these against the rated yields. Botanical composition was determined by estimating the percentage of sown species and other species in each plot and calculating the yield of the sown species.

Composition and vigour were measured in December 2000 and March 2002. In legume plots, density was measured by counting old plants and seedlings (two categories) and, in the grass plots, by estimating the ground cover (0 to 100%). Yield, composition and vigour were measured in March 2002 as for the sampling in May 2000. No yield measurements were made in autumn 2001 because of the very dry conditions.

Grazing stock had access to the experimental area following sampling in May 2000 to October 2000, from December 2000 to February 2001, and again from May 2002 to September 2002.

Sodium molybdate was sprayed on foliage in November 2000 at a rate supplying 100 g/ha of molybdenum.

2002 planting

Density of established plants was measured in May by counting emerged seedlings and vigour was rated on a scale of 1 to 3.

Results

Seasonal conditions

Rainfall at the two sites for 2000, 2001 and 2002 (Table 2) was below average, with some extended dry periods. For the 2000 planting, subsoil moisture accumulated over the preparatory cultivation phase and an effective rainfall event in February resulted in good establishment and early pasture growth. However, establishment from the 2002 planting was poor because of very low rainfall following planting in late February.

Establishment and density

2000 planting

All accessions established at both sites, although initial plant densities were higher at Cinnabar, where

Table 2. Rainfall (mm) at Cinnabar and Broad Creek for 2000 and 2001 and long-term averages for Kilkivan and Durong.

Location	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Cinnabar	2000	51	72	37	41	49	44	13	7	0	141	62	112	629
	2001	48	99	69	34	23	3	40	6	15	64	217	54	672
	2002	35	114	29	0	21	37	11	16					
Kilkivan long-term average		134	122	97	58	49	47	44	34	38	68	73	117	881
Broad Creek	2000	128	44	0	9	20	21	5	0	0	87	52	97	463
	2001	37	147	32	40	14	0	29	8	15	84	172	70	648
	2002	0	99	80	4	20	40	0	3					
Durong long-term average		86	83	64	40	36	33	35	27	30	58	70	102	664

rainfall was marginally better. Mean plant densities were, for legumes, 52 plants/m^2 at Cinnabar and 34 plants/m^2 at Broad Creek and, for grasses, 270 plants/m^2 at Cinnabar and 116 plants/m^2 at Broad Creek (Table 3). In March 2002, of the 139 legumes planted, 111 were still present at Cinnabar but only 79 at Broad Creek.

Legume density declined markedly between planting and March 2002 at both sites, with dry conditions over late winter and spring, but weeds such as black pigweed (*Trianthema portulacastrum*), *Sida* spp., a range of chenopods and summer-growing grasses also depleted soil moisture and affected all but the fastest-growing legumes. Plant density of most accessions was adequate to allow comparisons and some accessions had moderate to high densities. There was also large variation between accessions within each genus, which more probably reflect differences in adaptation. At Cinnabar, there were, in all, 36 accessions with plant densities greater than 7 plants/m^2. They were *Aeschynomene falcata* (3 accessions), *Aeschynomene histrix* (2), *Arachis paraguariensis* (2), *Desmanthus* spp. (18), *Macroptilium bracteatum* cv. Juanita and *Stylosanthes* spp. (10). Plant densities were lower at Broad Creek, with only *Arachis paraguariensis*, *Desmanthus virgatus* CPI 37538, *Stylosanthes scabra* CPI 110116 and cvv. Seca and Siran, *S. guianensis* var. *intermedia* cv. Oxley (fine-stem stylo) and *S. seabrana* cvv. Primar and Unica having more than 7 plants/m^2.

In contrast to the legumes, all the grasses grew well at both sites, competing better with weeds and responding to nitrogen mineralised by cultivation. By March 2002, the estimated cover of all grasses except

Table 3. The number of accessions from each genus that established (Mar 2000) and the number surviving (Mar 2002) at Cinnabar and Broad Creek and the plant density (mean for each genus) in March 2000 and March 2002.

	Cinnabar				Broad Creek		
	Accessions sown	Accessions Mar 2002	Density (plants/m^2)		Accessions	Density (plants/m^2)	
Genus			Mar 2000	Mar 2002	Mar 2002	Mar 2000	Mar 2002
Legumes							
Aeschynomene	16	5	96	5	6	40	1
Alysicarpus	6	0	64	0	0	17	0
Arachis	4	4	15	6	2	34	5
Centrosema	3	0	77	0	0	59	0
Clitoria	1	1	9	1	0	1	0
Desmanthus	81	80	42	5	54	30	1
Lablab	3	0	43	0	0	27	0
Macroptilium	4	4	56	4	4	48	3
Medicago	1	1	101	1	1	46	1
Neonotonia	8	5	18	0	2	11	0
Stylosanthes	11	11	75	11	10	75	7
Vigna	1	0	42	0	0	16	0
Mean of 138 accessions			**52**	**2.8**		**34**	**1.5**
Grasses							
Bothriochloa	8	8	220	86[a]	8	173	87[a]
Cenchrus	6	6	189	60	6	123	77
Dichanthium	3	3	92	58	3	79	84
Digitaria	13	13	257	73	13	155	80
Panicum	5	5	319	34	5	59	70
Paspalum	1	1	404	40	1	139	70
Urochloa	14	14	163	68	14	66	76
Mean of 48 accessions			**270**	**60**		**116**	**78**

[a] Figures for grasses in March 2002 are estimates of cover.

Panicum and *Paspalum* spp. had increased at Cinnabar and Broad Creek. At Cinnabar, cover for some grasses was 100%.

2002 planting

Of the 48 accessions planted in small plots at Cinnabar, all but 3 established, although a further 23 had populations of less than 2 plants/m^2. Best establishment was for *Aeschymonene americana* ATF 1086, *Desmanthus* sp. ATF 3930, *Macroptilium atropurpureum* cv. Aztec, *Stylosanthes guianensis* var. *intermedia* cv. Oxley and *Stylosanthes seabrana* ATF 2523 and ATF 2539. All grasses established at densities that should allow some evaluation. At Broad Creek, 16 accessions did not establish and only 4 legumes, *Aeschynomene americana* ATF 1086, *Clitoria ternatea* cv. Milgarra and CPI 47187 and *Stylosanthes seabrana* ATF 2539 had densities greater than 2 plants/m^2. Except for *Panicum coloratum* cv. Bambatsi, all grasses established poorly.

In the larger plots at Cinnabar, all accessions established but some had low populations. Legumes with the highest establishment were *Aeschymonene falcata* ATF 2914 and Bargoo, *Desmanthus glandulosus* CPI 90319A, *Desmanthus leptophyllus* CPI 38820, *Macroptilium bracteatum* cvv. Cardaga and Juanita, *Stylosanthes guianensis* var. *intermedia* cv. Oxley and *S. seabreana* cv. Unica. At Broad Creek, most accessions failed to establish and the best had populations of less than 5 plants/m^2.

Yield and other attributes

Legumes — 2000 planting

Annual legumes such as *Lablab* and some accessions of *Aeschynomene*, *Alysicarpus*, *Centrosema* and *Macroptilium* produced higher yields in the first season than the perennial legumes which were generally slower growing at both sites (Tables 4 and 5).

Production was higher at Cinnabar than at Broad Creek. At Cinnabar, *Lablab purpureus* cv. Rongai yielded over 4000 kg/ha and some accessions of *Centrosema pascuorum* over 3000 kg/ha. *Macroptilium*

Table 4. Forage yields measured in May 2000 (2000), December 2000 (2001) and March 2002 (2002) of the better adapted legume cultivars and accessions at Cinnabar (ranked by yields for 2002).

Genus	Species	Acc/Cvv	Yield (kg/ha)		
			2000	2001	2002
Desmanthus	*leptophyllus*	92809	1363	213	6560
Stylosanthes	*scabra*	Seca	2045	181	5529
Desmanthus	sp.	AC 11	2045	380	5061
Desmanthus	*glandulosus*	90319A	1363	83	3686
Desmanthus	*leptophyllus*	TQ 90	2045	233	3249
Desmanthus	*virgatus*	91491	1818	39	3124
Desmanthus	*virgatus*	91326	1590	287	3061
Desmanthus	*leptophyllus*	63453	1590	130	3030
Stylosanthes	*guianensis* var. *intermedia*	Oxley	1818	125	2967
Desmanthus	*leptophyllus*	Bayamo	1818	273	2674
Desmanthus	*leptophyllus*	38351	1818	100	2662
Desmanthus	*leptophyllus*	92806	1818	139	2561
Desmanthus	*leptophyllus*	92818	2045	170	2374
Desmanthus	*leptophyllus*	38820	1818	157	2343
Desmanthus	*leptophyllus*	87876	2045	304	2237
Desmanthus	*leptophyllus*	87860	1590	143	1843
Desmanthus	*leptophyllus*	92722	2499	172	1299
Desmanthus	*bicornutus*	90906	2272	167	1062
Desmanthus	*virgatus*	ATF 3009	2045	83	1062
Macroptilium	*bracteatum*	Juanita	2499	88	687
Lablab	*purpureus*	Rongai	4545	69	
Lablab	*purpureus*	Highworth	3863	59	
Centrosema	*pascuorum*	Q 10050	3636	0	
Lablab	*purpureus*	Endurance	3409	59	

bracteatum cv. Juanita persisted and produced a yield of over 600 kg/ha in year 3 but the other annual and short-term legumes which yielded well in the first year did not survive or regenerate (Table 4).

In the second season, legume yields were low when measured in December 2000 because of competition with weeds. Forage yields in the third summer were high, with *Stylosanthes scabra* cv. Seca and *S. guianensis* var. *intermedia* cv. Oxley producing 3000–5000 kg/ha. A range of *Desmanthus* spp. grew well, with several accessions performing better than available cultivars (Table 4).

Desmanthus leptophyllus CPI 92809, TQ 90 and CPI 63453 are strong leafy types that grew 0.8–1.0 m tall and outyielded *D. leptophyllus* cv. Bayamo. *D. leptophyllus* CPI 38351 is a tall, woody type. Other accessions such as *D. leptophyllus* CPI 92722, although not as high yielding, were leafy and more compact and should be well suited to grazing. *Desmanthus glandulosus* CPI 90319A and *Desmanthus bicornutus* CPI 90906 are tall, 'stemmy' types while *Desmanthus virgatus* was variable from *D. virgatus* CPI 91491 and 91326, which grew to 0.8 m, to the more compact ATF 3009, which also looks a good grazing type. Many of the lower-yielding *Desmanthus* spp. were small and unthrifty plants, suggesting that rhizobial associations were not fully effective. *Aeschynomene falcata* ATF 2194 was the best of the joint vetch accessions producing over 1000 kg/ha but forming a dense sward. *Arachis paraguariensis* CPI 91419 with a yield of 500 kg/ha was the best of the forage peanuts and is now starting to spread from the sown rows. These are accessions with some potential but are low-yielding, especially in establishment years. Only accessions with higher yields are shown in Table 4.

At Broad Creek, maximum yields in the first year were lower than at Cinnabar, ranging from 1000 to 2000 kg/ha, but the order of ranking was similar. With the exception of *Macroptilium bracteatum* cv. Juanita, legumes that produced high yields in the first season failed to persist or regenerate. In the second season, *Stylosanthes scabra* (cvv. Seca and Siran and CPI 110116) and Stylosanthes seabrana (cvv. Primar and Unica) were the highest yielding. These and *S. guianensis* var. *intermedia* cv. Oxley also produced high yields in the third season (Table 5).

Desmanthus appeared to be less well adapted to this site than to the Cinnabar site, but some accessions, such as *Desmanthus leptophyllus* CPI 38820 and 63454, gave high yields at both sites. Similarly, *Arachis paraguariensis* CPI 91419 was spreading at

Table 5. Forage yields measured in May 2000 (2000), December 2000 (2001) and March 2002 (2002) of the better adapted legume cultivars and accessions at Broad Creek (ranked by 2002 yields).

Genus	Species	Acc/Vvv	Yield (kg/ha)		
			2000	2001	2002
Stylosanthes	*scabra*	Seca	714	1265	7498
Stylosanthes	*scabra*	Siran	1071	552	5082
Stylosanthes	*scabra*	110116	892	302	3957
Stylosanthes	*guianensis* var. *intermedia*	Oxley	1091	21	3041
Macroptilium	*atropurpureum*	Aztec	1070	192	2458
Stylosanthes	*seabrana*	Primar	1249	2449	2332
Desmanthus	*leptophyllus*	38820	1785	589	1541
Stylosanthes	*seabrana*	Unica	1071	2251	1374
Macroptilium	*bracteatum*	Juanita	2142	177	1250
Desmanthus	*leptophyllus*	63453	714	236	1250
Desmanthus	*glandulosus*	90319A	892	545	833
Desmanthus	*leptophyllus*	Bayamo	1607	221	750
Arachis	*paraguariensis*	91419	892	221	666
Desmanthus	*pernambucanus*	83566	1249	40	533
Aeschynomene	*falcata*	ATF 2196	1964	986	108
Lablab	*purpureus*	Rongai	2142	618	
Centrosema	*pascuorum*	Q 10050	1964	6	
Lablab	*purpureus*	Endurance	1964	9	
Lablab	*purpureus*	Highworth	1964	1	

this site and *Aeschynomene falcata* ATF 2194 grew into a dense sward early in the summer but was adversely affected later by dry weather.

Grasses — 2000 planting

Many of the available cultivars of grasses are productive and well adapted to grazing in permanent and ley pasture systems. *Bothriochloa insculpta* cvv. Hatch and Bisset were high yielding at both sites and in all years. After the third summer, they were almost pure swards (Table 6). Similarly, some of the *Urochloa* spp. were high yielding and formed dense swards. An objective of this study, however, was to identify grasses that would be more compatible with legumes in medium to longer-term leys in the subtropical areas. To this end, some of the other, less-productive grasses in Table 6 are of interest.

Bothriochloa insculpta CPI 69517 is very similar to the cultivar Bisset but is earlier flowering by about 2 weeks. This could be an advantage in central and southern areas where Bisset is often frosted before seed matures. Earlier flowering should mean more reliable seed production, which could improve the supply of seed and reduce its cost to farmers. Also being from a drier environment at Bulawayo, this accession could extend the range of *B. insculpta*. *Digitaria* and *Urochloa* varieties are also good colonising and productive grasses. The digit grasses are known to be very palatable, which could be an advantage where higher animal growth rates are sought. More palatable grasses could also be helpful in managing to manipulate the composition of the pasture. Several accessions (including *D. eriantha* ATF 2109 and ATF 605 and *D. milanjiana* CPI 59828 and CPI 59777) could be used as alternatives to the cultivars Premier and Strickland. *Urochloa mosambicensis* CPI 46876 and 60127 are leafier types than Nixon but are likely to have similar weedy characteristics (heavy seeding, good colonising ability and lower palatability when mature) that are not favoured by some farmers. *Dichanthium annulatum* CPI 50819 and 84148.2 and *Panicum coloratum* ATF 714 have been less aggressive and lower yielding but they are very leafy and may combine well with legumes in leys.

Discussion

While the observations and measurements to date can only be regarded as preliminary, they indicate that other legumes are unlikely to be more productive than *Lablab purpureus* in the first year. *Centrosema*

Table 6. The percentage of plots covered by and yields of well-adapted cultivars and accessions of grasses at Cinnabar and Broad Creek in March 2002

Genus	Species	Cinnabar			Broad Creek	
		Acc/Cvv	%	(kg/ha)	%	kg/ha
Bothriochloa	*bladhii*	Swann	85	4248	90	5915
Bothriochloa	*insculpta*	Hatch	95	9497	92.5	10039
Bothriochloa	*insculpta*	Bisset	97.5	5497	100	9998
Bothriochloa	*insculpta*	69517	92.5	4591	97.5	8956
Dichanthium	*annulatum*	84148.2	65	4561	not sown	not sown
Dichanthium	*annulatum*	50819	50	3624	45	3749
Digitaria	*eriantha*	ATF 2109	80	3435	82.5	7498
Digitaria	*eriantha*	ATF 605	70	2936	92.5	8456
Digitaria	*eriantha*	Premier	90	3373	92.5	6914
Digitaria	*milanjiana*	59828	85	4185	97.5	7289
Digitaria	*milanjiana*	Strickland	82.5	4123	97.5	8081
Digitaria	*milanjiana*	59761	82.5	3560	40	2666
Digitaria	*natalensis*	59752	95	4185	90	4498
Panicum	*coloratum*	Bambatsi	55	3374	40	2666
Panicum	*coloratum*	ATF 714	55	2811	40	3499
Urochloa	*mosambicensis*	46876	95	7185	97.5	8956
Urochloa	*mosambicensis*	Nixon	70	4936	82.5	7665
Urochloa	*mosambicensis*	60127	80	4873	95	7164
Urochloa	*stolonifera*	47173	87.5	4966	98	8123

pascuorum CPI 65950 and Q 10050 appear better adapted to this environment than the cultivar Cavalcade and some *Alysicarpus rugosus* could be considered. However, for these to be serious contenders, they would need to regenerate with some reliability from seed in most years. This has not occurred over the last 3 years, but rainfall has been lower than average. Burgundy bean (*M. bracteatum*)*,* presently being developed for use in leys in cropping systems (Pengelly and Conway 2000) has again demonstrated it can produce high yields in the first season and persist at least into the second and third season.

Some of the more promising perennial legumes, although they have not been widely tested in this region, merit further consideration. The larger plots planted in 2002 at these sites will provide some opportunity for this, although the establishment was less than optimum. It is important now to confirm to farmers that these legumes can contribute better-quality leguminous forage to the grass pasture systems and show how they can benefit subsequent crops. Seed production of a range of legumes to allow testing in larger plots should be a priority — these include *Aeschynomene falcata* ATF 2194, *Desmanthus glandulosus* CPI 90319A, *Desmanthus bicornutus* CPI 90906*, Desmanthus leptophyllus* CPI 92809, 38820 and 63453*, Desmanthus virgatus* CPI 91326*,* 91491 and ATF 3009, and *Desmanthus* sp. AC 11.

A range of well-adapted and productive grass cultivars is available and farmers recognise their value. The main issue now is to encourage the use of the most appropriate grasses and better define their management requirements to meet specific needs. These needs are likely to vary widely from minimum inputs in extensive grazing to very complex requirements for more intensive livestock/cropping systems.

There has been ongoing interaction with farmers since the project commenced. Researchers and extension officers have met with farmer groups on several occasions to canvass their views and to determine priority areas. These farmers have always been supportive and are now using pasture information from this project in decision-making on issues that affect their properties and enterprises.

Farmers have been involved with a range of activities including meetings, field days, site selection and in compilation of the list of species entries, through recommending local standards and describing the types of plants required for their various production systems, as well as preparation for planting and stock management. Farmers at the Broad Creek site initially indicated they do not want accessions of *Chamaecrista rotundifolia* and *Urochloa panicoides* included in the evaluation. In the case of Wynn cassia (*C. rotundifolia* cv. Wynn) however, some farmers, through a better understanding of the role of legumes, now believe it can benefit their enterprises and are more comfortable to use it, knowing they can manage it to their advantage.

The cooperator at Broad Creek has also planted a small area (20 ha) of *Leucaena leucocephala* cv. Tarramba and is now planting Premier digit grass, a grass he was not familiar with before the project commenced, between the rows. Adjoining farmers are using larger areas of lablab in cattle finishing programs and others are considering lablab and leucaena as alternatives to planting oats. Fine-stem stylo is naturalised over areas on some properties and its value is being increasingly recognised. Other farmers in the district have planted areas of *Stylosanthes seabrana* on the basis of visits to the project sites. These outcomes confirm that these farmers now have a better understanding of the current and future role of legumes and grasses in their farming and grazing enterprises.

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Appendix I

List of legume species planted at Cinnabar (C) and Broad Creek (BC) in 2000 and 2002. A rating of the performance of each accession/cultivar is given as 0 = did not establish, 1 = established but poor (no promise), 2 = fair, 3 = good, 4 = very good (promising).

Species	Sites			
	C2000	C2002	BC2000	BC2002
Aeschynomene americana CPI 56282	1		1	
Aeschynomene americana CPI 93624	1		1	
Aeschynomene americana ATF 1086		3		1
Aeschynomene americana cv. Glenn	1		1	
Aeschynomene americana cv. Lee	1		1	
Aeschynomene falcata ATF 2194	2	3	2	2
Aeschynomene falcata ATF 2196	1		2	
Aeschynomene falcata cv. Bargoo	1	3	2	2
Aeschynomene hystrix CPI 93599	1		1	
Aeschynomene hystrix CPI 93636	1		1	
Aeschynomene hystrix CPI 93638	1		1	
Aeschynomene hystrix ATF 977	1		2	
Aeschynomene hystrix ATF 2191	2		2	
Aeschynomene villosa CPI 37235	1		1	
Aeschynomene villosa TPI 88	1		1	
Aeschynomene villosa cv. Kretchmer	1		1	
Aeschynomene villosa cv. Reid	1		1	
Alysicarpus monilifer CPI 52359	1		1	
Alysicarpus rugosus CPI 30034	2		1	
Alysicarpus rugosus CPI 30187	1		1	
Alysicarpus rugosus CPI 51655	1		1	
Alysicarpus rugosus CPI 76978	1		1	
Alysicarpus rugosus CPI 94489	2		1	
Arachis paraguariensis CPI 91419	2	2	2	0
Arachis paraguariensis Q 25237	2		2	
Arachis stenosperma CPI 91420	1		1	
Arachis stenosperma ATF 377	1		1	
Centrosema pascuorum CPI 65950	1		2	
Centrosema pascuorum Q 10050	2		2	
Centrosema pascuorum cv. Cavalcade	1		1	
Clitoria ternatea CPI 28810		1		1
Clitoria ternatea CPI 34582		1		1
Clitoria ternatea CPI 37456		1		1
Clitoria ternatea CPI 46379		1		1

Species	Sites			
	C2000	C2002	BC2000	BC2002
Clitoria ternatea CPI 47187		1		1
Clitoria ternatea CPI 49705		1		1
Clitoria ternatea CPI 50973		1		1
Clitoria ternatea CPI 51380B		1		1
Clitoria ternatea CPI 72531		1		1
Clitoria ternatea cv. Milgarra	1	1	1	2
Desmanthus acuminatus CPI 78379	1		1	
Desmanthus acuminatus CPI 78380	1		1	
Desmanthus acuminatus ATF 2986	2		1	
Desmanthus bicornutus CPI 81336	1		2	
Desmanthus bicornutus CPI 81341	1		1	
Desmanthus bicornutus CPI 84508	2		1	
Desmanthus bicornutus CPI 90906	3		1	
Desmanthus bicornutus CPI 91095	1		1	
Desmanthus bicornutus CPI 91162	3	4	1	0
Desmanthus glandulosus CPI 90319A	4	4	3	3
Desmanthus leptophyllus CPI 38351	3	2	2	0
Desmanthus leptophyllus CPI 38820	3	2	3	2
Desmanthus leptophyllus CPI 55719	4		1	
Desmanthus leptophyllus CPI 63453	4	2	3	2
Desmanthus leptophyllus CPI 65947	2		1	
Desmanthus leptophyllus CPI 87860	3		2	
Desmanthus leptophyllus CPI 87876	3		1	
Desmanthus leptophyllus CPI 92655	2		2	
Desmanthus leptophyllus CPI 92806	4		2	
Desmanthus leptophyllus CPI 92809	4		1	
Desmanthus leptophyllus CPI 92818	4		2	
Desmanthus leptophyllus TQ 90	4		2	
Desmanthus leptophyllus cv. Bayamo	4	2	3	2
Desmanthus paspalaceus CPI 78385	2		1	
Desmanthus paspalaceus CPI 83570	2		1	
Desmanthus paspalaceus ATF 3015	1		1	
Desmanthus paspalaceus ATF 3023	2		1	
Desmanthus pernambucanus CPI 21825	1		1	
Desmanthus pernambucanus CPI 30205	1		1	
Desmanthus pernambucanus CPI 33201	2		2	
Desmanthus pernambucanus CPI 33220	1		1	
Desmanthus pernambucanus CPI 40071	2		2	
Desmanthus pernambucanus CPI 49728	2		1	
Desmanthus pernambucanus CPI 55718	2		2	

Species	Sites			
	C2000	C2002	BC2000	BC2002
Desmanthus pernambucanus CPI 73463	1		1	
Desmanthus pernambucanus CPI 83565	3		2	
Desmanthus pernambucanus CPI 83566	3		2	
Desmanthus pubescens CPI 92804	2		1	
Desmanthus pubescens CPI 92815	1		1	
Desmanthus pubescens CPI 92829	1		1	
Desmanthus pubescens CPI 92830	2		1	
Desmanthus pubescens cv. Uman	2		1	
Desmanthus tatuhyensis CPI 25840	1		1	
Desmanthus tatuhyensis CPI 37538	1		1	
Desmanthus tatuhyensis CPI 90362	1		1	
Desmanthus tatuhyensis ATF 2240	2		1	
Desmanthus tatuhyensis ATF 2247	1		1	
Desmanthus tatuhyensis ATF 3024	1		1	
Desmanthus virgatus CPI 67643	3		1	
Desmanthus virgatus CPI 73465	2		1	
Desmanthus virgatus CPI 73467	1		1	
Desmanthus virgatus CPI 76055	1		1	
Desmanthus virgatus CPI 78371	1		1	
Desmanthus virgatus CPI 78372	2	2	2	0
Desmanthus virgatus CPI 78382	2		1	
Desmanthus virgatus CPI 79653	1		1	
Desmanthus virgatus CPI 83571	3		1	
Desmanthus virgatus CPI 83580	1		1	
Desmanthus virgatus CPI 85172	1		1	
Desmanthus virgatus CPI 85177	1		1	
Desmanthus virgatus CPI 85184	1		1	
Desmanthus virgatus CPI 89197	2		1	
Desmanthus virgatus CPI 90751	1		1	
Desmanthus virgatus CPI 90759	1		1	
Desmanthus virgatus CPI 91181	1		1	
Desmanthus virgatus CPI 91326	3	1	2	2
Desmanthus virgatus CPI 91459	1		1	
Desmanthus virgatus CPI 91491	4		1	
Desmanthus virgatus CPI 92722	2		1	
Desmanthus virgatus CPI 92805	2		1	
Desmanthus virgatus ATF 2250	1		1	
Desmanthus virgatus ATF 2253	1		1	
Desmanthus virgatus ATF 2256	1		1	
Desmanthus virgatus ATF 3009	3		1	

Species	Sites			
	C2000	C2002	BC2000	BC2002
Desmanthus virgatus Q 9153	1	2	2	0
Desmanthus virgatus cv. Marc	2		2	
Desmanthus sp. CPI 121840		1		1
Desmanthus sp. CQ 3650		1		2
Desmanthus sp. AC 10	4		1	
Desmanthus sp. AC 11	4		1	
Desmanthus sp. ATF 3785	2		1	
Desmanthus sp. ATF 3786	2	1	1	0
Desmanthus sp. ATF 3788	1		1	
Desmanthus sp. ATF 3897		1		1
Desmanthus sp. ATF 3898		1		1
Desmanthus sp. ATF 3910		1		1
Desmanthus sp. ATF 3911		1		1
Desmanthus sp. ATF 3912		1		1
Desmanthus sp. ATF 3913		1		0
Desmanthus sp. ATF 3914		1		1
Desmanthus sp. ATF 3915		1		1
Desmanthus sp. ATF 3916		1		1
Desmanthus sp. ATF 3917		1		1
Desmanthus sp. ATF 3922		1		0
Desmanthus sp. ATF 3926		1		1
Desmanthus sp. ATF 3928		1		1
Desmanthus sp. ATF 3930		1		1
Desmanthus sp. ATF 3931		1		1
Desmanthus comp cv. Jaribu				1
Lablab purpureus cv. Endurance	4		4	
Lablab purpureus cv. Highworth	4		4	
Lablab purpureus cv. Rongai	4		4	
Macroptilium atropurpureum cv. Aztec	3	3	3	2
Macroptilium atropurpureum CPI 84989		3		3
Macroptilium bracteatum CPI 55750	3		3	
Macroptilium bracteatum CPI 55758	3		3	
Macroptilium bracteatum cv. Cadarga	3	3	3	3
Macroptilium bracteatum cv. Juanita		3		3
Medicago sativa cv. Trifecta	1		3	
Neonotonia wightii CPI 111766	1		1	
Neonotonia wightii CPI 111767	1		1	
Neonotonia wightii CPI 111770	1		1	
Neonotonia wightii CPI 111771	1		1	
Neonotonia wightii CPI 111772	2		2	

Species	Sites			
	C2000	C2002	BC2000	BC2002
Neonotonia wightii CPI 111773	1		1	
Neonotonia wightii CPI 111775	1		0	
Neonotonia wightii CPI 111776	1		0	
Neonotonia wightii cv. Cooper	1		2	
Stylosanthes guianensis var. *intermedia* ATF 3067	3		2	
Stylosanthes guianensis var. *intermedia* ATF 3070	3	3	2	0
Stylosanthes guianensis var. *intermedia* ATF 3071		1		1
Stylosanthes guianensis var. *intermedia* cv. Oxley	3	2	3	2
Stylosanthes mexicana CPI 87469	2		1	
Stylosanthes mexicana CPI 87479	2		1	
Stylosanthes mexicana CPI 87484	3		1	
Stylosanthes scabra CPI 110116	3		3	
Stylosanthes scabra ATF 3076		1		2
Stylosanthes scabra ATF 3077		2		0
Stylosanthes scabra cv. Seca	4	3	4	2
Stylosanthes scabra cv. Siran	4		4	
Stylosanthes seabrana ATF 2523		1		2
Stylosanthes seabrana ATF 2539		2		2
Stylosanthes seabrana cv. Primar	3		3	
Stylosanthes seabrana cv. Unica	3	2	3	2
*Vigna oblongifoli*a Q 25362	1		1	
*Vigna oblongifoli*a CPI 60433		1		1
Vigna trilobata CPI 13671		1		1
Vigna unguiculata CPI 121688		1		0

Appendix II

List of grass species planted at Cinnabar (C) and Broad Creek (BC) in 2000 and 2002. A rating of the performance of each accession/cultivar is given as 0 = did not establish, 1 = established but poor (no promise), 2 = fair, 3 = good, 4 = very good (promising)

Species	Sites			
	C2000	C2002	BC2000	BC2002
Bothriochloa bladhii CPI 104802A	2		1	
Bothriochloa bladhii cv. Swann	2		2	
Bothriochloa insculpta CPI 69517	4		4	
Bothriochloa insculpta CPI 106671	2		2	
Bothriochloa insculpta cv. Bisset	4		4	
Bothriochloa insculpta cv. Hatch	4		4	
Bothriochloa pertusa cv. Keppel	2		1	
Bothriochloa pertusa cv. Medway	2		1	
Cenchrus ciliaris CPI 71914	2		1	
Cenchrus ciliaris CPI 73393	2		1	
Cenchrus ciliaris cv. American	3		2	
Cenchrus ciliaris cv. Bella	3		1	
Cenchrus ciliaris cv. Gayndah	3		2	
Cenchrus ciliaris cv. Viva	2		3	
Chloris gayana ATF 3964		2		
Dichanthium annulatum CPI 50819	2		1	
Dichanthium annulatum CPI 84148.2	3		ns	
Dichanthium aristatum cv. Floren	2		1	
Digitaria eriantha CPI 125659		2		
Digitaria eriantha CPI 125659A		2		
Digitaria eriantha CPI 125659B		2		
Digitaria eriantha ATF 605	3	2	4	
Digitaria eriantha ATF 616	2		3	
Digitaria eriantha ATF 618	2		3	
Digitaria eriantha ATF 2109	3		3	
Digitaria eriantha cv. Premier	3	3	4	3
Digitaria milanjiana CPI 59755	3		2	
Digitaria milanjiana CPI 59761	3		2	
Digitaria milanjiana CPI 59777	4		3	
Digitaria milanjiana CPI 59787	2		3	
Digitaria milanjiana CPI 59828	3		3	
Digitaria milanjiana cv. Jarra	2		1	
Digitaria milanjiana cv. Strickland	4		3	
Digitaria natalensis CPI 59752	3		1	
Panicum coloratum CPI 16796		1		

Species	Sites			
	C2000	C2002	BC2000	BC2002
Panicum coloratum ATF 714	2		1	
Panicum coloratum ATF 3957		1		
Panicum coloratum cv. Bambatsi	2	1	1	
Panicum maximum cv. Gatton	2		3	
Panicum maximum cv. Petrie	3		3	
Panicum sp. aff. *infestum* cv. C1	1		1	
Paspalum simplex ATF 3128	1		1	
Urochloa mosambicensis CPI46876	4		4	
Urochloa mosambicensis CPI 47167	4		4	
Urochloa mosambicensis CPI 60127	4		4	
Urochloa mosambicensis CPI 60139	3		3	
Urochloa mosambicensis CPI 60151	4		3	
Urochloa mosambicensis cv. Nixon	4		3	
Urochloa mosambicensis cv. Saraji	2		3	
Urochloa oligotricha CPI 47122	3		1	
Urochloa oligotricha CPI 47129	2		2	
Urochloa oligotricha CPI 60122	2		2	
Urochloa oligotricha CPI 60123	4		1	
Urochloa oligotricha CPI 73436	2		ns	
Urochloa stolonifera CPI 47173	4		4	
Urochloa stolonifera CPI 47178	3		2	

Farming Systems Research

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The Role of Dual Purpose and Forage Legumes to Improve Soil Fertility and Provide High Quality Forage: Options in a Maize-based System in Zimbabwe

O. Jiri,* B.V. Maasdorp,* E. Temba* and A.M. Whitbread†

Abstract

Mucuna pruriens and *Lablab purpureus* have emerged as successful forage or green-manure legumes for use in the smallholder crop–livestock systems of Zimbabwe. Two experiments were established in the 1999–2000 wet season at on-farm sites within a mixed livestock–cropping farming system in Wedza district (average rainfall 650–900 mm) located on acidic ($pH < 5$) and infertile sandy and sandy-loam soils. Two additional sites were located on more-fertile clay soils.

Experiment 1 showed that improved fallows of mucuna grown for 19 weeks produced between 4.7 and 11.2 t/ha DM and generally doubled that produced by cowpea or a first-year *Macrotyloma axillare* cv. Archer–*Chloris gayana* perennial pasture. Weedy fallow treatments, which represent typical farmer practice, produced 3.3–6.3 t/ha DM. After harvest of the mucuna system, the biomass was either removed as hay or ploughed in as green manure. A maize crop was then grown on these treatments and on the weed-fallow treatments in the following 2000–2001 wet season. On sandy sites where no P fertiliser was applied to the previous mucuna phase, a maize grain yield of 2.3 t/ha was achieved following the mucuna green-manure system; this was 64% higher than the maize yield following the weedy fallow and 100% higher than the maize yield following the mucuna 'removed' hay system. Averaged across the seven sites, grain yield declined from 2810 to 1680 kg/ha when mucuna residues were removed as hay. The fertilised (93 kg/ha N, 18 kg/ha P) continuous maize system produced 2920 and 4460 kg/ha on the sandy and clay sites, respectively.

Experiment 2 investigated the maize-grain response to the application of 0, 30, 60, 90 and 120 kg/ha of fertiliser N, and compared it with maize production following a one-year weed fallow or forage lablab. Results showed that, by integrating forage lablab into arable fallow land, subsequent maize grain yield could be from 8 to 57% higher than maize following a weedy fallow. Farmers could rotate forage lablab and maize and benefit from large amounts of high-quality fodder from the lablab above-ground biomass and also gain soil fertility amelioration from the residual effect of the lablab below-ground biomass.

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* Crop Science Department, University of Zimbabwe, PO Box MP 167, Harare, Zimbabwe.

† CSIRO Sustainable Ecosystems, 306 Carmody Road, St Lucia, Queensland 4067, Australia.

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For improved fallow management to be adopted by crop–livestock farmers, the practice must enhance both dry-season feed supply and soil fertility for subsequent cropping. An improvement of weed fallow management systems with sown legumes has the potential to enhance the restoration of soil fertility through the fixation of atmospheric N_2, and/or through an improvement in soil-physical properties (Wilson 1988). Suitable legumes also have the potential to alleviate feed constraints, especially for cattle and during the dry season, through their higher nutritive value compared with natural fallow (Minson 1984).

Mucuna (*Mucuna pruriens* var *utilis*) is a vigorous, twining annual legume whose primary roles are soil-fertility maintenance, soil protection and weed suppression (Carsky et al. 1998). The biomass can also be used as fodder, and the seed as feed or food (Duke (1981) and Olaboro (1993), quoted by Buckles et al. (1998)). Dry-matter production in mucuna, as with all other crops, is affected by soil fertility. Dry matter and ground cover will also depend on the occurrence of drought or waterlogging (Buckles et al. 1998). There is thus a need to evaluate mucuna dry-matter production under the poor soil-fertility, sub-humid conditions that prevail in the smallholder farming sector of Zimbabwe, where it could have potential in alleviating the problems of poor soil fertility and inadequate animal feed.

Lablab (*Lablab purpureus*) is also a twining annual legume capable of producing large quantities of biomass. It makes excellent hay if harvested at the right time when most of the leaf is still intact. Its crude protein content is approximately 12% (Muchadeyi 1998). Lablab tolerates drought, a common phenomenon in most cropping environments in Zimbabwe. Like mucuna, it is large-seeded, hence easy to handle and establish, and its deep and extensive root system contributes to soil organic matter content when decomposed and improves aeration and soil structure. As with mucuna, it is an excellent nitrogen fixer, hence has the potential to maintain and improve available soil nitrogen (Ayoub (1986), quoted in Haque et al. (1986)). It would appear, therefore, that lablab grown for forage on arable lands also has the potential to enhance soil fertility while at the same time supplying large quantities of good-quality fodder.

Two, on-farm, multi-site experiments that were conducted in the Wedza district of Zimbabwe are described in this paper. Experiment 1, drawn from the MPhil thesis of Jiri (2003), was established to compare the relative benefits of a weedy fallow and a system where mucuna was grown and either removed for hay (for animal feeding) or ploughed in as a green manure, on the yield of a subsequent maize-cropping phase. Comparisons were also made with continuous fertilised maize. The response to P and lime application by mucuna, and to P application by cowpea and a perennial grass–legume system, were also investigated. Experiment 2, based on the studies of Temba (2001), investigated the effect of a lablab or weed fallow, with the biomass used for forage, on the growth of maize, as compared with the application of inorganic fertiliser N.

Methods and Materials

Both experiments were conducted in the smallholder farming community of Wedza (18°41’S latitude, 31°42’E longitude; 1400 masl), which lies in Natural Regions IIb and III (Surveyor-General 1984) and is located 150 km southeast of Harare in Zimbabwe. Mean annual rainfall ranges from 600 to 900 mm, with most falling during November–March. Details of the environment and farming system at Wedza can be found in Chigariro (2004).

Rotation experiment 1

An on-farm experiment was established at nine separate farmers’ fields across a range of soil types. Difficulties in the field activities at two of these sites resulted in data from only seven of the sites being reported here. The aim of this experiment (Jiri 2003) was to determine the residual effects of year 1 treatments (Table 1) established in November–December 1999 on the subsequent maize yield in the 2000–2001 season. At each site, treatment plots of 8 × 9 m were laid out randomly in a block with no on-farm replication. While farmers were responsible for tillage operations, weeding, and assisted in the planting and harvesting operations, the experiments were essentially researcher-designed and managed on-farm trials.

1999–2000 season. Weeds on the weed fallow treatments grew unchecked from November 1999 until they were measured for biomass on 11–13 April 2000 and removed (simulating dry-season grazing).

Mucuna (*Mucuna pruriens* var. *utilis*) and cowpea (*Vigna unguiculata*, a trailing variety ex Matopos) fallow and continuous maize (*Zea mays* var. SC501) were planted (two seeds per station) from 25–30

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November 1999 in 90 cm rows with 30 cm spacing between plants. All legume seed was inoculated with rhizobium before planting. The maize, mucuna and cowpea plants were thinned to one plant per station when the maize had reached the three-leaf stage. Phosphorus was applied as single superphosphate (8% P, 12% S) at a rate of 16 kg/ha to +P mucuna and +P cowpea treatments before planting. An additional mucuna treatment that received 16 kg/ha P (as single superphosphate) and 500 kg/ha of dolomitic lime was included at each site to test the response of mucuna to lime.

The continuous maize plots, also started in the 1999–2000 season, received 18 kg/ha P and 24 kg/ha N banded near the plants in the form of ‘Compound D’ fertiliser (8:6:6:6.5% N:P:K:S) at planting and 69 kg/ha N applied 5 weeks after planting (WAP) in the form of ammonium nitrate (34.5% N). Hand-weeding of all plots occurred at the same time as the topdressings were applied. Carbaryl and dimethoate were used as required to control leaf eaters and aphids.

Macrotyloma axillare cv. Archer mixed with *Chloris gayana* (Katambora rhodes grass) was planted in year 1 into shallow furrows and lightly covered with soil. An additional treatment that received 16 kg/ha P at planting was also established. Being a perennial system, the archer–rhodes grass mix was grown for 2 years, and its forage production compared with mucuna and cowpea in year 1.

All treatments were harvested 11–13 April 2000 (~19 WAP) using a net plot area (42 m^2) formed after removing a 1 m border area for mucuna and 43.2 m^2 for maize. The archer–rhodes grass plots were cut at 10 cm above the ground to facilitate regrowth. Plant material from the net plots was weighed, subsampled and dried at 60°C for 48 hours to determine dry matter. In the continuous maize treatments, cobs were removed from the stalk, dehusked and shelled for grain. Plant residues from the mucuna, cowpea and archer–grass hay treatments were removed from the plots to simulate a hay system. Plant residues from the mucuna green-manure treatment were returned to the plots and immediately incorporated by ploughing with an animal-drawn implement. Mucuna pods were considered as biomass.

Grazing livestock were allowed access to these areas during the dry season (May–October), as these farms are situated in the communal farming areas where livestock roam freely during the non-cropping season.

Maize crop 2000–2001. Maize was planted across all treatments (except archer–grass) in the 2000–2001 season. All fields were ox-ploughed by the farmers by 11 October 2000. Maize var. SC501 was planted into all plots on 28–29 November 2000 and, other than fertiliser application, managed as in year 1. The continuous maize treatments received 18 kg/ha P and 24 kg/ha N banded near the plants in the form of Compound D at planting and 69 kg/ha N split-applied at 3 and 6 WAP in the form of ammonium nitrate. All other plots received 30 kg/ha of N as ammonium nitrate, split-applied at 3 and 6 WAP. Hand-weeding of all plots was undertaken at the same time as the topdressings were applied. Harvesting took place on

Table 1. List of treatments used in experiment 1 conducted by Jiri (2003).

Year 1 treatments	N (kg/ha)	P (kg/ha)	Year 2 treatments	N (kg/ha)	P (kg/ha)
Weed fallow			Maize	30	
Maize (full fertiliser rate)	93	18	Maize	93	18
Mucuna (ley)		16	Maize	30	
Mucuna (ley)			Maize	30	
Mucuna (green manure)		16	Maize	30	
Mucuna (green manure)			Maize	30	
Mucuna (ley) + lime		16	Maize	30	
Cowpea		16	Maize	30	
Cowpea			Maize	30	
Perennial ley		16			
Perennial ley					

10 April 2001 using the same procedures as described for year 1.

Rotation experiment 2

Full details of this experiment can be found in Temba (2001). In the 1999–2000 season on two farms in the Wedza district with granitic sandy soils, a block was planted to lablab (with 27 kg/ha P as SSP and 500 kg/ha lime) and an adjacent area remained under weedy fallow (no inputs). At the end of the season, lablab was harvested by cutting at the base of the stem (whole plants cut with sickles) and made into hay for feeding dairy animals. The roots of lablab and their crowns, together with fallen leaves, remained *in situ*. The lablab grew well, but no estimate of either the above or below-ground biomass was measured. In May 2000, the sites were tilled with an ox-drawn plough.

In mid-November 2000, a short season maize variety (SC407) was sown with 6 fertiliser treatments × 3 replicates marked out in each of the lablab and weed areas at the 2 farms (plots size 5 × 4 m). The lablab treatments received 0, 30 and 60 kg/ha N (as ammonium nitrate) ± basal fertiliser (16.7 kg/ha P and 22 kg/ha S as SSP, and 15 kg/ha K as potassium chloride). The weed treatments received 0, 30, 60, 90 and 120 kg/ha N (as ammonium nitrate) + basal fertiliser as above, and an additional 0 N plot received no basal fertiliser (Table 2). The basal fertilisers were applied before sowing and the N fertiliser was split and applied at 4 and 7 WAP.

The maize was planted in 90 cm rows with 30 cm between plants for a target population of 37,000 plants/ha. At maturity, net plot areas of 2.7 × 2.8 m, which excluded border rows and plants, were harvested.

Soil types. Experiment 1 was conducted at 7 sites, 5 of which were located on sandy or sandy loam soil, all of which were derived from granite and classified as Ferralic Arenosol (FAO–UNESCO 1974) (Table 3). The 'Gunzvenzve' site was located on a red clay classified as a Chromic Luvisol derived from doleritic parent material, and the black clay 'Dzunza' site was classified as a Vertisol. Experiment 2 was conducted at two sites, one of which was located adjacent to the Mbavha sandy site and the other at the farm of Muparadzi located on a sandy loam (Table 3). Both soils are classified as Ferralic Arenosols.

Soil and plant analyses

In experiment 1, soil samples (0–15 and 15–30 cm depth) collected from each of the seven sites at the start of the experiment were dried, ground (< 2 mm) and analysed for total organic carbon using the Walkley and Black method with a correction factor of 1.3 (Walkley 1947), and for plant available P using the Bray I (0.03M ammonium fluoride in 0.025M HCl) method (Bray and Kurt 1945). The basic cations K^+, Ca^{2+} and Mg^{2+} were determined using atomic absorption spectrometry on extractions in 1M ammonium chloride at pH 7 (Rayment and Higginson 1992). The soil pH was determined using a pH meter in a 1:5 soil/0.1M $CaCl_2$ solution. In experiment 2, soil samples were collected from the weed fallow and lablab treatments following the 1999–2000 season.

Statistical analysis

In year 1, the mucuna hay and green-manure treatments and an additional mucuna treatment that was to be resown as a two-season hay crop were used as

Table 2. List of treatments used in experiment 2 conducted by Temba (2001).

Treatment number	Maize following lablab		Treatment number	Maize following one year weed fallow	
	N fertiliser[1] (kg/ha)	±Basal fertiliser[2]		N level (kg/ha)	±Basal fertiliser
1	0	+	7	0	–
2	0	–	8	0	+
3	30	+	9	30	+
4	30	–	10	60	+
5	60	+	11	90	+
6	60	–	12	120	+

[1] Ammonium nitrate applied at 4 and 7 weeks after planting.

[2] 16.7 P:22 S:15 K kg/ha applied as SSP and potassium chloride.

three replicates in an analysis of variance (ANOVA). Treatment differences in the growth of mucuna between the –P, +P and +P+lime treatments were tested in an ANOVA using the 7 sites as replicates. Significant difference was used to calculate mean separation based on Duncan's multiple range test (DMRT). In year 2, treatment differences in maize grain and biomass were tested using the sites as replicates in an ANOVA. and least-significant difference was used to calculate mean separation based on DMRT.

Results

Soil properties

The sandy and sandy-loam soils were, in general, highly acidic, with the pH (CaCl2) below 4.4 and very low in the status of base cations K+, Ca++ and Mg++ (Table 3), reflecting very low soil-organic matter (total carbon, CT < 0.4%) and an associated low cation-exchange capacity. According to Gourley (1999), a soil K concentration below 0.2 cmol(+)/kg is considered to be low for tropical pastures, while a value of <0.3 cmol(+)/kg is the critical concentration for maize. Aitken and Scott (1999) considered 0.21–0.27 cmol(+)/kg to be the critical soil concentration of Mg for maize growth. The two clay soils were slightly less acidic, contained more soil organic C and cations. According to the Zimbabwean Classification of Bray extracted P, available P was considered to be low (less than 7 μg/g Bray-1 P) at all sites, with the exception of the Mbavha site in experiment 1, where P status was considered medium (Zvomuya (1996), quoted in Chenje et al. (1998)). This confirms the infertility of these over-cropped soils.

Rotation experiment 1

Year 1 treatments (1999–2000). Average rainfall received across the seven sites during the growing season was 660 mm. There was a significant difference in biomass between sites (Figure 1). The highest biomass measurements were obtained on the sandy-loam and clay soil types. These heavier soil types contained the highest concentrations of soil C and cations (Table 3), and most likely had a higher water-holding capacity. In the continuous maize treatments, the average grain and stover yield of the clay sites was almost double that of the sandy and sandy-loam sites (Table 4). Weed biomass produced on the clay sites was also double the biomass grown on the sandy sites.

Averaged across all sites, mucuna biomass, relative to the mucuna treatments that received no inputs, increased by 31% with the application of 16 kg/ha of P, and by 52% with the addition of 16 kg/ha of P and 500 kg/ha of lime (Figure 2). There were no significant differences, however, between the +P and +P+Lime treatments.

Year 2 maize response (2000–2001). Average rainfall received across the seven sites during the growing season was 918 mm; a mid-season drought

Table 3. Soil properties of the seven on-farm sites (0–30 cm depth).

Location	Soil type	pH ($CaCl_2$)	P[a] (μg/g)	C[b] (%)	K^+	Mg^{2+}	Ca^{2+}
					cmol+/kg		
Experiment 1							
Mbavha	Sand	4.2	11.5	0.29	0.09	0.44	0.09
Mumvana	Sand	4.2	7.0	0.27	0.11	0.53	0.10
Mapira A	Sand	4.3	5.5	0.36	0.11	1.00	0.26
Chikumbirike	Sand	4.2	3.5	0.36	0.11	0.13	0.12
Mapira C	Sandy loam	4.4	7.0	0.34	0.17	0.32	0.14
Gunzvenzve	Red clay	4.8	1.0	0.96	0.19	7.67	4.40
Dzuna	Black clay	5.2	1.0	1.22	0.23	8.10	6.21
Experiment 2							
Mbavha	Lablab	4.6	3.4	–	0.16	0.32	0.46
	Weed	4.1	1.0	–	0.09	0.17	0.31
Muparadzi	Lablab	4.3	1.5	–	0.04	0.19	0.26
	Weed	4.6	1.0	–	0.04	0.17	0.28

[a] Fluoride extractable phosphorus (Bray 1-P).
[b] Walkley–Black (Walkley1947)

occurred. An ANOVA using the sites as replicates (n = 7) revealed a significant difference between replicates, though when the 5 sandy and 2 clay sites were analysed separately, no significant difference was found between them. The weed fallow was used as the control for the treatments that did not receive P in the previous season. On the sandy sites, the mucuna green-manure treatments produced 64 and 100% ($p < 0.05$) more than the maize produced following a weed fallow or mucuna that was removed for hay, respectively (Figure 3). No significant difference was found between treatments at the clay sites.

Table 4. The yield (kg/ha) of maize grain and stover, and the biomass (kg/ha) of weeds in the weedy fallow treatments, produced during the 1999–2000 season.

	Sand/sandy loam	Clay
Maize[a] grain	2160[b] (690)	5750 (350)
stover	2888 (870)	6550 (250)
Weed	3308 (660)	6280 (70)

[a] (Maize received 93, 18, 18, 19.5 kg/ha N, P, K, S respectively).
[b] Standard error in brackets calculated for sand ($n = 5$) and clay ($n = 2$)

The fertilised continuous maize control was used as the control for the mucuna treatments that received P in year 1 of the experiment. At the sandy sites, no significant difference in maize yield was found between the treatments (Figure 4). At the clay sites, however, maize grain yield was greatest with full fertiliser application, and was significantly further reduced where the mucuna was removed for hay in the previous season (Figure 4).

There was a significant interaction between P application and the management of the mucuna residues on the 2000–01 maize grain yield. There was no difference in maize growth where P had been applied to the mucuna hay or green-manure treatments in the 1999–2000 season (Figure 5). However, where fertiliser P was not applied, compared with maize following mucuna green manure, maize yield was significantly reduced following the mucuna hay treatment in the 1999–2000 season (Figure 5). P applied to a preceding mucuna hay crop significantly increased maize grain yield, but there was no maize response to P applied to mucuna green manure.

The maize that followed the cowpea treatments did not respond to the P applications that were applied to the cowpea crop (data not shown). There were also no significant differences between cowpea sites: mean grain yield following cowpea was 3710 kg/ha. There were no results for the maize crop following the two-year perennial ley system due to drought in 2001–02.

Rotation experiment 2

Following a weed fallow, there was a response up to 30 kg/ha N at Muparadzi site and up to 60 kg/ha N

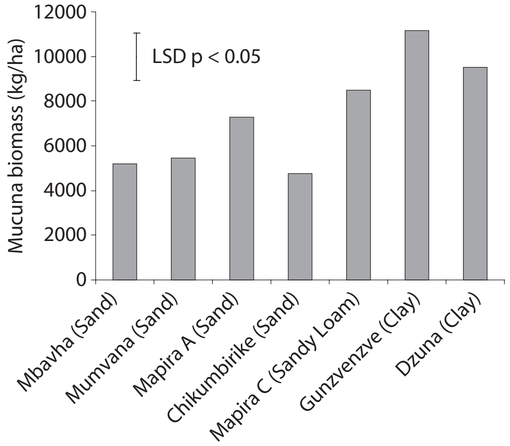

Figure 1. The biomass of mucuna produced at 7 on-farm sites in Wedza District, Zimbabwe in the 1999–2000 wet season.

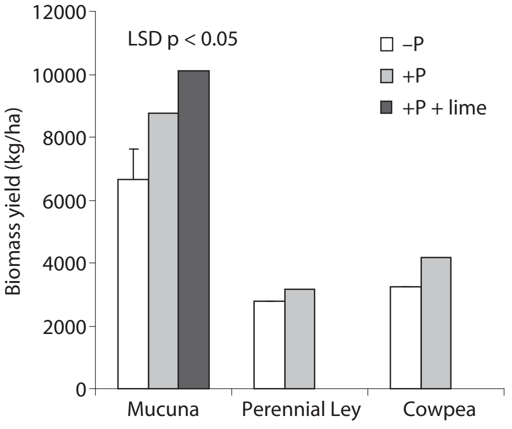

Figure 2. The response of mucuna, the perennial ley and cowpea to P fertilisation and mucuna to 500 kg/ha of dolomitic lime in 1999–2000. (LSD refers to the treatment mean differences within the mucuna treatment only.)

at Mhuka site (Figure 6). This lack of further response to higher levels of N indicates that limitations other than nitrogen may have affected plant growth. The basal fertilisers containing P, K and S did not overcome these limitations in the weed treatments.

Maize following a lablab hay crop to which P, S and lime had been applied, showed no significant response to the basal P, K and S (hence ± means are shown). Maize following the lablab at the Mhuka site yielded significantly more grain than that following the weed fallow. The effect of lablab on maize yield was much smaller at the Muparadzi site.

Maize yield was significantly lower with the treatments that received no N or basal fertiliser grown after the weed fallow (Figure 6).

Discussion

Experiment 1

The biomass production of mucuna was excellent at all sites, and exceptional on the soils that had a higher clay content (9500–11200 kg/ha) and consequently greater water-holding capacity and more cations. Mucuna was able to grow across a range of soils where the available P status was medium (Mbavha) to low (all other sites), it responded significantly to the addition of P and lime. A separate study reported in Jiri (2003) showed some evidence that, with dolomitic lime application, mucuna was responding to the increase in the availability of P, rather than to an increase in the supply of Mg or Ca. This warrants further investigation.

The fact that mucuna produced more biomass than cowpea and the archer–rhodes grass system is important for farmers who need to replenish soil fertility and produce fodder for livestock. However, for farmers who value relish (young leaf) more than fodder, cowpea would be more important.

The growth of maize in 2000–2001 was influenced by an interaction between soil type, fertiliser application and management of the previous season's residues. Where fertiliser P was not added to either the fallow or maize phase, significantly more maize was grown where mucuna was green-manured (Figure 5), particularly on the sandy sites (Figure 4), presumably the result of P uptake by mucuna and recycling during the maize phase. The removal of the mucuna residues for hay generally resulted in a negative effect at all sites where fertiliser P had not been added. Under the

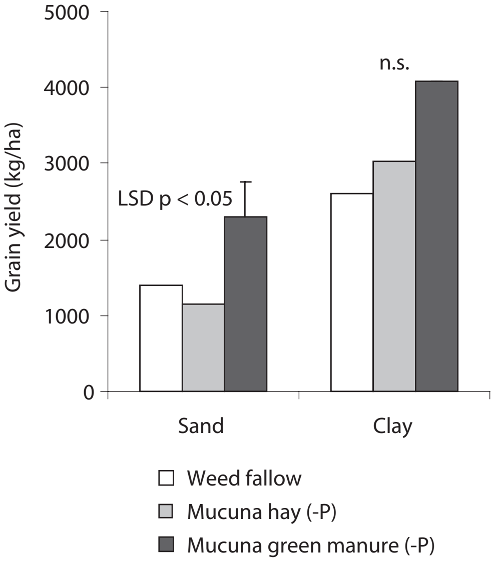

Figure 3. The effect of a weed fallow, mucuna (–P) grown as hay or green-manure in the 1999–2000 season on maize grain yield (kg/ha) in the 2000–2001 season. (LSD refers to the treatment mean differences within the sandy site only.)

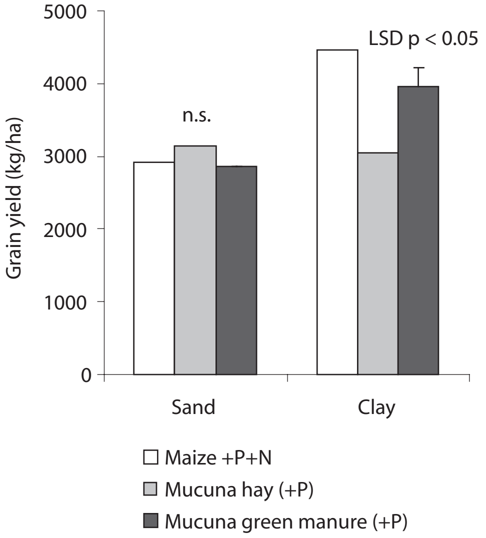

Figure 4. The effect of maize (fully fertilised), mucuna (+P) grown as hay or green-manure in the 1999–2000 season (+P) on maize grain yield (kg/ha) in the 2000–2001 season. (LSD refers to the treatment mean differences within the clay site only.)

marginal to very low available soil P concentrations measured at all sites (Table 3), maize was highly responsive to P additions. Carsky et al. (2001) found that maize response to a lablab fallow that received 9 kg/ha P was similar to maize that received 30–60 kg/ha N. Studies showing the effect of recycled P on subsequent crops are rare. Breman (1998), cited by Carsky et al. (2001), suggests that the introduction of improved legume fallows is not an adequate strategy where P is limiting.

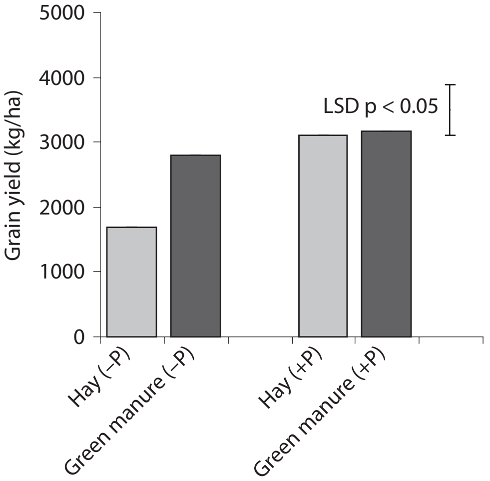

Figure 5. The effect of P-fertilised or unfertilised mucuna grown as hay or green-manure (1999–2000) on the grain yield of maize in 2000–2001 averaged across all sites.

Experiment 2

The growth of forage lablab can result in superior performance by a subsequent maize crop in terms of grain yields when compared to a one-year weed fallowed land, by an average of 57% at the Mhuka site and 8% at the Muparadzi site (Figure 6). Following lablab at the Mhuka site, the maize yield without N was similar to that achieved with 60 kg/ha N after weed fallow. Nitrogen fixed by lablab must have partly contributed to the higher maize grain yields achieved when maize followed forage lablab when compared to yields obtained on land fallowed for one year. Another factor contributing to this could be residual effects of the SSP and lime applied to the lablab. Removal of above-ground biomass (for hay making) implied that N that could have contributed to superior performance of maize following lablab would have been sourced from that which remained in roots, crowns and fallen leaves of the lablab.

The decomposition of lablab roots, crowns and leaf litter would also have led to addition of soil organic matter, an important component of a good soil which improves water-holding and cation exchange capacities of the soil and, in consequence, an improved soil physical-environment for subsequent crops (Muhr et al. 1999). In the mucuna trials, it was found that in some cases there were no significant differences in following maize yields between above-ground mucuna biomass removal and incorporation, indicating that it would be more judiciously used as fodder, with the remaining below-ground biomass still contributing significantly to soil improvement.

Thus, farmers in the smallholder sector, who are usually on poor soils in terms of fertility, could apply up to 60 kg/ha N less to maize if forage lablab is used in an improved fallow system instead of leaving land under weed fallow.

Conclusion

In year 1 of the experiment, mucuna was able to produce significant biomass across a range of soil types containing marginal to very low available soil P. Mucuna produced the highest biomass on soils with the highest water-holding capacity and responded significantly to applications of P fertiliser (16 kg/ha P) at planting. In year 2 of the experiment, where maize was grown across the treatments, on the sandy sites in the absence of fertiliser P additions, maize grain production was much higher following green-manuring practices than after a weedy fallow or mucuna ‘removed’ as hay.

The lablab forage system, with P, S and lime applied, has the potential to restore soil fertility to a greater extent than a weed fallow and contribute to increased subsequent crop yield. By growing forage lablab, farmers could reduce the amount of fertiliser N from organic sources and cut down on production costs. Farmers could apply 30 kg N/ha and be able to produce satisfactory maize grain yields following lablab and simultaneously obtain quality hay for animal feed.

Leaving land under weedy fallow for a season does little to restore soil fertility, having little effect on the yield of a subsequent crop. The results clearly show that smallholder farmers could benefit more by integrating SSP-fertilised forage legumes into fallow lands as leys (for hay), or as green manure if unferti-

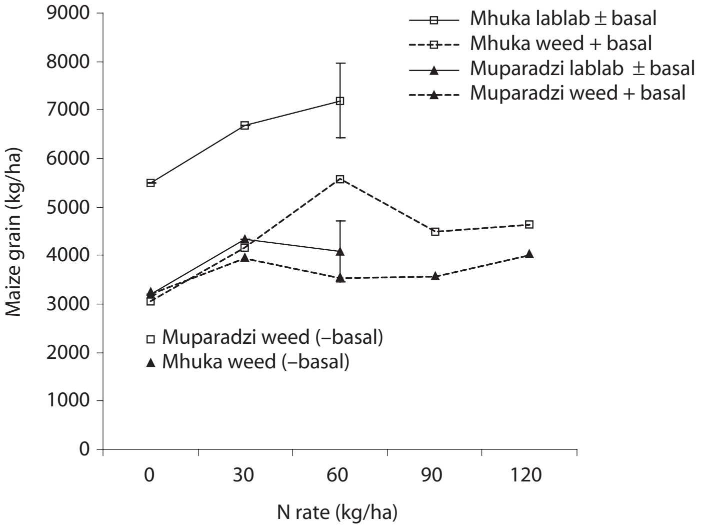

Figure 6. Effect of forage lablab on subsequent maize grain yield with different fertiliser levels relative to a one-year weed fallow at Mhuka and Muparadzi sites. (The LSD bar refers to the treatment mean differences between the lablab and weed fallow treatments at each of the sites separately.)

lised. Instead of leaving arable lands under weedy fallow, farmers could crop them to a forage legume, such as mucuna or lablab. They can harvest the large quantities of high-quality above-ground biomass for livestock feed and still benefit the following season in terms of soil-fertility improvement and increased yield, with reduced inorganic fertiliser inputs.

Recommendations for future research

1. Further investigations of the options of using leguminous hay and green-manure crops and applying various rates of fertilisers using a farming systems model such as the Agricultural Production System sIMulator (APSIM) (Keating et al. 2003).
2. Further investigations of the lablab and mucuna forage systems on different soils with replications at sites. This would lead to more conclusive evidence than the single-site data derived here for mucuna.
3. It would also be important to design a system in which the potential conflicts between mucuna or lablab integration systems are fully compared and contrasted in terms of costs and benefits in an economic analysis.
4. There is need to assess and quantify the forage legume root contribution to N for the subsequent crop.

Acknowledgments

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Growth and Symbiotic Activities of Cowpea Cultivars in Sole and Binary Cultures with Maize

K.K. Ayisi and P.N.Z. Mpangane*

Abstract

Nitrogen is a major limiting plant nutrient in cereal production in smallholder farming systems in the Limpopo Province of South Africa and the practice of intercropping the cereal with legumes is usually proposed to enhance nitrogen nutrition in the system. The benefit of symbiotic nitrogen fixation in intercropping systems has, however, been variable over diverse environments and needs further clarification. Alternate intercropping studies of maize and four distinct cowpea cultivars were conducted in 1998/99 and 1999/2000 at Syferkuil and Thabina/Dan in the Limpopo Province to determine the effect of the system on growth, nodulation, N_2 fixation and nitrogen uptake of the component crops. Maize dry-matter accumulation was generally not influenced by intercropping and nitrogen uptake of intercropped maize was only improved relative to the sole culture maize at Syferkuil in 1999/2000. On average, the amount of nitrogen fixed by the cowpea cultivars was higher in the intercropped cowpea than the sole crops, except in 1999/2000 at Syferkuil, where the amount fixed was 8.6% higher in the sole than the intercropped cowpea. The amount of nitrogen fixed by the legumes ranged from 20 to 69 kg N/ha and 87 to 217 kg N/ha at Syferkuil in 1998/99 and 1999/2000, respectively, whereas at Thabina/Dan, the range was 103 to 175 kg N/ha and 83 to 147 kg N/ha, in 1998/99 and 1999/2000, respectively. Nodule formation differed among the cowpea cultivars tested, with the long-season cowpea cultivars generally producing heavier nodules at both locations in the two growing seasons. The different performance of the cowpea cultivars in nitrogen fixation at the two locations emphasises the importance of the environment on symbiotic nitrogen fixation activities in cowpea.

Intercropped systems consisting of cereals and legumes are common throughout Africa, including in smallholder farming systems in the Limpopo Province of South Africa. However, in this province, the proportion of the legume is relatively small compared to the cereal, since maize is the priority crop. The widespread practice of intercropping cereals and legumes may be due to some of the established and speculated advantages of intercropping, such as higher grain yields (Harris et al. 1987; Putnam and Allan 1992), greater land-use efficiency per unit land area (Baker and Blamey 1985; Harris et al. 1987) and improvement of soil fertility by addition of nitrogen through symbiotic fixation and excretion from component legume species (Patra et al. 1986).

The dominance of maize in the smallholder cropping system of the Limpopo Province has resulted in poor soil fertility, particularly in nitrogen and phosphorus, in many rural communities of the province. Nitrogen is a nutrient that is required in larger amounts among plant nutrients and therefore farmers must apply large amounts of inorganic fertilisers to maintain crop yields. The use of artificial nitrogen fertilisers plays an important role in supplying crop nutrient needs but continuous application is costly and many smallholder farmers cannot afford fertilisers or can only apply marginal quantities (Jones and Wendt 1995). In addition, excessive application

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* School of Agricultural and Environmental Sciences, Plant Production, University of the North, Private Bag X1106, Sovenga, 0727 Republic of South Africa.

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can sometimes cause environmental problems, such as contamination of surface and underground water through run-off and leaching. Intercropping a cereal with a legume can benefit an associated cereal crop (Patra et al. 1986) or a following cereal in a rotational system. The nitrogen benefit from a legume in an intercropping system will depend on its active symbiotic activity under such system. In an intercropping situation, the quantity of nitrogen derived from biological fixation from a legume is influenced by a number of factors, such as soil nitrogen (Patra et al. 1986; Stern 1993), species or cultivar of legume (Stern 1993; Watiki et al. 1993), soil moisture, and legume density in the intercrop (Stern 1993; Watiki et al. 1993). The importance of legume variety in nitrogen nutrition in the maize–cowpea intercropping system in the Limpopo Province and many parts of South Africa has not yet been documented. Some of these cowpea cultivars exhibit differences in their symbiotic activities as sole crops in the province (Ayisi et al. 2000) but their fixation in an intercropping situation is yet to be established. The objectives of this study were to: (i) assess dry-matter production and nitrogen uptake of the associated maize crop in an intercropped system with different cowpea varieties; and (ii) determine the effect of the intercropping on biomass production, nodulation, and nitrogen fixation of the cowpea varieties in the system.

Materials and methods

Field experiments were carried out at two locations in the Limpopo Province of South Africa — namely, the University of the North experimental farm at Syferkuil and a communal field at Thabina/Dan during the 1998/99 and 1999/2000 growing seasons. The experiments were established at different sites within each location. Syferkuil has relatively higher soil fertility compared to that of Thabina/Dan (Table 1).

The experiments were established as randomised complete block designs with four replications at each location. Treatments examined were four cowpea cultivars — namely, Pan 311, Pan 326, Bechuana White and Agrinawa — which were either intercropped in alternate 90 cm rows with maize variety SNK2147 or planted as sole cultures. Thus, the cowpea replaced a maize row in an alternate manner in the intercropped plots. Maize in sole culture was included as separate treatment. The final densities were 30,000 and 15,000 plants per hectare for the sole and intercropped maize, respectively, and 60,000 and 30,000 plants per hectare for the sole and intercropped cowpea, respectively. Pan 311 and Pan 326 are short-duration types whereas Bechuana White and Agrinawa are medium- and long-duration cultivars, respectively. The cowpea seeds were inoculated with commercial *Bradyrhizobium* strain CB756 just before planting. The data collected were seasonal dry-matter accumulation, nodulation and nitrogen fixation. Dry-matter samples of the component crops were taken twice from two 1 m length rows of each experimental unit in both growing seasons and at each location. During sampling, maize plants were cut at ground level to determine the above-ground dry matter, whereas in cowpea, whole-plant samples, including roots, were taken. The cowpea plants were dug carefully to maintain their root systems and then immersed in water to remove

Table 1. Initial soil analysis results at the experimental sites at all seasons.

Location	Season	Depth (cm)	$pH_{(H2O)}$[a]	N[b]	P[c]	K[d]
				mg/kg	mg/kg	(cmol(+)/kg)
Syferkuil	1998/99	0–15	7.1	13.5	50.4	0.32
		15–30	7.0	14.0	46.5	0.31
	1999/2000	0–15	6.8	14.3	44.3	0.30
		15–30	7.0	13.2	40.2	0.31
Thabina/Dan	1998/99	0–15	6.8	8.7	6.4	0.17
		15–30	6.3	7.7	4.2	0.17
	1999/2000	0–15	5.6	6.9	1.6	0.12
		15–30	5.4	5.7	1.1	0.11

[a] 1:5 soil:water.
[b] $NH_4 + NO_3$ 1:5 Extractant 0.1 N K_2SO_4.
[c] 1:7.5 extractant Bray 2.
[d] 1:10 extractant ammonium acetate 1 N, pH 7.

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bound soil. The samples were carefully washed under a tap on a sieve to recover all loose roots, after which root nodules were detached from each plant. Both maize and cowpea plant materials were oven-dried at 60°C to constant moisture content and weighed.

Nitrogen fixation in the legume was assessed using the 15N natural abundance technique with sole maize as the reference crop (Unkovich et al. 1993). Delta (d) 15N values were determined using mass spectrometer model NA15000NC (CHNN) analyser. The proportion of plant nitrogen derived from the atmosphere (%Ndfa) was calculated as follows:

$$\%\text{Ndfa} = \frac{(\partial^{15}\text{N ref plant} - \partial^{15}\text{N legume})}{(\partial^{15}\text{N ref plant} - \text{B})} \times \frac{100}{1}$$

where δ15N ref plant is the value of a non-leguminous reference plant grown simultaneously in close proximity to the legume and sampled simultaneously; and B is the δ^{15}N value of cowpea grown in the glasshouse on sand culture, where the crops depended solely on symbiotic fixation for their N nutrition. The sole maize crop within each experimental block was used as a reference crop for the legume in that block, as soil conditions within the block were largely similar. Data were subjected to analysis of variance (ANOVA) using the Statistical Analysis System (SAS). Differences between treatment means were separated using the least significant difference (LSD) procedure (Gomez and Gomez 1984).

Results and Discussion

Maize dry-matter accumulation and nitrogen yield

No significant differences in seasonal dry-matter accumulation of maize were observed among the treatments at either Syferkuil or Thabina/Dan or in either year (Tables 2 and 3); except at Syferkuil in 1999/2000, 58 days after planting (DAP), where maize grown in intercrop with cowpea cultivar

Table 2. Dry-matter accumulation and nitrogen yield (kg/ha) of maize intercropped with different cowpea cultivars (Pan 311, Pan 326, Bechuana (BC) White and Agrinawa) at Syferkuil in the 1998/99 and 1999/2000 growing seasons (M = maize; DAP = days after planting).

Crop	1988/89 growing season				1999/2000 growing season			
	Dry matter[a]		N yield[a]		Dry matter		N yield	
	55 DAP	80 DAP	55 DAP	80 DAP	58 DAP	95 DAP	58 DAP	95 DAP
M + Pan 311	1539	3609	34	57	2320 b	4291	45	73 b
M + Pan 326	1668	3219	39	54	2596 b	4594	51	77 b
M + BC White	1367	4015	33	66	2334 b	5199	43	85 ab
M + Agrinawa	1768	3251	40	58	3755 a	5713	83	110 a
Sole M	1476	3016	34	48	2439 b	4176	39	59 b

[a] Not significant.

Note: numbers in each column followed by different letters are significantly different at $p \leq 0.05$.

Table 3. Dry-matter accumulation and nitrogen yield (kg/ha) of maize, intercropped with different cowpea cultivars Pan 311, Pan 326, Bechuana (BC) White and Agrinawa) at Thabina/Dan in the 1998/99 and 1999/2000 growing seasons (M = maize; DAP =days after planting).

Cropping	1998/99 growing season				1999/2000 growing season	
	Dry matter[a]		N Yield[a]		Dry matter[a]	N yield[a]
	40 DAP	88 DAP	40 DAP	88 DAP	60 DAP	60 DAP
M + Pan 311	1119	6380	20	119	2608	45
M + Pan 326	1226	7307	24	124	2965	63
M + BC white	1119	6853	20	121	2180	37
M + Agrinawa	1610	5980	29	92	2508	48
Sole M	1261	6726	24	135	1734	37

[a] No significant differences at the $p \leq 0.05$ level of testing.

Agrinawa produced the highest dry-matter yield of 376 g/m^2. This was 55.2% higher than the average yield of the other treatments and 54% higher than the sole maize yield (Table 2).

The general lack of significant differences between the sole maize and all the intercropped systems is an indication that the cowpea species studied can be incorporated into the maize culture in this alternate intercropping system without depressing the maize growth.

The nitrogen yield response of maize to cropping system was significant ($p \leq 0.05$) only at Syferkuil in 1999/2000 (Tables 2 and 3) and not at the other locations and years. At both 58 and 95 DAP, at this location, the nitrogen yield of maize intercropped with cowpea cultivar Agrinawa was higher than in the sole crop, whereas all other maize intercrops were similar to the sole cropped maize. The intercrops, however, showed a tendency towards higher nitrogen yields, about 44% and 47% higher on average than the sole culture maize at 58 and 95 DAP, respectively (Table 2). The increased nitrogen yield of maize intercropped with cowpea cultivar Agrinawa could be attributed to the high nodulating ability of this cowpea cultivar (Tables 4 and 5), indicating the possibility of some nitrogen transfer from the cowpea to the maize, as has been reported previously (Patra et al. 1986). The nitrogen yield of maize intercropped

Table 4. Whole-plant dry-matter accumulation and nodule mass of cowpea cultivars (Pan 311, Pan 326, Bechuana (CB) White and Agrinawa) at Syferkuil during the 1998/99 and 1999/00 growing seasons (DAP = days after planting).

Cropping system	1998/99		1999/2000	
	Dry matter (55 DAP) (kg/ha)	Nodule mass (55 DAP) (mg/plant)	Dry matter (58 DAP) (kg/ha)	Nodule mass (58 DAP) (mg/plant)
Sole Pan 311	1444 a	2.1 c	1055 a	2.3 c
Sole Pan 326	857 c	2.7 bc	1265 bc	4.4 b
Sole BC White	1592 a	6.8 a	2531 a	10.2 a
Sole Agrinawa	1281 ab	4.3 a	2167 a	8.3 ab
Intercropped Pan 311	922 bc	2.8 bc	907 d	2.5 c
Intercropped Pan 326	995 bc	5.8 abc	1207 cd	3.0 c
Intercropped BC White	1100 abc	8.8 a	1750 b	5.9 abc
Intercropped Agrinawa	1249 ab	5.1 abc	1547 b	4.9 bc

Note: numbers in each column followed by different letters are significantly different at $p \leq 0.05$).

Table 5. Whole-plant dry-matter accumulation and nodule mass of cowpea cultivars (Pan 311, Pan 326, Bechuana (BC) White and Agrinawa) at Thabina/Dan during the 1998/99 and 1999/2000 growing seasons (DAP = days after planting).

Cropping system	1998/99		1999/2000	
	Dry matter (40 DAP) (kg/ha)	Nodule mass (40 DAP) (mg/plant)	Dry matter[a] (60 DAP) (kg/ha)	Nodule mass (60 DAP) (mg/plant)
Sole Pan 311	1174 a	16.9 cd	668	6.8 c
Sole Pan 326	648 c	24.3 bc	987	9.7 bc
Sole BC white	1209 a	27.7 bc	606	9.1 bc
Sole Agrinawa	1039 ab	32.2 b	1269	14.7 ab
Intercropped Pan 311	805 bc	7.6 d	750	6.9 c
Intercropped Pan 326	812 bc	29.8 b	1022	12.0 bc
Intercropped BC white	844 bc	46.7 a	536	20.5 a
Intercropped Agrinawa	1076 ab	35.3 ab	440	14.0 abc

[a] Not significant at the $p \leq 0.05$ level of testing.

Note: numbers in each column followed by different letters are significantly different at $p \leq 0.05$).

with cowpea cultivar Bechuana White, which is also a high-nodulating cultivar, was statistically similar to that of maize intercropped with Agrinawa, confiriming possible transfer. The lack of nitrogen benefit between intercropped and sole culture maize, as observed in other seasons and locations has also been reported previously (Van Kessel and Roskoski 1988).

Cowpea dry-matter accumulation

Cowpea dry-matter accumulation differed significantly among the cultivars at all locations and seasons, except at Thabina/Dan in 1999/2000 where it was not significant (Tables 4 and 5).

With the exception of Pan 311 and Bechuana White at Thabina/Dan in 1998/99, where dry-matter accumulation in the intercrop was reduced by about 43 to 46% relative to the sole crops, dry-matter accumulation in the other legumes did not differ whether planted in sole or in intercropped systems. Legume growth suppression by maize in intercropped systems has been reported (Clement et al. 1992). The longer-duration cultivars (Bechuana White and Agrinawa) also accumulated much more dry matter than the early-maturing types (Pan 311 and Pan 326) earlier in the growing season.

Nodule mass

Nodule mass differed among the cowpea cultivars, locations, seasons and also whether the cowpeas were grown as intercrops or sole cultures (Tables 4 and 5). The highest nodule weights were generally recorded in Bechuana White and Agrinawa across locations and seasons. The nodules produced by these two cultivars when grown as intercrops were also, on average, 25–45% heavier than when grown as sole crops, except in the 1999–2000 season at Syferkuil, where the average sole crop nodule weight of the cultivars was about 41% lower in the intercrops. Generally, the cultivar Bechuana White appeared to be the most consistent in terms of nodule weight and might be the cultivar with the highest potential for improved soil fertility.

Percentage nitrogen derived from fixation

The delta ^{15}N value enables one to determine the extent of a plant's dependence on soil and atmospheric nitrogen. The percentage of nitrogen derived from fixation ranged from 4.3% to 11.7% and 16.8% to 50.0% in the 1998/99 and 1999/2000 growing seasons, respectively, at Syferkuil (Table 6), whereas at Thabina/Dan, the range was 19.3% to 50.6% and 71.3% to 92.7%, respectively, during the two seasons (Table 7). The legumes at Syferkuil (experimental farm) were largely dependent on soil nitrogen during the 1998/99 growing season but this dependence was relatively lower in 1999/2000. This is an indication of the importance of seasonal variations in the cultivars' symbiotic activities. In general, the percentage dependence on symbiotic fixation was much higher at Thabina/Dan (farmers' field) than at Syferkuil, which could partly be attributed to the relatively higher initial soil nitrogen at the experimental station.

Table 6. Percentage nitrogen derived from symbiotic fixation (%Ndfa = proportion of plant N derived from the atmosphere) and the amount of nitrogen fixed by sole and intercropped cowpea cultivars (Pan 311, Pan 326, Bechuana (BC) White and Agrinawa) at Syferkuil, 55 days after planting.

Cropping system	1998–99		1999–2000	
	%Ndfa	N fixed (kg/ha)	%Ndfa	N fixed (kg/ha)
Sole Pan 311	6.3 ± 0.3	63.3 ± 3	31.0 ± 17	124 ± 27
Sole Pan 326	8.4 ± 0.1	28.2 ± 3	16.8 ± 8	87 ± 31
Sole BC White	4.3 ± 0.3	19.5 ± 5	29.5 ± 12	217 ± 58
Sole Agrinawa	–	–	23.0 ± 16	167 ± 2
Intercropped Pan 311	11.7± 0.7	68.5 ± 8	12.7 ± 2	136 ± 14
Intercropped Pan 326	5.3 ± 0.0	24.7 ± 3	33.8 ± 18	121 ± 17
Intercropped BC White	5.7 ± 0.6	24.3 ± 3	28.2 ± 1	144 ± 2
Intercropped Agrinawa	–	–	50.0 ± 4	148 ± 29

Note: values are means ± SE.

Table 7. Percentage nitrogen derived from symbiotic fixation (%Ndfa = proportion of plant N derived from the atmosphere) and the amount of nitrogen fixed by sole and intercropped cowpea cultivars (Pan 311, Pan 326, Bechuana (BC) White and Agrinawa) at Thabina/Dan, 55 days after planting.

Cropping system	1998/99		1999/2000	
	%Ndfa	N fixed (kg/ha)	%Ndfa	N fixed (kg/ha)
Sole Pan 311	20.2 ± 11.1	168 ± 17	92.7 ± 6	124 ± 4
Sole Pan 326	32.6 ± 0.1	103 ± 22	89.3 ± 3	83 ± 26
Sole BC White	41.8 ± 0.6	175 ± 21	80.7 ± 6	99 ± 21
Sole Agrinawa	36.1 ± 8.0	107 ± 7	84.4 ± 10	147 ± 17
Intercropped Pan 311	19.3 ± 1.6	151 ± 6	71.3 ± 3	123 ± 29
Intercropped Pan 326	50.6 ± 7.5	170 ± 10	78.1 ± 17	117 ± 30
Intercropped BC White	44.8 ± 9.9	169 ± 53	84.3 ± 12	146 ± 21
Intercropped Agrinawa	32.9 ± 2.3	148 ± 12	79.7 ± 11	136 ± 6

Note: values are means ± SE.

Amount of nitrogen fixed

A wide variation in the amount of nitrogen fixed by the legumes was observed, ranging from as low as 19.5 kg N/ha to as high as 217 kg N/ha across locations and seasons (Tables 6 and 7). There were also inconsistencies in the amount of nitrogen fixed by the individual cultivars, but Pan 326 generally appears to be a lower nitrogen fixer compared to the others. Comparing sole and intercropped cowpea, the amount of nitrogen fixed was on average 6 to 15% greater in the intercropped systems than in the sole cultures. This observation is partly similar to the findings of Patra et al. (1986), who reported higher amounts of nitrogen fixed by legumes under intercropping conditions.

Conclusions

The cowpea cultivars Pan 311, Pan 326, Bechuana White and Agrinawa can be incorporated into maize culture in an alternate intercropping system without depressing maize growth. The accumulation of nitrogen by maize did not change whether maize was planted as a sole crop or as an intercrop and there were also no differences among maize crops grown with the different cowpea species, except in 1999/2000 at Syferkuil.

Significant differences in dry-matter accumulation by the cowpea varieties were, however, observed under both sole culture and intercropping systems, with the longer-season cultivars accumulating much higher dry matter at the mid-vegetative growth stage. Biomass accumulation in the intercrop was reduced compared to the sole crops. Nodule formation also differed among the cultivars, with Bechuana White and Agrinawa producing many more nodules than the short-duration type. In terms of the cultivars' dependence on symbiotic nitrogen fixation, plants grown under farmers' field conditions depended more on symbiotic nitrogen for their nitrogen requirement than those grown at the experimental farm. The actual amount of nitrogen fixed by the legumes ranged from about 20 to 217 kg/ha depending on season, location and cropping system, sole crop or intercrop.

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Lablab Density and Planting-Date Effects on Growth and Grain Yield in Maize–Lablab Intercrops

H.M. Maluleke,[*] K.K. Ayisi[*],[†] and A.M. Whitbread[§]

Abstract

Incorporation of legumes into the predominantly smallholder maize monoculture systems in the Limpopo Province of South Africa adds to soil fertility and animal and human nutrition. Lablab (*Lablab purpureus*) has been found to be well adapted to the dry environment of the Limpopo Province and has the potential to be intercropped with maize. Its potential for prolific growth requires that lablab is well managed if the staple maize yield is to be maintained or enhanced. Field experiments were established in the 2001/02 and 2002/03 seasons at two locations to test the effect of two relative planting dates of lablab — namely, simultaneously with maize, and 28 days later, as well as lablab planting densities of 2, 4, 6, 8 and 10 plants/m, on the grain yield of maize and biomass accumulation of the component crops in a row intercropping system. Grain yield reduction generally occurred when maize was simultaneously planted with lablab, except at densities of two and four lablab plants/m in one season. When lablab was planted later, the associated maize produced yields that were similar to or enhanced compared to the maize by itself. Maize dry-matter yields were reduced at lablab densities beyond four plants/m whereas lablab dry-matter accumulation increased with increasing density.

Introduction

Maize is the major staple food in the Limpopo Province of South Africa and it therefore dominates the smallholder farming system of the province. This preference for maize has led to continuous culture of the crop, which together with low levels of external inputs, has resulted in severe soil degradation in many smallholder farming systems throughout the Limpopo Province. Identification of alternative cropping systems and practices to break the dominant maize monoculture system is required to enhance crop productivity on farmers' fields. Intercropping maize and leguminous species, mainly cowpea (*Vigna unguiculata*), groundnut (*Arachis hypogeae*) and bambara groundnut (*Vigna subterranean*), is common amongst farmers but usually the legume component is minimal. Lablab (*Lablab purpureus*) is a legume species that can be successfully cultivated in the Limpopo Province and has the potential to be incorporated into the maize monoculture system. However, preliminary studies conducted on lablab indicated that the crop has prolific growth characteristics and, if not well managed, could severely suppress maize growth and yields in an intercropping system. Planting date and density of lablab are two important management tools that could be explored to minimise competitive pressure created by a com-

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[*] School of Agricultural and Environmental Sciences, Plant Production, University of the North, Private Bag X1106, Sovenga, 0727 Republic of South Africa.

[†] Corresponding author.

[§] CSIRO Sustainable Ecosystems, 306 Carmody Road, St Lucia, Queensland 4067, Australia.

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ponent crop in an intercropping system (Ofori and Stern 1987).

The objectives of this research, therefore, were to determine the influence of lablab planting date and density on grain yield and to determine the agronomic characteristics of maize and dry-matter production of the component crops in an intercropping system.

Materials and Methods

Field experiments were carried out at two locations in the Limpopo Province of South Africa — namely, the University of the North experimental farm at Syferkuil and a smallholder farmer's field at Dalmada near Polokwane during the 2001/02 and 2002/03 growing seasons. The pre-sowing soil fertility status at the two locations is presented in Table 1.

The experimental fields were ploughed 2–3 days before planting and 30 kg/ha of phosphorus was applied in the form of superphosphate at Dalmada, 2001, followed by disking to incorporate the fertiliser. Nitrogen at 30 kg/ha was applied as urea at planting to maize at this location. No inorganic fertiliser was applied at Syferkuil due to the relatively high soil fertility at the site. The lablab seeds were inoculated with a commercial *Bradyrhizobium* strain just before planting.

In the 2001/02 season, the experiments were planted on 12 and 13 December 2001 at Dalmada and Syferkuil, respectively. In 2002/03, planting occurred on 6 and 12 December 2002 at Dalmada and Syferkuil, respectively. The experiments were in factorial arrangement as a randomised complete block design with three replications at each location. The treatments examined were five different densities of lablab — namely, 0 (sole maize), 2, 4, 6 and 8 plants/m in 2001/02 and an additional treatment of 10 plants/m in 2002/03. These densities were either planted simultaneously with maize or 28 days after planting (DAP). The lablab was planted between the 90 cm inter-row spacing of maize, thus creating a distance of 45 cm between the maize and lablab rows. Each experimental unit consisted of six rows of maize 6 m long. The maize cultivar used was SNK 2147 and that of lablab was Rongai, which is a long-duration type.

Dry-matter samples of the crops were taken periodically from a 1.8 m^2 area of each experimental unit throughout the growing season. Maize plants were cut at ground level to determine the above-ground dry matter. With lablab, whole-plant samples were taken during dry-matter determination. The plants were dug carefully to maintain their root system and then immersed in water to remove bound soil. The samples were carefully washed under a tap on a sieve to recover all loose roots. The biomass accumulation for lablab consisted of both the tops and root material. Both maize and lablab plant materials were oven-dried at 60°C to constant moisture content, then weighed.

Weeds were controlled by hand twice during the growing season. Days to flowering in both crops were recorded when 50% of the plants in a plot had flowered. Physiological maturity of maize was scored when 90% of the plants in a plot revealed cobs with no milk line (Stoskopf 1981). Grain yield samples of maize were taken from the middle four rows, 2.5 m long, of each plot, leaving one row on each side as a border row.

Table 1. Initial topsoil (0–15 cm) and subsoil (15–30 cm depth) nutrient status at Syferkuil and Dalmada during the 2001/02 and 2002/03 growing seasons.

Location	Season	pH[a]		Mineral N[b] (mg/g)		P[c] (mg/g)		K[d] (cmol(+)/kg)	
		0–15	15–30	0–15	15–30	0–15	15–30	0–15	15–30
Syferkuil	2001/02	6.6	7.0	20.0	12.0	23	14	0.38	0.49
	2002/03	7.8	7.5	11.0	9.0	33	27	0.29	0.30
Dalmada	2001/02	7.6	7.9	3.2	2.8	9	7	1.41	0.82
	2002/03	6.9	7.1	3.0	2.0	43	27	1.02	0.95

[a] 1:5 soil:water.
[b] $NH_4 + NO_3$ 1:5 Extractant 0.1N K_2SO_4
[c] 1:7.5 extractant Bray 2.
[d] 1:10 extractant ammonium acetate 1 N, pH 7.

Data were subjected to analysis of variance (ANOVA) using the Statistical Analysis System (SAS). Differences between treatment means were separated using the least significant difference (LSD) procedure (Gomez and Gomez 1984).

Results and Discussion

Grain yield

There was no lablab grain produced during any of the field trials so only the grain yield of maize is presented here. Maize grain yield was influenced by both lablab planting date and density at both locations and seasons (Tables 2 and 3). The interaction effect of planting date and density was also significant at all locations and seasons except at Dalmada in the 2002/03 season. Grain yield of maize simultaneously planted with lablab was, on average, reduced by 26% and 57% compared to those intercropped with later-planted lablab in 2001/02 at Dalmada and Syferkuil, respectively (Table 2). In 2002/03, the yield reduction was 20% and 41%, respectively (Table 3.). A general trend of decreasing maize grain yield with increase in lablab density under the simultaneous planting system was observed in both seasons at the two locations. In 2001/02, greater maize yield reduction occurred at densities of 6 plants/m and above (Table 2). However, in 2002/03, the planting density of 2 plants/m at Syferkuil resulted in similar yields as the sole crop under the simultaneous planting. In maize–legume intercrops, most researchers have reported yield depression of the legume by maize (Ezumah et al. 1987; Ofori and Stern 1987; Clement et al. 1992). The yield reduction of maize observed in this study could be attributed to increased competition created by lablab at higher densities. Maize grain yield reduction has been reported in maize–cowpea intercrops (Shumba et al. 1990; Siame et al. 1998) and in maize–bean systems (Siame et al. 1998).

When lablab was planted 28 days after maize, grain yield at planting densities of 2 and 4 lablab plants/m was similar to the sole maize in 2001/02 at Dalmada, whereas at Syferkuil, a significantly higher grain yield — an average of 59% — was obtained at lablab densities of 2 and 4 plants/m compared to the sole maize yield during the same season (Table 2). During the 2002/03 season at Dalmada, the grain yield of maize intercropped with later-planted lablab at a density of 2 plants/m was 14% higher than for the sole crop, whereas at a planting density of 4 plants/m, grain yield was similar to the sole crop yield. At Syferkuil, grain yields at 2 and 4 plants/m were

Table 2. Response of maize grain yield (kg/ha) to lablab planting date and density (plants/m) at Dalmada and Syferkuil during the 2001/02 growing season (Sim = maize and lablab planted simultaneously, 28 DAP = lablab planted 28 days after the maize).

Density (plants/m)	Dalmada		Syferkuil	
	Sim	28 DAP	Sim	28 DAP
0	1076 a	1076 a	863 a	863 c
2	802 b	999 a	528 b	1615 a
4	721 b	971 a	436 c	1126 b
6	321 c	539 b	189 d	803 c
8	90 d	464 b	122 d	583 d
10	–	–	–	–
Date	**	**	**	**
Density	**	**	**	**
Interaction	**	**	**	**

Note: means followed by the same letter within columns are similar statistically; ** = $P < 0.01$; * = $P < 0.05$; NS = not statistically significant.

Table 3. Response of maize grain yield (kg/ha) to lablab planting date and density at Dalmada and Syferkuil during the 2002/03 growing season (Sim = maize and lablab planted simultaneously, 28 DAP = lablab planted 28 days after the maize).

Density (plants/m)	Dalmada		Syferkuil	
	Sim	28 DAP	Sim	28 DAP
0	1674 a	1674 b	5181 a	5181 b
2	1438 b	1908 a	4729 a	7550 a
4	1217 c	1654 b	3055 b	7141 a
6	733 d	971 c	2567 bc	5797 b
8	819 d	961 c	2041 bc	3985 c
10	572 e	884 c	1583 c	2875 c
Date	**	**	**	**
Density	**	**	**	**
Interaction	NS	NS	*	**

Note: means followed by the same letter within columns are similar statistically; ** = $P < 0.01$; * = $P < 0.05$; NS = not statistically significant.

higher than the sole maize by about 46% and 38%, respectively (Table 3). The greater yield boost under the later-planted lablab system could primarily be attributed to the better suppression of lablab vigour by the earlier-planted maize. Yield advantage in intercropping can arise when component crops have different growth patterns and make major demands on resources at different times (Harris et al. 1987; Putnam and Allan 1992). In an intercropping system, a component crop can positively modify the growing environment for the benefit of the other crop, which can lead to an overall yield advantage relative to the sole crop (Vandermeer 1992). In this study, the later-planted lablab, though less competitive with maize, was observed to completely cover the soil late in the season which could act to suppress weeds, create cooler soil conditions and possibly minimise moisture loss compared to the sole crops. These combined impacts would contribute to the enhanced yield of the intercropped maize compared to maize sole crops.

Maize biomass accumulation

Planting density of lablab significantly ($P \leq 0.05$) reduced maize dry-matter accumulation at all sampling dates at both Dalmada and Syferkuil during the two seasons of experimentation, except at 45 and 59 DAP at Syferkuil in 2002/03 (Tables 4 and 5). The interaction effect between planting density and date was not significant at the two locations and seasons. Pooled across planting date, maize biomass accumulation declined as the number of lablab plants/m increased at both locations. The decreased biomass accumulation with increasing density resulted in the lower grain yields at higher densities. However, in 2001/02 at Dalmada, maize dry-matter accumulation was not reduced by intercropping compared to sole maize when planted with lablab at 2 and 4 plants/m (Table 4). At Syferkuil, this effect was observed only at 45 DAP, beyond which the dry matter was reduced significantly compared to the sole crops. In 2002/03, yields of maize intercropped at 2 and 4 lablab plants/m were similar to the sole crop at all sampling dates at the two locations, except at 54 DAP at Dalmada, where dry-matter accumulation intercropped with 4 lablab plants/m was reduced by 31% compared to the sole maize (Table 5). On average, maize dry-matter accumulation was reduced at all sampling dates when planted simultaneously with lablab, especially at the later stage of growth.

Lablab biomass accumulation

During the 2001/02 growing season, significant differences in seasonal lablab dry-matter accumulation related to planting date were observed. Biomass accumulation of later-planted lablab was consistently reduced in the intercropping system with maize compared to those simultaneously planted with maize (Tables 6 and 7). When lablab was simultaneously planted with maize, a general increase in biomass accumulation with increasing density of the legume was observed at all locations and seasons. This is contrary to the accumulation pattern of maize, where an increase in lablab density resulted in a decrease in maize biomass accumulation. When lablab was planted 28 days after the maize, biomass accumulation did not differ with planting density in the 2001/02 growing season, but in the 2002/03 seasons, there was an increase in biomass accumulation with increasing density (Tables 8 and 9).

Table 4. Total maize dry-matter accumulation (kg/ha) at different growth stages as influenced by lablab planting density at Dalmada and Syferkuil during the 2001/02 growing season (DAP = days after planting).

Density (plants/m)	Dalmada				Syferkuil			
	41 DAP	55 DAP	88 DAP	102 DAP	45 DAP	59 DAP	83 DAP	102 DAP
0	858 a	2712 a	5752 a	8488 c	623 a	892 a	4784 a	7878 a
2	788 a	2958 a	5508 a	9780 a	562 ab	782 b	3626 b	6091 b
4	710 ab	2655 a	4037 b	9314 b	633 a	774 bc	3560 bc	5688 b
6	579 bc	1672 b	3347 bc	4590 d	456 bc	737 c	2890 cd	4026 c
8	534 c	1619 b	2737 c	3292 e	425 c	683 c	2447 d	3563 c
Date	**	**	**	**	NS	NS	**	*
Density	**	**	**	**	**	**	**	**
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

Note: means followed by the same letter within columns are similar statistically; ** = $P < 0.01$; * = $P < 0.05$; NS = not statistically significant.

Table 5. Total maize dry-matter accumulation (kg/ha) at different growth stages as influenced by lablab planting density at Dalmada and Syferkuil during the 2002/03 growing season (DAP = days after planting).

Density (plants/m)	Dalmada			Syferkuil		
	54 DAP	68 DAP	82 DAP	54 DAP	68 DAP	82 DAP
0	1001 a	2616 a	3911 a	2630 a	3956 a	9673 a
2	954 a	2512 a	3896 a	2587 a	3999 a	9077 a
4	690 b	2537 a	3853 a	2475 a	3839 a	9188 a
6	615 bc	1734 b	2703 b	1187 b	2546 b	7205 b
8	596 bc	1584 bc	2686 b	1173 b	2431 b	7058 bc
10	581 c	1336 c	2296 b	1028 b	2307 b	6482 c
Date	**	**	**	**	**	**
Density	NS	NS	NS	**	**	**
Interaction	NS	NS	NS	NS	NS	NS

Note: means followed by the same letter within columns are similar statistically; ** = $P < 0.01$; * = $P < 0.05$; NS = not statistically significant.

Table 6. Total dry-matter accumulation (kg/ha) of lablab at Dalmada as affected by planting density and date during the 2001/02 growing season (Sim = maize and lablab planted simultaneously, 28 DAP = lablab planted 28 days after the maize).

Density (plants/m)	41 DAP		55 DAP		88 DAP		102 DAP	
	Sim	28 DAP	Sim	28 DAP	Sim	28 DAP	Sim	28 DAP
2	150.0 b	29.2 a	358 d	42.5 a	667 c	45 a	671 c	34 a
4	170.8 b	29.7 a	441 c	59.0 a	511 c	63 a	562 c	53 a
6	225.0 a	29.7 a	608 b	44.4 a	1020 b	48 a	1196 b	34 a
8	212.5 a	37.5 a	754 a	44.0 a	1375 a	48 a	1546 a	24 a
10	–	–	–	–	–	–	–	–
Density	**	**	**	**	**	**	**	**
Date	**	**	**	**	**	**	**	**
Interaction	**	**	**	**	**	**	**	**

Note: means followed by the same letter within columns are similar statistically; ** = $P < 0.01$; * = $P < 0.05$; NS = not statistically significant.

Table 7. Total dry-matter accumulation (kg/ha) of lablab at Syferkuil as affected by planting density and date during the 2001/02 growing season (Sim = maize and lablab planted simultaneously, 28 DAP = lablab planted 28 days after the maize).

Density (plants/m)	41 DAP		55 DAP		88 DAP		102 DAP	
	Sim	28 DAP	Sim	28 DAP	Sim	28 DAP	Sim	28 DAP
2	182 b	48 a	621 c	60 a	3480 d	170 a	5589 c	239 a
4	117 c	50 a	575 c	68 a	4018 c	204 a	6093 b	308 a
6	200 b	69 a	746 b	85 a	4411 b	256 a	6514 b	331 a
8	256 a	78 a	921 a	92 a	4784 a	296 a	7421 a	357 a
10	–	–	–	–	–	–	–	–
LSD (≤0.05)	29	29	102	102	238	238	475	475
Density	**	**	**	**	**	**	**	**
Date	**	**	**	**	**	**	**	**
Interaction	**	**	**	**	NS	NS	*	*

Note: means followed by the same letter within columns are similar statistically; ** = $P < 0.01$; * = $P < 0.05$; NS = not statistically significant.

Flowering and maturity of maize

Days to flowering of maize ranged from 61–75 DAP across locations and seasons (Tables 10 and 11). The timing of flowering and maturity was similar across all treatments in the 2001/02 season (Table 10). In the 2002/03 season, flowering was delayed by 2–10 days at the intercrop densities of 6–10 lablab plants/m. Where the maize and the lablab were planted simultaneously, maturity was generally delayed at lablab densities of 6–10 plants/m.

Conclusion

The grain yield of maize simultaneously planted with lablab was generally reduced compared to the sole crop. However, at the intercropped lablab densities of 2 and 4 plants/m at Dalmada and density of 2 plants/m at Syferkuil in 2002/03, maize produced similar yields as the sole crop maize. There was a general trend of decreasing maize grain yields as lablab density increased after simultaneous planting. When lablab was planted 28 days after maize, grain yields of the associated maize crop were similar to or higher than the sole crop yield. Maize dry-matter accumulation at intercrop densities of 2 and 4 plants/m was generally similar to the sole crop. Beyond this density, a general decrease in dry matter was observed. Dry-matter accumulation of lablab, on the other hand, increased with increasing density of the legume.

Table 8. Total dry-matter accumulation (kg/ha) of lablab at Dalmada as affected by planting density and date during the 2002/03 growing season (Sim = maize and lablab planted simultaneously, 28 DAP = lablab planted 28 days after the maize).

Density (plants/m)	54 DAP		68 DAP		82 DAP	
	Sim	28 DAP	Sim	28 DAP	Sim	28 DAP
2	177 c	25 c	709 b	62 b	798 d	94 b
4	208 c	35 bc	744 b	59 b	922 c	90 b
6	259 b	52 bc	770 b	90 a	916 c	115 b
8	263 b	60 b	852 a	108 a	998 b	140 b
10	298 a	101 a	925 a	125 a	1392 a	190 a
Density	**	**	**	**	**	**
Date	**	**	**	**	**	**
Interaction	**	**	**	**	**	**

Note: means followed by the same letter within columns are similar statistically; ** = $P < 0.01$; * = $P < 0.05$; NS = not statistically significant.

Table 9. Total dry-matter accumulation (kg/ha) of lablab at Syferkuil as affected by planting density and date during the 2002/03 growing season (Sim = maize and lablab planted simultaneously, 28 DAP = lablab planted 28 days after the maize).

Density (plants/m)	54 DAP		68 DAP		82 DAP	
	Sim	28 DAP	Sim	28	Sim	28 DAP
2	213 c	60 c	539 c	84 a	893 d	189 b
4	244 c	70 c	635 c	96 a	1016 c	185 b
6	294 b	87 b	845 b	142 a	1011 c	210 b
8	299 a	96 b	873 a	152 a	1093 b	236 b
10	333 a	137 a	1001 a	172 a	1485 a	286 a
Density	**	**	**	**	**	**
Date	**	**	**	**	**	**
Interaction	**	**	**	**	**	**

Note: means followed by the same letter within columns are similar statistically; ** = $P < 0.01$; * = $P < 0.05$; NS = not statistically significant.

Table 10. Days to flowering and maturity of maize at Dalmada and Syferkuil during the 2001/02 growing season (Sim = maize and lablab planted simultaneously, 28 DAP = lablab planted 28 days after the maize).

Density (plants/m)	Dalmada				Syferkuil			
	Flowering		Maturity		Flowering		Maturity	
	Sim	28 DAP	Sim	28 DAP	Sim	28 DAP	Sim	28 DAP
0	64	64	110	109	73	73	115	115
2	65	64	111	110	70	72	118	112
4	68	64	111	109	71	71	120	115
6	70	64	108	109	66	69	120	112
8	68	64	110	110	62	70	118	114

Table 11. Flowering and maturity of maize at Dalmada and Syferkuil during the 2002/03 growing season (Sim = maize and lablab planted simultaneously, 28 DAP = lablab planted 28 days after the maize).

Density (plants/m)	Dalmada				Syferkuil			
	Flowering		Maturity		Flowering		Maturity	
	Sim	28 DAP	Sim	28 DAP	Sim	28 DAP	Sim	28 DAP
0	66	66	118	118	65	65	110	110
2	66	69	113	125	65	61	111	116
4	62	70	109	122	67	65	121	108
6	75	71	122	124	65	71	120	112
8	74	71	124	117	67	75	120	108
10	75	70	126	124	75	75	128	109

The flowering date of maize intercropped with high-density lablab tended to be longer compared to lower lablab densities as well as the sole maize crop. The planting date of lablab did not influence flowering in maize. Similar to flowering, the maturity of maize was also delayed with increasing lablab densities. Lablab could therefore be incorporated in the predominantly maize monoculture without reducing yield of the cereal if planted about a month later. If planted simultaneously with maize, a density of 4 lablab plants/m should not be exceeded.

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Grain Yield of Maize Grown in Sole and Binary Cultures with Cowpea and Lablab in the Limpopo Province of South Africa

P.N.Z. Mpangane,* K.K. Ayisi,*,† M.G. Mishiyi* and A. Whitbread§

Abstract

The smallholder cropping system in the Limpopo Province of South Africa is characterised by predominantly maize monoculture, low external inputs and poor soil fertility, particularly low nitrogen and phosphorus. The need to include significant amounts of leguminous species in the system without sacrificing maize yields is essential. Field studies were conducted to assess the yield performance and agronomic characteristics of maize in sole and intercropped systems with diverse cowpea and lablab cultivars. Two different experiments were carried out at two locations in the Limpopo Province — namely, the University of the North experimental farm at Syferkuil and at a communal field at Thabina/Dan community during the 1998/99 and 1999/2000 growing seasons, and in the 2001/02 season, at Syferkuil and a farmer's field at Dalmada. The 1998/99 and 1999/2000 trials consisted of four cowpea cultivars (Pan 311, Pan 326, Bechuana White and Agrinawa) intercropped at alternate 90 cm inter-row spacing with the maize variety SNK2147 and their respective sole crops. The 2001/02 trials consisted of two cowpea cultivars (Glenda and Bechuana White) and two lablab cultivars (Rongai and Common) planted as sole crops or interplanted between two maize rows, spaced 90 cm apart. Differences in maize grain yield during the 1998/99 and 1999/2000 trials were only observed at Syferkuil in 1999/2000. The yield of maize intercropped with Pan 311 was superior to the sole crop yield, whereas the others were similar. In the 2001/02 trials, intercropped maize grain yields were generally lower than the sole crops. Seed yield of the cowpea cultivars Pan 326, Bechuana White and Agrinawa were similar in sole and intercropped systems, whereas the seed yield of cowpea cultivar Pan 311 was reduced by intercropping.

Intercropping involving cereals and legumes is a common practice in many developing countries of Africa, Asia and South America but the advantages of intercropped systems over sole cultures are influenced by several factors including habitat, soil fertility and moisture, and crop species and varieties (Vandermeer 1992). Most researchers have discovered that when intercropping maize and a grain legume, the maize often depresses the yield of the legume crop, especially at high levels of soil nitrogen. Combinations in which the legume crop was depressed by maize include: maize–cowpea (Ezumah et al. 1987; Ofori and Stern 1987), maize–peanut (Searle et al. 1981) and maize–soybean (Searle et al. 1981; Clement et al. 1992). However, other researchers have reported yield depression of maize when intercropped with cowpea (Shumba et al. 1990; Siame et al. 1998). This inconsistent performance of component crops requires critical investigation in each particular locality if farmers are to benefit from the practice of intercropping in that

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* School of Agricultural and Environmental Sciences, Plant Production, University of the North, Private Bag X1106, Sovenga, 0727 Republic of South Africa.

† Corresponding author.

§ CSIRO Sustainable Ecosystems, 306 Carmody Road, St Lucia, Queensland 4067, Australia.

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locality. The smallholder farming system of the Limpopo Province of South Africa is characterised by variable seasonal rainfall, predominantly maize monocultures, low soil organic-matter levels, poor soil fertility, particularly low nitrogen and phosphorus, and minimal external inputs into the farming systems. The consequent effect is the levelling of crop yields at extremely low levels which, if not checked, will render the farming land in most rural communities unsuitable for sustainable production. Recent efforts to improve soil fertility have been through the introduction of leguminous species into the farming systems of many rural communities, mainly as intercrops with maize. Cowpea (*Vigna unguiculata*) is a grain legume that is receiving much attention from researchers for its improved growth and yield under sole culture. However, cowpea is usually intercropped with maize or grain sorghum on farmers' fields, but the proportion of the legume in the mixture is often too low to constitute a true intercropping system. Since maize is also a priority crop, the challenge is to maintain or enhance growth and yield of the cereal under increased proportion of legumes in a mixture. Lablab (*Lablab purpureus*) is another leguminous species that has shown a potential for prolific growth in the province. Both cowpea and lablab are sources of food for humans as a grain crop and as a leafy vegetable, and also as a fodder crop for animals. The performance of the two legumes as intercropped species with maize is, however, not yet established. The objectives of this study were to determine the effects of intercropping maize with diverse cowpea cultivars and lablab on grain yields and agronomic characteristics of the component crops in the Limpopo Province.

Materials and Methods

Two separate field experiments were carried out at three locations in the Limpopo Province of South Africa — namely, the University of the North experimental farm at Syferkuil and a communal farmers' field at Thabina/Dan during the 1998/99 and 1999/2000 growing seasons, and then at Syferkuil and a semi-commercial farmer's field at Dalmada in the 2001/02 growing season. Syferkuil has relatively higher soil fertility than on the farmers' fields at Thabina/Dan and Dalmada due to a long history of fertilisation at Syferkuil (Table 1). The low soil fertility at the farmers' fields is typical of the smallholder systems in the province. Thabina/Dan receives higher annual rainfall (750 mm) than Syferkuil and Dalmada, where the annual rainfall is 500 mm and 600 mm, respectively. The experimental fields were ploughed 2–7 days before planting and 50 kg P/ha was applied in the form of single superphosphate. This was followed by disking to incorporate the fertiliser at all sites and years. Nitrogen fertilisers were applied at planting as urea, at 40 kg N/ha, to the maize at Thabina and Dalmada only.

Table 1. Pre-sowing soil analysis results at the experimental sites at all seasons.

Location	Season	Depth (cm)	$pH_{(H2O)}$[a]	N[b] (mg/kg)	P[c] (mg/kg)	K[d] (cmol(+)/kg)
Syferkuil	1998/99	0–15	7.1	13.5	50.4	0.32
		15–30	7.0	14.0	46.5	0.31
	1999/2000	0–15	6.8	14.3	44.3	0.30
		15–30	7.0	13.2	40.2	0.31
Thabina/Dan	1998/99	0–15	6.8	8.7	6.4	0.17
		15–30	6.3	7.7	4.2	0.17
	1999/2000	0–15	5.6	6.9	1.6	0.12
		15–30	5.4	5.7	1.1	0.11
Syferkuil	2001/02	0–15	7.1	10.5	33	0.55
		15–30	6.9	9.5	27	0.53
Dalmada	2001/02	0–15	7.8	4.5	13	1.48
		15–30	7.3	5.0	11	1.43

[a] 1:5 soil:water

[b] $NH_4 + NO_3$ 1:5 Extractant 0.1 N K_2SO_4.

[c] 1:7.5 extractant Bray 2.

[d] 1:10 extractant ammonium acetate 1 N, pH 7.

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The 1998/99 and 1999/2000 trials were established on 16 and 26 November 1998 at Syferkuil and Thabina/Dan, respectively, and then on 6 and 13 December 1999 at the two locations, respectively, during the second season. The experiments were established as randomised complete block designs with four replications at each location under dryland conditions. Treatments examined during the 1998/99 and 1999/2000 were four cowpea cultivars, namely, Pan 311, Pan 326, Bechuana White and Agrinawa, which were either intercropped in alternate 90 cm rows with maize variety SNK2147 or planted as sole cultures. Thus, the cowpea replaced a maize row in an alternate manner in the intercropped plots. Sole culture maize was included as a separate treatment. The final densities were 30,000 and 15,000 plants/ha for the sole and intercropped maize, respectively, and 30,000 and 60,000 plants for the intercropped and sole culture cowpea, respectively. Pan 311 and Pan 326 are short-duration types whereas Bechuana White and Agrinawa are medium- and long-duration cultivars, respectively.

In the 2001/02 trials at Syferkuil and Dalmada, the treatments included two cowpea cultivars, namely, Glenda and Bechuana White, and two lablab cultivars, Rongai and Common, grown as sole cultures or intercropped with maize. The trials were established on 6 and 10 December 2001 at the two locations, respectively. The lablab cultivars were both long-duration types obtained from a commercial seed company in South Africa. Unlike the 1998/99 and 1999/2000 trials, where the legume was planted at 90 cm inter-row spacing from the maize, the legumes in the 2001/02 trials were planted between two maize rows spaced 90 cm apart. Thus, the legumes were 45 cm from the maize. The maize density in this trial was 60,000 plants/ha and that of the legume was 25,000 plants/ha in both the intercrop and sole crop systems. The legume seeds in all trials were inoculated with the commercial *Bradyrhizobium* strain CB756 just before planting. The data collected were agronomic characteristics, seasonal dry-matter production of the legumes in the 2001/02 season and the grain yield of the component crops.

Weeding was done twice during the growing season in all the trials by hoeing and hand-pulling. All the legumes were sprayed once with Metasystox during the growing season to control aphids. Days to flowering for all crops were recorded when 50% of the plants in a plot had flowered. Physiological maturity of the legumes was scored when 90% of the plants in a plot revealed pods that rattled when shaken and of maize when 90% of the plants had no milk line (Stoskopf 1981). Seed yield samples of maize and cowpea were taken from the middle rows of each plot, leaving one row on each side as a border row. Harvested maize and the legumes samples were oven-dried at 65°C to constant moisture content (14%) and then weighed to determine grain yield.

Results and Discussion

Maize grain yield

In the 1998/99 and 1999/2000 trials, maize grain yield was significantly ($p \leq 0.05$) affected by cropping system only in 1999/2000 at Syferkuil. The yield at this location ranged from 4956–7757 kg/ha with the highest yields occurring in maize intercropped with Pan 311, Pan 326 and Agrinawa (Figure 1). Maize intercropped with Pan 311 was 41.7% superior to the sole maize whereas intercrops with Pan 326, Agrinawa and Bechuana White were similar to the sole maize. Maize yield in 1998/99 averaged across the five treatments was 2813 kg/ha at Syferkuil and 3378 kg/ha at Thabina/Dan. Maize yield in 1999/2000 at Thabina/Dan was unavailable due to excessively high rainfall late in the season, which prevented access to the experimental site and severely damaged the crops.

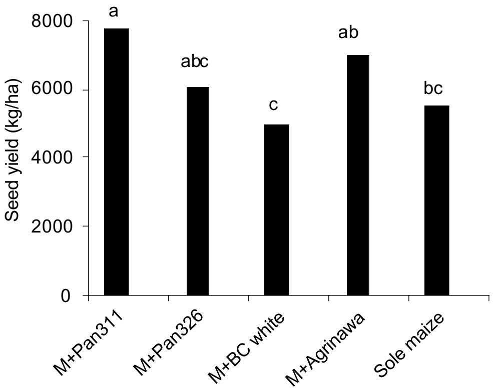

Figure 1. Grain (seed) yield of maize (M) in sole culture and intercropped with cowpea cultivars Pan 311, Pan 326, Bechuana (BC) White and Agrinawa at Syferkuil in the 1999/2000 growing season.

The highest performance of maize intercropped with cowpea cultivar Pan 311 could be due to this cultivar being small and generally early maturing — thus offering minimal competition to the maize. The above results agree with other researchers' findings that yield advantages in intercrops may arise when the growth duration of the component crops differs. Each crop will be exposed to greater resources because they will make major demands for those resources at different times (Ofori and Stern 1987; Putnam and Allan 1992; Ayisi and Poswall 1997). The lack of significant difference in the grain yield of the sole and intercropped maize is an indication that maize could be successfully intercropped with these cowpea cultivars without sacrificing the maize grain yield.

Table 2. Grain yield (kg/ha) of sole and intercropped maize at Syferkuil and Dalmada during the 2001/02 season (M = maize; BC White = cowpea cv. Bechuana White; Glenda = cowpea cultivar; Rongai and Common = lablab cultivars).

Cropping system	Syferkuil	Dalmada
Sole M	1238 a	1420 a
M + BC White	172 b	455 b
M + Glenda	330 b	1213 a
M + Rongai	172 b	595 b
M + Common	44 b	168 b
LSD (p ≤ 0.05)	434	462
CV (%)	56	32

Note: LSD = least significant difference; CV = coefficient of variation; means followed by the same letter or letters within a column are not significantly different from each other (p ≤ 0.05).

Grain yield in the 2001/02 trials, where the legume was planted between maize at 90 cm inter-row spacing, was influenced by the cropping system at both locations. At Syferkuil, the yield of all the intercropped maize was severely reduced relative to the sole maize (Table 2). However, at Dalmada, the grain yield of maize intercropped with cowpea cultivar Glenda was similar to the sole crop, whereas the yield of maize in the other intercrops was lower than that of the sole maize. The generally poor grain yield performance of the intercropped maize at both locations indicates that the presence of all legumes in the maize culture created a severe competitive condition, which prevented effective growth and yield of the associated maize. Increased competition in an intercropping system could either result from the increased number of plants per unit area compared to the sole culture, or an effective reduction in resources as both plant species must 'share' them — if the resources are lower than the combined demands of the participating species, yield reduction is bound to occur (Vandermeer 1992). Other researchers have reported that yield advantages through intercropping may arise if the growth duration of the component crops differ. Each crop will be exposed to higher resources because they will make major demands for resources at different times (Putman and Allan 1992; Ayisi and Poswall 1997). The generally lower yields of the intercropped maize were due to intense competition from the legume resulting from to narrower inter-row spacing of the 2001/02 trials.

Cowpea grain yield

Cowpea grain yield was influenced by cropping system in both the 1998/99 and 1999/2000 trials at Syferkuil, but only in 1998/99 at Thabina/Dan. At Syferkuil in 1998/99, the highest grain yield was recorded in sole cropped Pan 311, with a yield of 532 kg/ha, followed by maize intercrops with Pan 311 and Pan 326 (Figure 2). The lowest yields were recorded in sole and intercropped Bechuana White and Agrinawa. Comparing the effect of cropping system on individual cowpea yields, grain yields of Pan 326, Bechuana White and Agrinawa remained unchanged whether they were intercropped or planted as sole cultures. However, the yield of Pan 311 was reduced by 27% when intercropped. Across the various cropping systems, intercropping reduced cowpea seed yield by an average of 13% relative to the sole culture at Syferkuil in 1998/99. During the 1999/2000 growing season at this location, the highest yields were recorded in Bechuana White under both sole and intercropping systems, followed by sole cropped and intercropped Pan 311 and Agrinawa (Figure 3). These results are contrary to the previous season's observations where Bechuana White and Agrinawa produced the lowest yields — thus indicating the importance of season on cowpea performance in the intercropped system. Similar to the 1998/99 data, the yields of Pan 326, Bechuana White and Agrinawa were not dependent on whether they were planted as sole crops or as intercrops. However, the yield of Pan 311 was reduced by 53% when intercropped with maize. Yield reduction of intercropped Pan 311 could be attributed to the increased competitiveness of the associated maize crop as indicated by its superior yield performance.

At Thabina/Dan, a significant difference was only recorded in 1998/99 and not in 1999/2000. In 1998/99, the highest seed yield of 1547 kg/ha was recorded in sole cropped Pan 311 (Figure 4), which was similar to the results at Syferkuil during the same year. The seed yield of cowpea cultivar Pan 311 was reduced by 24% when intercropped. Similar to Syferkuil, yields of cultivars Pan 326, Bechuana White and Agrinawa remained unchanged whether they were intercropped or grown as sole crops. According to Ayisi et al. (2000), Pan 311 is a high-yielding cultivar, but from the present study it did not perform very well under the intercropped system with maize.

Intercropping usually results in increased yield of the more competitive component crop with a subsequent reduction in the weaker crop. However, this was not observed under maize intercropped with cowpea cultivars Pan 326, Bechuana White or Agrinawa. Relatively high rainfall throughout the growing seasons at both locations might have favoured the medium- to long-duration cowpea cultivars to increase yield under the intercropped system. The consistent performance of cultivars Pan 326, Bechuana White and Agrinawa

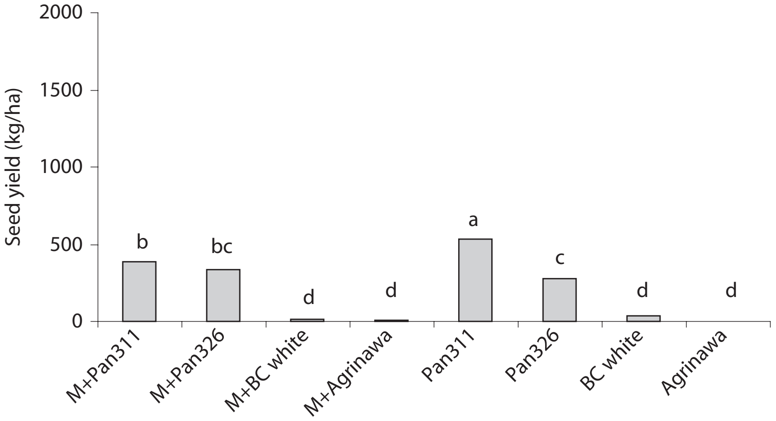

Figure 2. Seed yield of cowpea cultivars Pan 311, Pan 326, Bechuana (BC) White and Agrinawa as sole crops and intercropped with maize (M) at Syferkuil in the 1998/99 growing season.

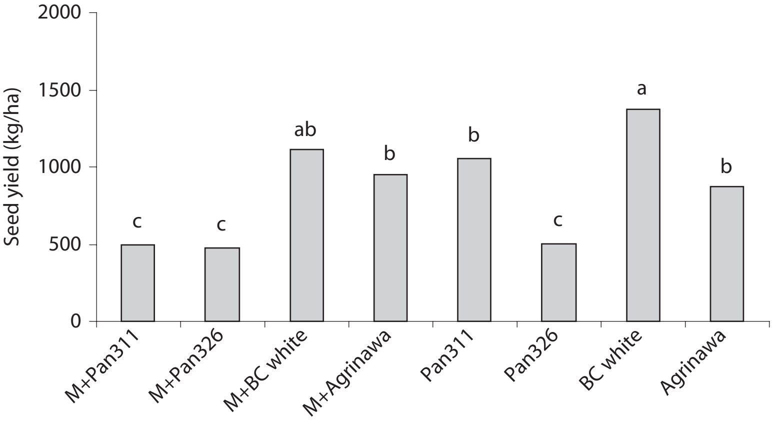

Figure 3. Seed yield of cowpea cultivars Pan 311, Pan 326, Bechuana (BC) White and Agrinawa as sole crops and intercropped with maize (M) at Syferkuil in the 1999/2000 growing season.

indicates their ability to maintain high productivity under intercropping situations and hence their potential as intercrop varieties in the maize–legume intercropped system. However, the inconsistency of the cultivars from season to season needs to be addressed through additional experimentation before final recommendations are made. Our results also indicate that maize can be intercropped with some of the cowpea cultivars in this particular system with no yield sacrifice of either crop, since seed yield was not affected by intercropping compared to sole cropping.

During the 2001/02 trials, the seed yield of cowpea responded significantly ($p \leq 0.05$) to cropping system at Dalmada but not at Syferkuil (Table 3). At Dalmada, the highest seed yields were recorded in sole cropped cultivar Glenda and sole Bechuana White.

On average, the seed yield of the cowpea varieties was 56% lower in the intercrops than in sole crops. The greatest reduction occurred in intercropped Glenda in which the yield was only 27% that of the sole crop yield. The observation that intercropping maize and grain legumes leads to severe depression of the legume yield is in agreement with reports by Searle et al. (1981) and Siame et al. (1998) who observed similar lower legume yields in maize–cowpea intercrop trials and also by Ezumah et al. (1987) and Ofori and Stern (1987) in maize–soybean intercrops. Yield depression of both component crops, such occurred in this study, suggested severe moisture and nutrient deficiency conditions. No grain was produced by lablab during the course of experimentation.

Flowering and physiological maturity of maize

No significant differences in days to flowering and physiological maturity of maize due to cropping system was observed at either location during the 1998/99 and the 1999/2000 trials. Maize flowering date ranged from 64 to 71 days after planting (DAP) and that of maturity from 122 to 128 DAP across the seasons and locations.

Table 3. Seed yield (kg/ha) of sole and intercropped cowpea cultivars Glenda and Bechuana (BC) White at Syferkuil and Dalmada during the 2001/02 season.

Cropping system	Syferkuil	Dalmada
Sole BC White	885	878 a
Sole Glenda	1009	1010 a
Intercropped BC White	938	543 b
Intercropped Glenda	740	280 c
LSD ($p \leq 0.05$)	NS	185
CV (%)	27	14

Note: LSD = least significant difference; CV = coefficient of variation; NS = not significant ($p \leq 0.05$); means followed by the same letter or letters within a column are not significantly different from each other ($p \leq 0.05$).

Flowering and physiological maturity of cowpea

Days to flowering in the cowpea cultivars ranged from 54 to 112 DAP and 63 to 84 DAP at Syferkuil

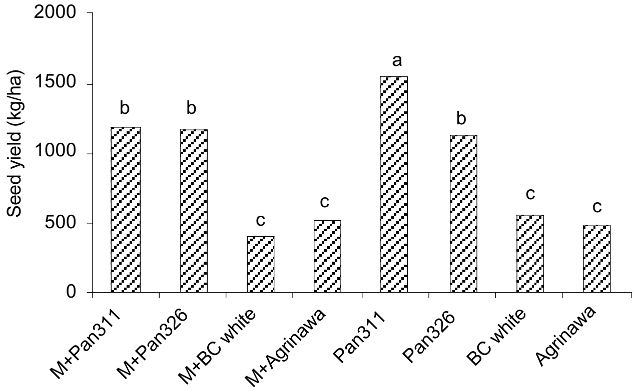

Figure 4. Seed yield of cowpea cultivars Pan 311, Pan 326, Bechuana (BC) White and Agrinawa as sole crops and intercropped with maize (M) at Thabina/Dan in the 1998/99 growing season.

for the 1998/99 and 1999/2000 growing seasons, respectively (Table 4). At Thabina/Dan (1999/2000), flowering of the cowpea cultivars ranged from 51 to about 70 DAP (Table 4). Based on days to physiological maturity, two groups of varieties could be identified, the early (Pan 311 and Pan 326) and medium to late (Bechuana White and Agrinawa) maturing types. Intercropping generally did not influence flowering or maturity in the cowpea cultivars.

During the 2001/02 trials, differences in days to flowering in maize due to cropping system were also not observed at the two locations. Flowering date ranged from 70 to 74 DAP at Syferkuil and from 74 to 79 DAP at Dalmada. The lack of a significant difference in days to flowering in maize is an indication that the presence of legume in the maize microenvironment did not alter the phenology of the crop.

Flowering and physiological maturity of cowpea

Similar to the previous season's trials, differences in days to flowering were observed among the cowpea and lablab cultivars ($p \le 0.05$) at both Syferkuil and Dalmada (Table 5).

Flowering of the legume cultivars ranged from 54 to 133 DAP at Syferkuil. The cowpea cultivars Glenda and Bechuana White flowered between 54 and 64 DAP, which is in the range reported by Ayisi et al. (2000) for several cowpea cultivars at these locations. The lablab cultivars Rongai and Common took longer to flower; from about 129 to 133 DAP.

Table 4. Flowering and physiological maturity (days after planting) of sole and intercropped cowpea cultivars (Pan 311, Pan 326, Bechuana (BC) White and Agrinawa) at Syferkuil and Thabina/Dan in 1998/99 and 1999/2000.

Cropping system	Syferkuil 1998/99		Thabina/Dan 1998/99		Syferkuil 1999/2000	
	Flowering	Maturity	Flowering	Maturity	Flowering	Maturity
Sole Pan 311	60.6 b	83.0 bc	54.3c	90.5 c	63.1b	113.5 bc
Sole Pan 326	70.3 b	84.0 bc	51.0c	93.2 c	65.1b	118.5 b
Sole BC White	118.6 a	162.4 a	69.0a	112.5 a	84.0a	123.9 a
Sole Agrinawa	111.9 a	164.2 a	62.8b	107.5 ab	80.4a	126.9 a
Intercropped Pan 311	63.1 b	82.0 c	52.3c	89.0 c	63.3b	109.3 c
Intercropped Pan 326	54.8 b	85.0 b	53.3c	90.0 c	64.0b	113.8 bc
Intercropped BC White	110.0 a	162.4 a	69.7a	111.5 bc	79.1a	123.9 a
Intercropped Agrinawa	111.9 a	163.9 a	61.5b	106.7 b	81.8a	125.4 a

Note: means followed by the same letter or letters within a column are not significantly different from each other ($p \le 0.05$)

Table 5. Flowering and physiological maturity (days after planting) of cowpea cultivars (Bechuana (BC) White and Glenda) and lablab cultivars (Rongai and Common) as influenced by the cropping system at Syferkuil and Dalmada during the 2001/02 growing season.

Cropping system	Syferkuil		Dalmada	
	Flowering	Maturity	Flowering	Maturity
Sole BC White	64.7 b	93.3	65.7 c	93.3
Sole Glenda	59.3 bc	96.7	61.0 c	93.3
Sole Rongai	130.7 a	–	114.3 b	–
Sole Common	130.3 a	–	124.3 ab	–
Intercropped BC White	55.3 c	93.3	64.3 c	90.0
Intercropped Glenda	54.0 c	92.4	64.0 c	96.7
Intercropped Rongai	133.0 a	–	124.3 ab	–
Intercropped Common	129.7 a	–	126.0 a	–
LSD ($p \le 0.05$)	9.2	NS	10.1	NS

Note: statistical significance for physiological maturity was tested only in cowpea, as the lablab was killed by frost before it matured; LSD = least significant difference; NS = not significant ($p \le 0.05$); means followed by the same letter or letters within a column are not significantly different from each other ($p \le 0.05$).

No differences in maturity of cowpea cultivars was observed and lablab matured before being killed by an early season frost at 146 DAP.

Total biomass accumulation of the legumes

A significant effect of cropping system on total dry weight of the legumes was observed at all sampling dates except 67 DAP at Syferkuil (Table 6). Biomass accumulation by 67 and 71 DAP at the two locations, respectively, generally did not differ much between the sole crops and intercrops for the individual legumes. However, at 54 DAP, for cv. Glenda, total dry weight was enhanced under intercrop by about 60% relative to the sole crop.

Conclusions

Intercropping maize with cowpea cultivar Pan 311 enhanced maize yield over the sole culture yield, but the yield of the legume was reduced by 27% when intercropped compared to the sole crop of this cowpea. From our study, it is clear that cowpea cultivars Pan 326, Bechuana White and Agrinawa could be successfully intercropped with maize in alternate, single 90 cm rows without sacrificing grain yields of the two crops in the system. Differences in days to flowering and physiological maturity due to cropping system were observed between cowpea cultivars but not in maize. The early-flowering cowpea cultivars were Pan 311 and Pan 326. In general, days to flowering days to maturity of all the cowpea cultivars did not vary between the sole cultures or the intercrops with maize.

When cowpea and lablab were planted between two rows of maize spaced at 90 cm, seed yields of both the maize and the cowpeas were generally reduced compared to the sole crops. However, when maize was intercropped with cowpea cultivar Glenda, the maize yield was comparable to the sole crop at one location but not the other. Biomass accumulation of the legumes generally did not differ between the crops grown in sole culture and those in intercropped systems. Further studies involving varying densities of the legumes will help identify the best combinations of the cereal and the legumes for intercropping.

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Table 6. Total dry-matter accumulation (kg/ha) of cowpea cultivars Bechuana (BC) White and Glenda and lablab cultivars Rongai and Common at Syferkuil and Dalmada, as influenced by cropping system during the 2001/02 growing season (DAP = days after planting).

Cropping system	Syferkuil 54 DAP	Syferkuil 67 DAP	Syferkuil 88 DAP	Dalmada 50 DAP	Dalmada 71 DAP	Dalmada 95 DAP
Sole BC White	1172 ab	2514	5750 a	771 abc	3312 ab	2268 bc
Sole Glenda	834 b	2438	5160 ab	971 a	4000 ab	2982 bc
Sole Rongai	1079 b	2778	5562 a	726 abc	3013 ab	5709 a
Sole Common	751 b	1940	5488 a	558 abc	3210 ab	3902 ab
Intercropped BC White	643 b	3378	2165 b	862 ab	4161 a	978 c
Intercropped Glenda	1744 a	2505	3442 ab	403 c	2375 ab	1629 c
Intercropped Rongai	1130 b	2052	3539 ab	462 bc	1865 b	2648 bc
Intercropped Common	666 b	3131	4936 ab	484 bc	2740 ab	2854 bc
LSD ($p \leq 0.05$)	587	NS	3271	446	2263	2261
CV (%)	33	34	41	39	42	45

Note: LSD = least significant difference; CV = coefficient of variation; NS = not significant ($p \leq 0.05$; means followed by the same letter or letters within a column are not significantly different from one another ($p \leq 0.05$).

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Grain Sorghum Production and Soil Nitrogen Dynamics Following Ley Pastures on a Vertosol in Queensland, Australia

A.M. Whitbread[*] and R.L. Clem[†]

Abstract

Highly productive sown pasture systems can result not only in high growth rates of beef cattle, but also lead to increases in soil nitrogen and the production of subsequent crops. The response of grain sorghum to various periods of annual legumes and grasses were investigated in a no-till system in the South Burnett district of Queensland. Two-to-four years of the tropical legumes *Macrotyloma daltonii* and *Vigna trilobata* (two self-regenerating annual legumes) and *Lablab purpureus* (a resown annual legume) resulted in soil nitrate nitrogen (0–90 cm depth) ranging from 36 to 102 kg/ha compared with 5 to 11 kg/ha after grass only pastures. Grain sorghum produced in up to four crops following the legume pastures exceeded 3000 kg/ha of grain in each season. Simulation studies utilising the farming systems model APSIM (Agricultural Production Systems sIMulator) indicated a high correlation with observed grain and biomass data ($r^2 > 0.68$) and soil N dynamics. In simulated sorghum crops (1954–2000), grain yield was unlikely to exceed 2000 kg/ha of grain in 60% of seasons following a grass pasture while following 2-year legume leys, grain exceeded 3000 kg/ha in 80% of seasons. It was concluded that mixed farming systems that utilise short-term, legume-based pastures for beef production in rotation with crop production enterprises can be highly productive.

In the northern grain belt of Australia, which takes in northern New South Wales and southern and central Queensland, lower crop yields and grain protein content as a result of declining soil fertility have prompted many farmers to consider the role of ley pastures as a source of forage and a way to improve soil fertility. The traditional winter-growing legume species of medic and lucerne have been used as ley pastures in the southern areas of Queensland where some winter rainfall is received. However, in the central Queensland areas, most of the rainfall is received during the hot summer months and tropical species of legumes are better adapted.

The increasing interest in legumes for use in farming and grazing systems is generated by the increasing need to provide nitrogen to the soil for subsequent crops in environmentally acceptable ways, and the need to provide high-quality forage to increase growth rates of stock to produce beef of better eating quality. Both longer-term perennial legumes that can persist with grass and forage legumes used in shorter-term leys can provide high-quality forage to finish cattle for premium beef markets.

The duration, species selection and management of pastures will depend on the soil type and farming enterprises. Farmers located on cropping country where animals are of minimal importance may look to ley pastures to provide soil fertility inputs (physical, biological and chemical) for subsequent cropping activities, while farmers involved with mixed-farming operations can utilise the leys as valuable

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[*] CSIRO Sustainable Ecosystems, 306 Carmody Road, St Lucia, Queensland 4067, Australia.

[†] Queensland Department of Primary Industries, Gympie, Queensland, Australia.

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forage as well as for improving the soil of the cropping country. They are more likely to economically justify pasture for longer durations and offset the losses in grain production with animal production.

A number of summer-growing legumes are now known to be well adapted to lower rainfall (700 to 800 mm MAR — mean annual rainfall) areas in central and southern Queensland. They have a range of characteristics that could complement or provide alternatives to the annual lablabs and cowpeas and include such legumes as Milgarra butterfly pea (*Clitoria ternatea* cv. Milgarra), Endurance lablab (*Lablab purpureus* cv. Endurance) and burgundy bean (*Macroptilium bracteatum* cvv. Cardaga and Juanita). Other self-regenerating legumes such as *Vigna trilobata and Macrotyloma daltonii*, tested by the Queensland Department of Primary Industries and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for many years, remain unreleased but may provide useful germplasm in the future.

The study described in this paper investigates the dynamics of soil nitrogen and the production of grain sorghum following various ley legume pastures. Using these data to validate the farming systems model APSIM (Agricultural Production Systems sIMulator) potential production of grain sorghum across a range of seasons was also analysed. The animal production phase of this trial is described in Clem (2004).

Methodology

Soil type

The experiment was conducted on the Brian Pastures Research Station on a moderately to strongly self-mulching Vertosol (black earth) on a 3–10% slope, Ug5.34 (Northcote 1979) with weak linear Gilgai (Reid et al. 1986). The three legume treatments were situated lower on the slope and had a soil depth of 0.9–1.2 m, a plant available water capacity (PAWC) of 171 mm (Table 1) and total organic carbon of 1.7% and 1.4% at 0–15 cm and 15–30 cm depth, respectively. The soil on which the grass pasture treatment was situated was only 90 cm deep with a PAWC of 115 mm and total organic carbon contents of 2% and 1.5% at 0–15 cm and 15–30 cm depth, respectively.

Pasture phase

From the pastures established in the summer of 1997/98 and described by Clem (2004), four pasture treatments were selected to test the response of sorghum production after the termination of these ley phases. The treatments selected were the improved grass pasture (*Bothriochloa insculpta* cv. Bisset, *Dichanthium sericeum* and *Panicum maximum* var. *trichoglume* cv. Petrie), the annual legume pasture *Lablab purpureus* cv. Highworth, and the self-regenerating legume pastures *Macrotyloma daltonii* CPI 60303 and *Vigna trilobata* CPI 13671 systems. Subsequent to the initial pasture plantings in 1997/98, *L. purpureus* had been resown on 7 December 1998, 4 January 2000 and 13 December 2000.

Sorghum phase

In November 1999, following a heavy grazing by cattle, approximately one-third of the 2 ha replicated treatments previously sown to *M. daltonii*, *V. trilobata* and *L. purpureus* and a smaller area (~500 m^2) in the grass pasture was sprayed with herbicide, kept free of weeds and planted to sorghum at the dates indicated in Table 2. Similarly, in the following season, these same areas and a further one-third of the plots were grazed, sprayed with a knockdown herbicide and planted to sorghum. In the fourth season (2002/03), only the *M. daltonii* and *L. purpureus* treatments were continued. The areas that had already been planted with sorghum for the past one or

Table 1. Soil properties of the experimental site near Mt Brambling, Brian Pastures.

Depth (cm)	Bulk density (g/cm^3)	Drained upper limit (%)	Sorghum lower limit (%)	Saturated (%)	Plant available water (mm)
0–15	1.23	45	25	48	31
15–30	1.29	43	26	46	25
30–60	1.28	44	24	47	59
60–90	1.30	43	24	46	57
90–120	1.44	38	28	41	28

two seasons, and the remaining third of the plots which were still sown to pasture were heavily grazed, sprayed and planted with sorghum.

Within each of the areas sown to sorghum, a representative test area (10 × 30 m) was selected to which all crop and soil measurements were confined. These test areas were divided into two plots (10 × 15 m) and one-half received 80 kg of N/ha as urea in two splits (Table 2) during the sorghum crops.

Three additional plots (10 × 5 m) established in the *M. daltonii* test areas received 20, 40 and 120 kg/ha of N applied as urea in a split application at the dates indicated in Table 2. All fertiliser was broadcast by hand to the soil surface. These plots were used to test the sorghum N response in each season.

Grain sorghum was planted into the legume and sorghum stubble that remained in the plots after grazing using a no-till planter. No estimate of the remaining residue at sowing was made. In the 1999/2000 season, sorghum (Pioneer S75) was planted at 3.2 kg/ha into 25 cm rows. In the three subsequent seasons, sorghum was planted at 3.0–3.6 kg/ha into 90 cm row spacings using sorghum variety Buster MR in 2000/01 and Pioneer M43 in 2001/02 and 2002/03.

Cattle grazed the sorghum residues remaining after harvest. Sorghum regrowth was sprayed with a knockdown herbicide and after the withholding period, cattle grazed the dead plant residues.

At physiological maturity, sorghum grain and stover were harvested for the determination of yield and nitrogen concentration. Two separate, centrally located 5 m rows within each plot were selected and the number of plants and grain heads were counted. The heads were cut from the plants, removed and the remaining stover was cut at ground level and removed. Stover was dried in a forced-air dehydrator at 80°C for 48 hours and weighed to determine dry matter. The sorghum heads were dried, threshed to remove grain and weighed. The panicle straw weight was added to the stover weights.

Soil samples were taken in each plot before planting and following harvest of each crop and analysed for nitrate nitrogen and water content. All samples were taken using a hydraulic soil sampler with cores to 90 cm being sampled and then partitioned into 0–15, 15–30, 30–60 and 60–90 depth increments for analysis. Soil nitrate nitrogen was determined using the method of Keeny and Nelson (1982) described in Rayment and Higginson (1992).

APSIM set-up

Soil was characterised (Table 1) following the procedures of Dalgliesh and Foale (1998). The drained upper limit (dul) was determined by slowly wetting the soil to saturation, allowing drainage to take place over 2–3 weeks and determining the moisture content. Bulk density was calculated at the dul using the relationship that exists between measured bulk density and gravimetric moisture content described by Gardner (1988) and referred to by Hochman et al. (2001). The crop lower limit (cll) for sorghum was determined by placing a rain-out shelter over a section of the 1999/2001 sorghum crop at flowering and determining the soil water content after the crop had reached maturity.

Simulation of measured sorghum phases

Daily climatic records from the research station (maximum and minimum temperatures, rainfall, solar radiation) were used to simulate sorghum growth. All management parameters in the model mimicked the actual field experimentation. Analysis of the modelled data was confined to the treatments where two seasons of legume pasture had preceded the sorghum phase and only the 1999/2000, 2000/01 and 2001/02 sorghum crops were simulated. The sorghum simulations in the 1999/2000, 2000/01 and 2001/02 seasons were preformed using the actual planting dates, the timing of nitrogen fertiliser applications and management information (Table 2). No attempt was made to include weeds in the model sim-

Table 2. Timing (dates) of cropping operations for the sorghum test phase.

Season	Spraying	Planting	N split 1	N split 2	Harvest
1999/2000	12 Nov 99	7 Jan 00	28 Jan 00	3 Mar 00	18 Apr 00
2000/2001	13 Nov 00	3 Jan 01	9 Feb 01	12 Mar 00	3 May 01
2001/2002	17 Aug 02	13 Dec 01	24 Jan 02	13 Feb 02	22 Apr 02
2002/2003	12 Dec 02	12 Feb 03	7 Mar 03	16 Apr 03	16 Jun 03

ulations and it was assumed that the low weed populations in the field during the sorghum crops did not limit growth.

Long-term simulations

To consider the long-term effect of seasonal conditions on sorghum production in the first season following the termination of a pasture, APSIM was initialised with the soil water and mineral nitrogen conditions that were measured following each of the pasture treatments on Julian day 319 (November 15) each year. Simulations were then run from 1954–2001 using the Brian Pastures long-term weather data. Each year, the sorghum crop was sown between November 15 and January 15 when at least 30 mm of rain was received over five consecutive days. As all soil conditions were reset to the same parameters each season, the effect of climate on sorghum grain production was predicted following each pasture treatment. The grass pasture treatment was also included with the same profile depth and PAWC as the soils on which the legume treatments were established.

Statistical analysis

The depth of soil under the grass treatment was found to be about 30 cm less than the other treatments. Sorghum production on this treatment could not be compared with that of the other treatments and was therefore not included in the statistical analysis of sorghum production.

In the first year of the sorghum phase, data were analysed as a fully randomised factorial design of 3 previous pasture treatments × 2 fertiliser rates × 2 replicates. In subsequent years, the number of previous seasons to sorghum was also included as a factorial treatment in the design. Mean separation was tested using Duncan's multiple range test (DMRT) at $P \leq 0.05$. All data were tested for the assumption of common variance and transformed if necessary. Total soil nitrate nitrogen data were found to have large difference in variance between replicates of different treatments and were statistically analysed after log transformation.

Results

Seasonal conditions

The previous legume pasture did not significantly influence soil water measured prior to sowing of the sorghum crops. The soil profile (0–90 cm) contained between 34 and 56% of the total PAWC (171 mm) at sowing over the four seasons (data not shown). Rainfall was generally near or below average over the five growing seasons (Table 3). The in-crop rainfall was 138 mm in 1999/2000, 222 mm in 2000/01, 276 mm in 2001/02 and 232 mm in 2002/03.

Sorghum production

Sorghum grain yield production in all years was highest following the *L. purpureus* pasture, however this was statistically significant only in the 2000/01 and 2002/03 sorghum crops (Table 4). Total biomass production (grain + stover) in the 2000/01 sorghum crop was highest in the *L. purpureus* treatment, and in 2001/02 was significantly lower in *V. trilobata* treatments than *M. daltonii* and *L. purpureus* treatments (Table 5).

There was no response in grain or biomass yield to nitrogen fertiliser application (0 or 80 kg N/ha) in any of the treatments or any of the years so the data presented in Tables 4 and 5 are averages of these fertiliser treatments. There was also no response in sorghum production to the additional nitrogen fertiliser treatments (0, 40, 120 kg/ha N) included within the *M. daltonii* treatments.

The sorghum grown on the grass treatment yielded very poorly in the first year (1999/2000) and con-

Table 3. Monthly rainfall received at Brian Pastures Research Station from July 1998 and the long-term average (1963–2002).

Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Year
1998/99	22	26	119	21	107	90	35	51	49	5	30	37	592
1999/00	84	14	33	107	118	53	78	61	27	33	27	26	661
2000/01	5	3	0	171	70	66	7	138	120	32	46	1	659
2001/02	46	1	38	33	155	52	18	164	60	5	49	70	691
2002/03	0	91	0	64	24	58	0	113	63	61	43	10	527
Average	35	29	29	61	70	105	110	94	71	37	40	29	710

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tinued to yield less than the other treatments in subsequent seasons (Table 4 and 5).

There was a decline in sorghum grain yield with an increase in the number of preceding sorghum phases. This decline became significant in the final sorghum phase where grain yield was 18% lower in the third year of sorghum and 27% lower in the fourth year of sorghum compared with the treatment where one previous sorghum phase had been grown (Table 6). There was no significant effect of the preceding legume species so the data shown in Table 6 are the mean of these treatments.

Soil nitrate

The effect of pastures

Soil nitrate measured after the termination of the two, three or four seasons of pasture was significantly lower following the grass treatments than following the legume treatments (Table 7). There was no significant difference in soil nitrate found between the legume treatments and there was no significant increase in soil nitrate with additional seasons of legume growth (tested using the repeated measures analysis of pasture treatment × replicate × year).

Residual value in the sorghum phase

In the first season following 2 years of legume pastures, soil nitrate nitrogen ranged from 36 to 86 kg N in the profile (0–90 cm) and declined to virtually zero following four sorghum crops (Figure 1). Although the amount of nitrogen mineralised between the harvest of a sorghum crop and the sowing of the next sorghum crop was similar in each year (averaged across the legume treatments it was 26, 43, 39 kg/ha nitrate nitrogen in 2000, 2001 and 2002, respectively), the starting soil nitrate successively declined with the removal of nitrogen in each sorghum crop

Table 4. Grain production (kg/ha) of the sorghum phases over the four seasons.

Pasture phase	1999/2000	2000/01	2001/02	2002/03
Macrotyloma daltonii	2825 a	3641 b	3053 a	3352 b
Vigna trilobata	2401 a	3860 b	3113 a	–
Lablab purpureus	4098 a	5362 a	3738 a	4004 a
Grass[a]	995 (244)	2405 (339)	3053 (1159)	–

[a] Brackets indicate standard error of the mean in the grass treatments only.
Note: means followed by a different letter within columns are significantly different according to Duncan's multiple range test at P ≤ 0.05.

Table 5. Biomass production (kg/ha) of the sorghum over the 3 seasons.

Pasture phase	1999/00	2000/01	2001/02	2002/03
Macrotyloma daltonii	6357 a	11243 b	11499 a	6949 a
Vigna trilobata	6182 a	11612 b	7178 b	–
Lablab purpureus	10407 a	16706 a	10662 a	8369 a
Grass[a]	4477 (919)	7379 (1923)	6635 (1068)	–

[a] Brackets indicate standard error of the mean in the grass treatments only.
Note: means followed by a different letter within columns are significantly different according to Duncan's multiple range test at P ≤ 0.05.

Table 6. Sorghum grain yield in areas preceded by legume pastures and 1, 2 and 3 years of sorghum crops.

Sorghum yield	1999/2000	2000/01	2001/02	2002/03
First year	3108	4562 a	3738 a	–
Second year		4013 a **(12%)**	3113 a **(17%)**	4318 a
Third year			3053 a **(18%)**	3556 b **(18%)**
Fourth year				3159 b **(27%)**

Notes: means followed by a different letter within columns are significantly different according to Duncan s multiple range test at $P \leq 0.05$. Percentages shown in brackets in bold: Decline in grain yield = (grain yield of new sorghum phase — grain yield of older sorghum phase)/grain yield of new sorghum phase.

(Figure 1). Soil nitrate nitrogen declined from the presowing to postharvest measurement in all seasons due to the uptake of nitrogen in sorghum.

Table 7. Soil nitrate (kg N/ha) measured prior to sowing sorghum following two, three or four seasons of pasture.

Years of pasture	2	3	4
Date sampled	24 Nov 1999	30 Nov 2000	6 Dec 2001
Macrotyloma daltonii	64 a	67 a	83 a
Vigna trilobata	36 a	40 a	46 a
Lablab purpureus	86 a	102 a	69 a
Grass	5 b	3 b	11 b

Note: means followed by a different letter within columns are significantly different according to Duncan s multiple range test at $P \leq 0.05$; tested on log transformed data.

The application of 80 kg/ha of fertiliser nitrogen had a significant effect on soil nitrate at the harvest samplings in 2000/01 and 2001/02. At harvest in the 2000/01 season, total soil nitrate nitrogen increased from 15 kg/ha with no fertiliser to 74 kg/ha with fertiliser applied in the two previous seasons. Similarly at the 2001/02 harvest sampling, soil nitrate nitrogen increased from 7 kg/ha to 48 kg/ha with nitrogen fertiliser additions. By the final harvest, soil nitrate was negligible in the treatments that did not receive nitrogen fertiliser and 24 kg N/ha was available in the treatments that had received the yearly fertiliser nitrogen application of 80 kg/ha.

A significant relationship was found between soil nitrate at sowing and grain yield in 1999/2000 and 2000/2001 of the treatments that did not receive fertiliser nitrogen, indicating that grain yield was increased with higher soil nitrate nitrogen following the pasture treatments (Figure 2). Similar correlations were not found in other years or between other treatments, including the fertiliser comparisons. This suggests that soil nitrate nitrogen was limiting sorghum yield, although the nitrogen rate trials did not indicate this effect.

APSIM simulation

The observed and predicted data for the sorghum crops (1999/2000, 2000/01 and 2001/02 seasons) that were grown on the area that had been sown to legume pasture for two seasons were compared and an r^2 = 0.68 was achieved for the simulation of sorghum grain yield (Figure 3) and an r^2 = 0.79 was achieved for the simulation of sorghum biomass (Figure 4).

Figure 5 displays the APSIM predicted soil nitrate content for the *L. purpureus* and *V. trilobata* zero nitrogen treatments from November 1999 until May 2002. The soil nitrate values in the model are reset at the measured pre-sowing value each year. With the

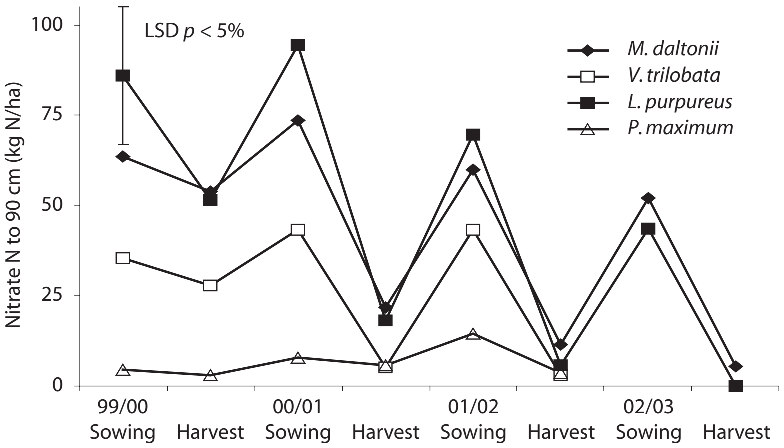

Figure 1. Total soil nitrate nitrogen (0–90 cm) measured before sowing and postharvest in each season from 1999/2000 to 2002/03 in the treatments that received no additional nitrogen fertiliser.

exception of the year 1 harvest nitrate value following the lablab pasture, each of the measured values of nitrate at harvest is in close agreement with the simulated data. There is a general decline in the amount of nitrate in the profile after harvest with each succeeding sorghum crop. This indicates the depletion of nitrate nitrogen as shown in the field data in Figure 1.

Resetting soil water and soil nitrate to the same values that were measured in 1999 after 2 years of the pasture treatments allowed the effect of seasonal conditions experienced in each season (1954–2001) to

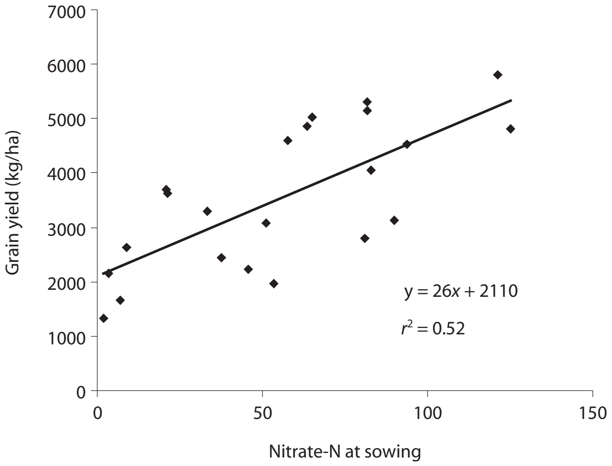

Figure 2. The relationship between nitrate nitrogen measured at sowing on the treatments that did not receive fertiliser nitrogen and grain yield in the 1999/2000 and 2000/01 sorghum crops.

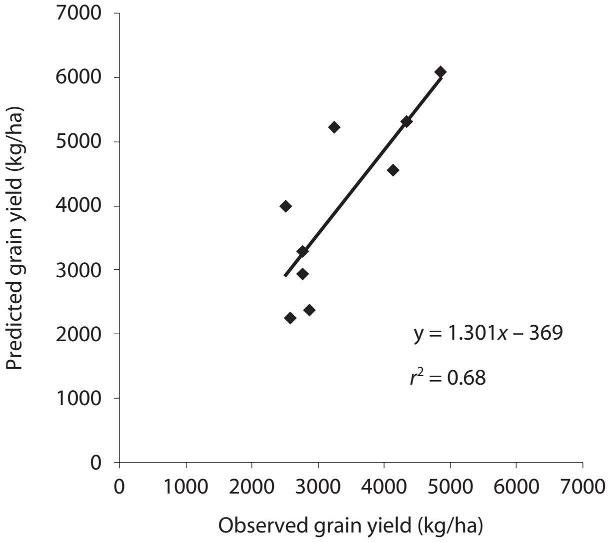

Figure 3. The observed and predicted data for sorghum grain yield in the 1999/2000, 2000/01 and 2001/02 seasons.

determine the sorghum growth (Figure 6). The probability of achieving no grain production following a grass pasture occurred during 15% of seasons. Following a grass pasture, grain production did not exceed 3000 kg/ha and approximately 60% of the time, grain production was between 1000 and 2000 kg/ha. Significantly higher grain yields were achieved following the legume pastures with much lower risk levels. Grain production was slightly more risky following the *L. purpureus* pasture, with 20% of seasons producing 1500–2600 kg/ha of grain compared with less than 10% for *V. trilobata* and *M. daltonii*. Grain production was between 3000 and 5300 kg/ha in at least 80% of the seasons between 1954 and 2001 following all of the legume pastures.

Discussion

Sorghum production

Legume treatments

In the 10 seasons prior to 1992–1993, average sorghum production in the South Burnett was 2.3 t/ha and ranged from 1.6 t/ha in 1983 to 2.6 t/ha in 1987 and 1989 (Crosthwaite and Harvey 1992). In the trial described here, sorghum production exceeded this average in all treatments following the legume pastures and grain production was exceptional following the *L. purpureus* pastures in most seasons (Table 4).

Sorghum production declined as the number of crops since a legume pasture increased. This decline was 12% in the second sorghum phase and increased to 27% after four sorghum phases (Table 6). The minimum yield remained above 3053 kg/ha (Tables 4 and 6), which is considered high by local standards. While a strong relationship between soil nitrate nitrogen at sowing and grain yield was found in the unfertilised treatments in the first 2 years of the sorghum production (Figure 2), this relationship did not exist in later crops. As soil nitrate nitrogen declined at each successive sowing, so too did grain yield. While the application of 80 kg/ha of nitrogen as urea significantly increased the after-harvest soil nitrate concentrations, there was no effect on grain yield as soil nitrogen declined with successive sorghum crops. Fertiliser was applied by hand to the soil surface and may not have been as effective as if applied to the root zone at or before planting, as is the usual farmer practice.

Grass treatments

Sorghum growth in the first and second season following grass pastures was very poor and mainly the result of very low soil nitrate nitrogen concentrations

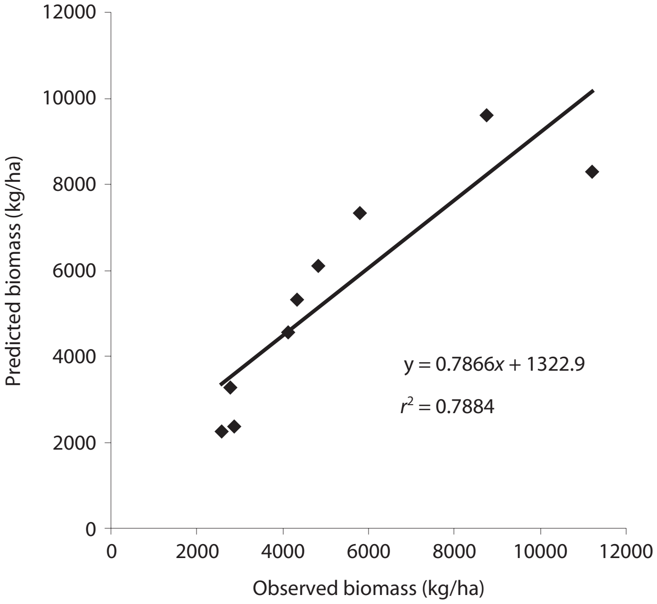

Figure 4. The observed and predicted data for sorghum biomass in the 1999/2000, 2000/01 and 2001/02 seasons.

present at sorghum sowing. Nitrogen deficiency in grassland pastures has been well documented in the Brigalow landscapes of central Queensland by Robertson et al. (1993a,b, 1994). Robertson et al. (1993a) found that up to 20 t/ha of surface litter and root residues of high C:N ratio accumulated under these pastures. Using incubation techniques, these authors found that pasture soil respired more CO_2 and mineralised less nitrogen than cultivated soils. Since the C:N ratio of pasture residues is high (>50), immobilisation of mineral nitrogen occurs.

In the system described in this study, sorghum was established using a no-till planter. This results in minimal soil disturbance and slow decomposition of surface and buried plant residues. The highest soil nitrate nitrogen concentrations were found at the sowing

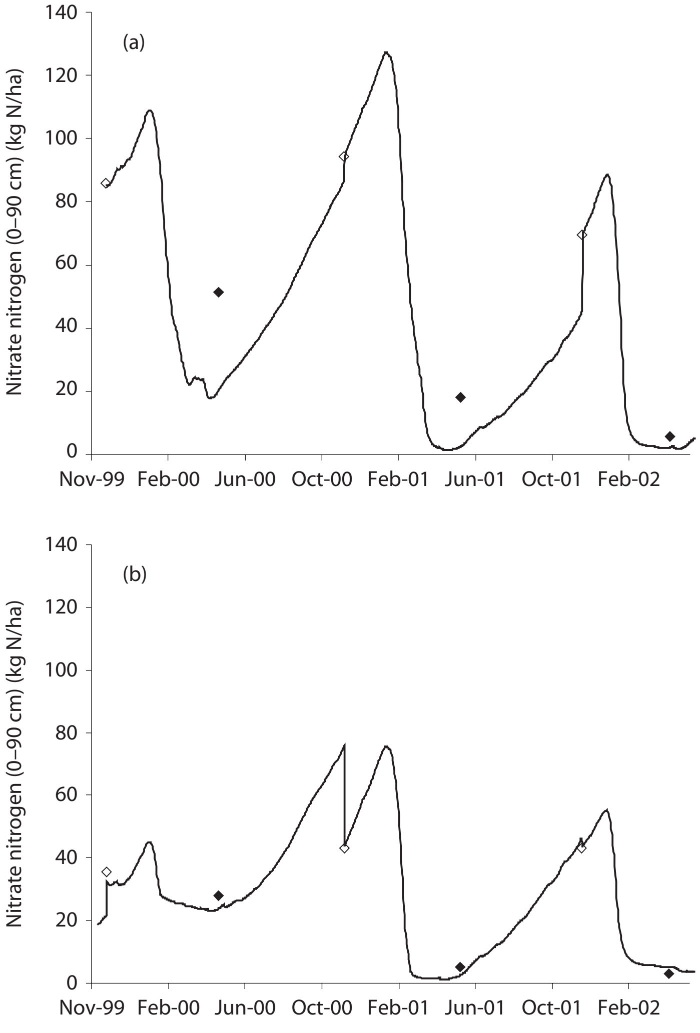

Figure 5. Soil nitrate (0–90 cm) during a cropping phase preceded by a) *Lablab purpureus* and b) *Vigna trilobata.* Solid line is the simulated value, The open points are the measured soil nitrate value before sorghum sowing and APSIM (Agricultural Production Systems sIMulator) has been reset to this value. The closed points are the measured soil nitrate value after harvest.)

of the 2001/02 sorghum phase (Figure 1) indicating that the mineral nitrogen was becoming available after a long period of immobilisation. Also contributing to the lower sorghum yield in this treatment was the shallower soil profile and a PAWC of 115 mm compared with 171 mm found in the other treatments.

Nitrogen dynamics

Since soil samples were not available from these experiments before the legume pastures were sown, the soil nitrogen status is not known. Before the legume pastures, successive sorghum crops and grass fodder crops had been planted for more than 20 years, so it could be reasonably assumed that soil nitrogen was depleted as studies on similar soil types have shown (Dalal and Mayer 1986; Whitbread et al. 1998). Soil nitrate nitrogen content (0–90 cm) ranged from 36 to 86 kg/ha after 2 years of legume pastures and significant increases in these concentrations was not found with further years of pasture. The studies of Armstrong et al. (1999) on vertosol soils in central Queensland found the percentage of nitrogen derived from atmosphere (%Ndfa) to be strongly negatively correlated to the amount of soil nitrate in the profile for two annual and two perennial legumes, including *L. purpureus*. They also found %Ndfa in *L. purpureus* to peak at 72% in the first year of a rotation, declining to <13% and 50% in the third and fourth year of the rotation, respectively. Soil sampling of the other treatments within this study described by Clem et al. (2004) indicates that where grass is also a component of the pasture, mineral nitrogen concentrations are kept low (A. Whitbread, unpublished data) and %Ndfa of the legume component may remain high.

APSIM simulations

The APSIM sorghum model was able to simulate biomass growth and grain production with a high degree of precision with the assumption of resetting soil water and soil nitrate to the measured pre-sowing values. Through the removal of nitrogen in sorghum grain, soil nitrate declined with each successive sorghum crop and was similar to the measured data. While the field trial described in this paper allowed measurement of the response of sorghum to various phases of legume pasture in four seasons, the simulation was able to extend this to the many different climatic conditions experienced between 1954 and 2001. Although the legume pasture treatments were established in the field on a deeper soil profile than the grass treatment, the PAWC and depth of all soil profiles could be made the same in the simulation study. All treatments could therefore be compared.

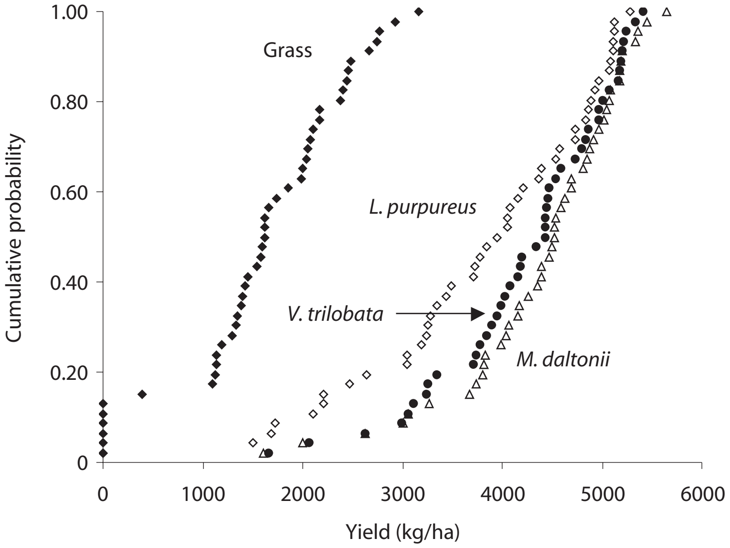

Figure 6. The probability of sorghum grain production using the soil water and nitrogen starting conditions of the various rotations simulated from 1954 to 2001.

Other simulation studies are under way to examine issues that may affect the pasture–grain system. These include: determining the precision of APSIM where soil water and nitrate are not reset on a yearly basis; determining the recharge of soil moisture after a pasture phase; determining crop production and soil nitrogen dynamics and potential responses to nitrogen fertiliser that may occur past the 4-year period examined in these field studies.

Conclusions

The potential for highly productive grain systems sustained by phases of highly productive pastures and beef production have been demonstrated through this paper and the study of Clem et al. (2004). There were no benefits in terms of nitrogen accumulation from continuing the sole legume pasture phases past two seasons. Although soil nitrate nitrogen declined with successive sorghum crops, the mineralisation of nitrogen in the time between the harvest of one crop and the sowing of the next remained high. The cropping component of this study did not continue for long enough to conclude for how long adequate soil nitrogen would be maintained. Sorghum grain yield did decline with each successive crop relative to the 'new' areas sown to sorghum each year, however crop responses to the addition of fertiliser nitrogen were highly variable. APSIM was able to simulate the sorghum growth and soil nitrogen dynamics of this cropping phase with a high degree of precision and could be applied to a range of other scenarios not able to be tested in the field. APSIM showed that sorghum production following a grass pasture was risky and unlikely to exceed 2000 kg/ha of grain in 60% of seasons. Sorghum production following 2-year legume leys was highly productive with >3000 kg/ha of grain produced in 80% of seasons.

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Mucuna, Lablab and Paprika Calyx as Substitutes for Commercial Protein Sources used in Dairy and Pen-fattening Diets by Smallholder Farmers of Zimbabwe

C. Murungweni, O. Mabuku and G.J. Manyawu*

Abstract

Five experiments were carried out to determine the role of *Lablab purpureus* (lablab) hay, *Mucuna pruriens* (mucuna) hay, paprika (*Capsicum anuum* L) calyx and commercial feeds on profitable and sustainable ruminant feeding systems. Three of the five experiments were carried out under a participatory research approach in two smallholder areas of the Wedza district in Zimbabwe. The other two were carried out under more controlled conditions at Grasslands Research Station in Marondera, Zimbabwe. The first on-farm experiment was carried out in Zana 2 ward in Wedza. Results determined the minimum amount of mucuna or lablab hay required to supplement cattle for maintaining liveweight to be equivalent to 1.5% of the animal's bodyweight on as-is basis. The second on-farm experiment determined the effect of lablab hay and paprika calyx on milk yield, compositional quality of milk and liveweight gain. In this experiment, four indigenous Mashona cows in early lactation were used in a crossover design of 21-day periods. All the four diets increased milk yield and improved milk quality. The third on-farm experiment tested the effect on liveweight gain of diets based on hay from lablab and mucuna. Six castrated indigenous Mashona cattle were used, three at each of the two sites. The animals were randomly allocated to the three diets. Replication was by site. The experimental animals were allowed an uninterrupted period of 73 days access to the assigned diet, with fortnightly weight recordings. Results showed no significant differences ($P > 0.05$) between the experimental diets. Animals feeding on these diets gained between 1.0 and 1.2 kg of liveweight per day. However, the diet with hay from mucuna resulted in highest total weight gain and gross margin. The last two experiments were carried out at Grasslands Research Station. The first on-station experiment had two parts. The first determined voluntary feed intake of diets based on hay from lablab and mucuna to be respectively, 3.0% and 3.1% of the animal's bodyweight on a dry matter basis. Levels above 2.6% of bodyweight caused metabolic problems resulting in diarrhoea in sheep. The second part of this experiment determined the effect of diets based on hay from lablab and mucuna on nitrogen balance and dry matter digestibility. This experiment used sheep in metabolism crates, with 21 days for adapting to the diets and 7 days of collection. Results showed higher dry matter digestibility ($P < 0.05$) in commercial feed (14% CP) and lablab-based diet (14% CP) than in a mucuna hay based diet (15% CP). No significant differences were observed between the three diets in terms of nitrogen balance and liveweight gain. The last on-station experiment determined the effect of diets based on lablab hay and mucuna hay on milk yield and milk quality of Jersey cows. Nine cows in early lactation were used in a completely randomised design, with three cows assigned to each diet. The experimental period was 28 days.

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* Grasslands Research Station, Agriculture Research and Extension Services (AREX), P. Bag 3701, Marondera, Zimbabwe.

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Results showed higher milk yields, protein, lactose and non-fat solids for cows fed either commercial or mucuna-based diets compared with those fed lablab-based diets. No differences were observed in butterfat. Profits were 120% higher with mucuna-based rations and 76% higher with lablab-based diets than when using commercial rations. In addition, mucuna and lablab options reduced maize usage by 24% and 30% respectively, compared with grain in commercial feed. Most smallholder farmers received these legume-based technologies very well because they are cheaper and convenient. The overall results from these trials generated a lot of interest from most farmers within and outside Wedza, resulting in overwhelming response in numbers of farmers now using these technologies in Zimbabwe. The recorded numbers of cattle farmers using these technologies increased from 9 in the 1999–2000 season, through 26 in the 2000–01 season, to 132 in the 2002–03 season.

The Wedza district lies between longitudes 31°10' and 32°00'E and latitudes 18°25' and 19°10'S. Long-term annual rainfall is 750 mm, falling predominantly between November and March. Temperatures rise to mean maximum of 28°C in October and fall to a mean minimum of 5°C in July. Soils vary from granitic sandy soils in most parts of Dendenyore Ward to some moderately deep red clay in Zana resettlement area. Zana resettlement area is subdivided into three wards, Zana 1, 2 and 3. The target group for this project was farmers in Zana 2 Ward and Dendenyore communal area. Households in Zana 2 own up to 6 ha of land. Most of these farmers grow tobacco and paprika as cash crops, and maize for human consumption and livestock feeding. Over 50% of the households are aspiring milk producers. Milk is either sold within the community or to the nearby Wedza Dairy Center. In contrast, most farmers in Dendenyore fatten beef cattle in pens for sale both to local markets and to commercial abattoirs. Some of the households have been doing this for over 10 years.

Animal production in Zimbabwe falls into two categories: wet season and dry season. During the wet season, ruminants normally consume enough nutritious green grass to ensure a balanced nutrient supply to post-ruminal sites for maintenance and productivity. A decline in nutrient level in summer (especially a decrease in crude protein) results in ruminants failing to eat enough of the basal diet to sustain productivity and, in some instances, maintenance. Crude protein falls from an average 12% in summer to between 3% and 4% in winter (Topps and Oliver 1993). Neutral detergent fibre was observed to rise above 30% during winter. However, earlier researchers (Ward 1968; Ngongoni and Manyuchi 1993; Topps and Oliver 1993) determined that protein supplementation of poor-quality forage (as is the case with dry season grass) can meet energy and protein requirements for both maintenance and production. Nutritional stress is a major cause for poor fertility of animals in rural areas (Hamudikuwanda 1999). This is due to poor ovulation patterns resulting from animals failing to reach the target 65% mature weight at breeding. Product output is naturally low in winter because of reduced intake resulting from poor digestibility of tough, low nutrient-level, dry season grass. Appropriate protein supplements are necessary for smallholder farmers to be successful cattle farmers.

Smallholder farmers in Zana 2 Ward and Dendenyore communal area, like most of their counterparts around Zimbabwe, use commercial feed sources in dairy and pen-fattening programs. However, the ever-spiralling cost and the irregular availability of these commercial feeds are two of the major challenges facing most farmers. Farmers in Zana 2 and Dendenyore have been growing and feeding lablab and mucuna to cattle since the inception of the Australian Centre for International Agriculture Research (ACIAR) project in 1998. The ACIAR project tested various feeding strategies and came up with recommendations on how best to use the two forage legumes when feeding for maintenance and for production. Experiments were carried out in on-farm farmer participatory research in Zana 2 and Dendenyore, as well as in controlled environments at Grasslands Research Station. Research and extension officers closely assisted the farmers in such operations as mixing of diets, feeding cattle, weighing, and sampling milk. The project went on to analyse the economic benefits of using these two forage legumes in cattle diets.

On-farm Experiments

Various treatments were formulated using plant material (chemical compositions shown in Table 1). Paprika

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calyx and hay from lablab and mucuna is high in crude protein (>17% CP) and high in ash (>8%). Digestibility of these three feed sources is above 54%. The crude protein content of paprika calyx, mucuna hay and lablab hay makes these three feedstuffs ideal for formulating diets for animals in production phase, especially when mixes use maize grain. The energy content of maize is high (>12 MJ ME/kgDM) and the acid detergent fibre content of maize is low (<6%). Mixing maize with any of the three defined protein sources will result in rations of high digestibility (>65%).

Experiment 1: Determination of the minimum level of mucuna hay required to maintain the liveweight of free-ranging cattle during a dry winter season

The objective of this experiment was to establish the minimum level of supplementing cattle on range with hay of mucuna to avoid liveweight loss during the eight-month dry season in Zimbabwe.

Materials and methods

Animals

Twelve indigenous cattle were used in this experiment, which was carried out at three different sites in Dendenyore. Four castrated male animals were used at each site under the management of the cattle owner.

Diets and experimental design

Mucuna was grown in November 2000 and harvested at flowering stage in March–April 2001. Harvesting was done using a sickle to cut the forage material at the bottom of the stem, close to the ground. The harvested forage was air-dried by hanging on A-frame rakes for two weeks, turning over the hay only once to avoid loss of leaf. The air-dried hay was chopped to an average length of 5 cm to make it easier to use both leaf and stem.

The cattle free-ranging on veld were supplemented with three levels of hay, equivalent to 1%, 1.5% or 2% of the animal's liveweight, on as-is basis. The animals were then randomly allocated to these treatments. 'As is' means that hay of 91–92% dry matter, cut and dried under conditions explained above, was used. The animals were given their supplement allocation in two equal portions: in the morning before free ranging, and in the afternoon.

Results

Animals supplemented with hay equivalent to 1.5% of their bodyweight maintained weight (Figure 1). Those eating an equivalent of 1% lost almost 20 kg of liveweight in three months, while animals that were not receiving any supplement at all lost twice as much. Animals that were allocated an equivalent of 2% of their bodyweight gained almost 20 kg in three months.

Discussion

Hay from mucuna can significantly benefit smallholder farmers, and especially those who rely on cattle as draught power. It is necessary for such farmers to supplement their animals during the dry winter season if they are to retain the draught capacity of the animals for the following season. Farmers who supplement animals normally reach the productive season with their animals in good shape. Topps and Oliver (1993) reported that protein supplementation for ruminant livestock, at levels high enough to facilitate intake of mature native pasture hay and prevent liveweight loss, is imperative. But protein supplementation is usually not practised,

Table 1. Dry matter and chemical composition of lablab hay, mucuna hay, paprika calyx, dairy meal, maize grain, maize stover, veld hay and wheat bra

	Lablab hay	Mucuna hay	Paprika calyx	Dairy meal	Maize grain	Maize stover	Veld hay	Wheat bran
Dry matter (g/kg)	915	914	881	890	890	920	930	930
Ash (g/kgDM)	100	85.6	125	44.9	112	54.3	43	64.5
Crude protein (g/kgDM)	173	203	195	151	115	50.9	42	47.4
Crude fibre (g/kgDM)	–	–	–	158	–	140	–	402
Ether extracts (g/kgDM)	–	–	29	51.0	48.5	6.10	15.0	9.70
Acid detergent fibre (g/kgDM)	–	–	392	195	55.7	436	633	494
Dry matter digestibility (g/kgDM)	543	575	546	815	805	560	344	390
Dry organic matter digestibility (g/kgDM)	587	584	600	835	812	580	354	410

especially in the smallholder sector, because of the high cost and/or non-availability of commercial protein supplements in times of need. Perhaps greater reliance on home-grown forage/browse nitrogen sources for ruminant animal production is more cost-effective than use of conventional commercial protein supplements (Matizha et al. 1997).

Mucuna proved to be a cost-effective forage legume. It is relatively easy to grow, yields well (over 3 t/ha of dry matter), and is useful to cattle, as was shown by the results. Alternative feeding strategies that rely on protein sources that are cheap and available on-farm would be more attractive to the smallholder farmers.

Experiment 2: Evaluation of lablab hay and paprika calyx as protein sources in diets for lactating indigenous Mashona cows

This experiment had two objectives. The first was to determine yield and compositional quality of milk from lactating indigenous Mashona cows that were eating diets based on lablab hay, paprika calyx and commercial diet (15% CP) over a period of 21 days. The second objective was to determine weight changes in cows eating diets based on lablab and paprika calyx, as well as weight changes in calves suckling from these cows.

Materials and methods

Animals

Four indigenous Mashona cows in early lactation were used in the Zana 2 experiment. Two of the cows were in second parity and the other two were in third parity. The cows were milked once per day, in the morning between 07.00 and 08.00. A calf was used to suckle the cow before milking to assist in the initiation of milk letdown. The cows were then left with their calves for the rest of the day, which is the normal practice in most smallholder areas in Zimbabwe.

Two other cows were observed under the normal practice of morning milking followed by free grazing, with minimum supplementation and using residues of any amount and type. Milk yield and composition of these cows were also analysed. They were then used as negative controls.

Diets and experimental design

Lablab and calyx from paprika grown and harvested in Zana 2 Ward were used in diets formulated with crushed maize grain as the major source of energy. Commercial dairy meal (15% CP) was used as the control diet. One farmer managed the four lactating cows used in this experiment. Four diets, formulated as shown in Table 2, contained crude protein of at least 14% and energy level of at least 10.7 MJ ME/kgDM — the general requirement for lactating cows. Lablab hay and paprika calyxes were milled to pass through a 5 mm screen before mixing, to ensure easy mixing of ration constituents. The cows were then allowed treatment diets equivalent to 2.5% of bodyweight plus 10% of milk yield (ARC 1984).

The cows were randomly allocated to the treatments and then fed half the total quantity at milking (07.00) and the remainder at 14.00. After the animals had completely consumed these diets, they were left

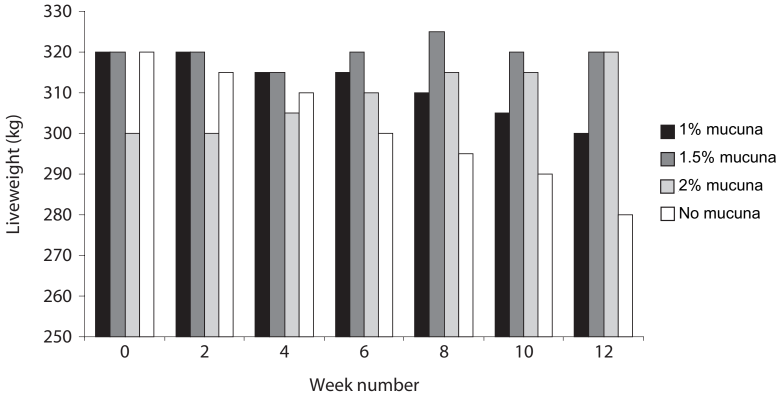

Figure 1. Liveweight changes in cattle supplemented with mucuna hay during the dry winter season in Wedza district, Zimbabwe

with unlimited access to maize stover. Each cow was fed all four diets, with a changeover period of 21 days. Data recorded during the last seven days of each period was used in statistical analysis. During the collection period, daily milk yield was recorded before samples were taken from each cow for compositional analysis at Zimbabwe Dairy Services Association, Harare. Liveweight for each cow and its calf was recorded at the beginning and end of each experimental period. The data was analysed by the general linear model procedure in SAS (1994).

Results

The diets based on lablab hay, paprika calyx and the commercial dairy meal (15% CP) had no significant effect on the milk yield or milk composition (Table 3). Milk yield from indigenous cows was double that of cows on common feeding practice. Results also showed an improvement in milk composition. Milk from cows eating experimental diets had non-fat solids levels above the standard minimum of 8%. Somatic cell counts (SCCs) were highest in milk from cows on diets that incorporated lablab hay. However, cows eating diets that incorporated both lablab and paprika calyx had SCCs that were a third of those eating the diet based on lablab alone. Nevertheless, the SCCs recorded were far below the maximum legal level of 1.0×10^6 cells per mL.

Discussion

Similarities in milk yield and milk composition between cows eating home-grown protein-based diets and commercial protein-based diet suggest that the diets have similar nutrient release patterns. However, the average yield was far below the minimum expected for commercial dairy farming in Zimbabwe (which is at least 7 L per cow per day), probably because the cows were only milked once a day and left with their calves for the rest of the day. This differs from commercial dairy practice, in which cows are milked twice a day and calves are separated from their mothers usually 4 days after birth. The low milk yields, which may have contributed to the lack of significant differences between the diets, might have resulted from genetic and/or environmental factors such as poor milk genes, poor nutrition and poor health management. Animals gradually adapt to adverse conditions, with a negative impact on production, and the same diets can produce different results even from medium- or high-producing breeds in optimal health.

Given the cost of commercial concentrates and the resulting total milk yields, it is not reasonable to feed bought-in concentrates to indigenous Mashona cattle for commercial milk production. The Wedza farmers in this project deduced that one month's production costs using commercial feed would equal one term of school fees for a child attending a local secondary

Table 2 Ration formula and chemical composition of experimental diets testing lablab and paprika calyx as dairy feeds.

Plant material/nutrient being considered	Ration 1	Ration 2	Ration 3	Ration 4
Crushed maize grain (%)	56	60	53	0
Milled lablab hay (%)	0	40	23.5	0
Milled paprika calyx (%)	44	0	23.5	0
Dairy meal 15% CP (%)	0	0	0	100

Table 3. Yield and composition of milk from indigenous cows eating diets based on lablab, paprika calyx and common practice during the dry winter season in Zimbabwe.

Diet	Milk yield (kg)	Fat (%)	Protein (%)	Lactose (%)	Non-fat solids (%)	SCC (cells per mL)
1	2.10	2.52	2.99	4.84	8.95	6.0×10^3
2	1.78	2.17	3.02	4.88	9.02	1.95×10^4
3	1.75	2.50	2.84	4.97	8.95	6.3×10^3
4	1.19	2.09	3.12	4.96	9.25	6.0×10^2
CP[a]	0.8	1.58	2.75	5.07	9.94	6.1×10^3

[a] CP = common practice of smallholder farmers in Zimbabwe

school. However, if other, indirect benefits (such as the better physical condition of cows, improved health, improved reproductive performance, and increased weight gain of suckling calves) are taken into account, there might be a net benefit.

Although there was an improvement in milk composition, the percentage of milk fat was far below the minimum of 3% set for commercial milk producers in Zimbabwe. Milk fat is determined by the genetic potential of the animal as well as by nutrition. Despite the lower fat level in milk from indigenous cattle, farmers who keep these breeds and use legumes may benefit from improvement in several other factors that affect cow's lifetime productivity, including increased milk yield, better milk quality, increased length of lactation, early return to oestrus, shorter calving intervals and earlier breeding of heifers. In fact, most farmers who have been part of the feeding trials since 1999 stated that their cows are now giving a calf every year. In addition to this, milk from cows feeding on rations based on forage legumes was richer in taste compared to milk from cows outside the experiment.

Experiment 3: Evaluation of lablab hay and mucuna hay as protein sources in diets for pen fattening cattle

The objective of this experiment was to determine liveweight gain by indigenous beef cattle eating diets based on mucuna hay and lablab hay over a period of two months. A diet based on the commercial diet (14.5% CP) was used as the control.

Materials and methods

Animals

Six castrated indigenous Mashona cattle were used at two experimental sites in Dendenyore. One farmer managed the three animals at each site.

Diets and experimental design

Three test diets were formulated as follows:

Diet 1 — 5:3 maize grain : mucuna
Diet 2 — 3:2 maize grain : lablab hay
Diet 3 — 9:1 maize grain : commercial concentrate.

The mucuna hay and lablab hay were grown locally from December 2000 and harvested in May 2001. The three animals at each site were randomly allocated to the three diets. The treatment allowance for each animal was equivalent to 2.5% of its bodyweight (Topps and Oliver 1993) given in two equal meals at 08.00 and 14.00. The animals were fattened in pens measuring an average of 3 × 4 m. Each animal was fed for 73 days and had an unlimited access to maize stover and water. Liveweight was recorded at the beginning of the experiment and every fortnight thereafter. The data were analysed by the general linear model procedure in SAS (1994).

Results

There were no significant differences ($P > 0.05$) in total weight gain between animals eating diets based on the home-grown forage legumes and those eating the commercial diet (Table 4).

Discussion

Mucuna and lablab hay can substitute for the commercial feed (14.5% CP) commonly used by most commercial farmers for pen fattening. This result should, however, be used cautiously because it was derived from only two experimental sites with a limited number of experimental units and still requires proper characterisation. Some positive characteristics of the forage legume diet are a good level of protein, digestibility above 54% and a high (>8%) ash content. It is also known that the buffering capacity of forage legumes creates a more stable rumen environment (Van Soest 1994), and this may be one factor contributing to the good performance of diets based on lablab and mucuna hays. Maize grain is normally used as a source of good-quality energy in pen-fattening meals, but maize is also the most important staple food in Zimbabwe. Farmers are often reluctant to include enough maize in cattle diets containing commercial protein concentrates: some end up reducing the level far enough to cause asynchronous release of energy and protein in the rumen, resulting in poor utilisation of the diets. It was observed that most farmers in Dendenyore reduce the 9:1 maize:concentrate mix to 7:1 or less during poor harvest seasons.

The energy level of the two forage legumes is above 8 MJ ME/kgDM. Although the quality of energy in the forage legumes may differ with that of maize, these results show that their incorporation in pen-fattening meals reduces the use of maize grain without compromising weight gain. By using these home-grown protein sources, farmers will also reduce production costs. Farmers will avoid shortages of commercial feeds, due to either ill-timed deliveries or unavailability, which sometimes occur, especially during drought years such as 2001–02. They will welcome any savings on maize grain when the savings are accompanied by increased profits from using low-cost, home-grown forage legumes like mucuna and lablab.

Results of a gross margin analysis made for this experiment by O. Jiri et al. (unpublished data) for the whole fattening period of 73 days suggest that smallholder farmers will be discouraged from pen fattening. The savings per beast over that period using the most economic diet (mucuna based) will be enough to buy one only 50 kg bag of maize grain at the current market rate. Using commercial rations in the current Zimbabwean economic environment would drain farmers of their financial resources and labour. However, most small-scale farmers do not cost their own labour, and therefore see lablab and mucuna forage as a great benefit in pen fattening. Because of these findings, the number of farmers growing mucuna and lablab for feeding animals is increasing in Dendenyore. The 2002–03 drought further increased farmers' interest, as these two forage legumes are relatively drought-tolerant.

On-station Experiments

Experiment 1: Determination of the maximum level of intake of diets made by mixing hay from mucuna or lablab with crushed maize grain

This experiment had two parts; determination of maximum and optimum intake of fattening diets, and the dry matter digestibility of diets that were formulated using hay from lablab and mucuna.

Materials and methods

Animals

Twelve ear-tagged Doper rams aged between four and ten months were used in these trials. The rams were dosed with valbazen against internal parasites and then vaccinated against pulpy kidney two weeks before the experiment began. They were stratified according to age, randomly allocated to the three treatments, and weighed on the morning before the beginning of the experiment.

Diets and experimental design

Mucuna and lablab were grown at Grasslands Research Station and harvested at flowering stage. The forage material was air-dried on A-frame racks for two weeks and then milled to allow proper mixing with crushed maize grain at ratios of 3:2 maize grain: lablab hay for ration 1 and 5:3 maize grain: mucuna hay for ration 2. The control diet was a commercial fattening diet (15% CP). These diets had already been tested in Wedza during participatory pen-fattening experiments. During the experiment, the animals were initially housed in individual pens, and had *ad libitum* access to the assigned treatment diets. After an adaptation period of 14 days, data were collected for seven days to determine maximum intake. In the second part of the experiment, the young rams were individually housed in metabolism crates and allowed treatment diets equivalent to 2.5% of each animal's bodyweight, twice daily in equal proportions (Topps and Oliver 1993), and wheat bran without restriction. The diets were introduced at 07.30 and at 14.00. Clean water was always available from buckets.

Results

No significant differences ($P > 0.05$) in maximum intake were observed between the commercial diet and the two forage legume based diets. The rams ate 3.1% of their bodyweight of the ration containing hay from mucuna, 3.0% of the ration containing hay from lablab, and 3.0% of the ration containing commercial feed (all values on dry-matter basis). Nevertheless, forage legume based diets were seen to lead to metabolic disorders manifested as diarrhoea if given in

Table 4. Total weight gain by indigenous Mashona cattle eating diets based on hay from mucuna and lablab and a commercial diet (14.5% CP) during two dry winter months in Dendenyore, Zimbabwe.

	Diet 1 Mucuna based	Diet 2 Lablab based	Diet 3 Commercial	CV[a]
Total gain (kg)	88.5 a	74.5 a	76.0 a	4.94

[a] CV = coefficient of variation.

Note: differences between means followed by the same letter are not statistically significant.

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excess of 2.6% of the animals' bodyweight. After several adjustments to the feeding structure, we found it ideal to feed the rations in equal proportions in the mornings and afternoons and to introduce poor-quality roughage such as wheat bran or maize stover. Dry-matter digestibility of the three rations was measured at ≥70%.

Discussion

Establishment of intake is necessary because pen fattening usually reaches a stage when food is given without limit (i.e. *ad libitum*). That levels of the forage-based diets over 2.6% of bodyweight caused diarrhoea may suggest that their roughage content could not adequately sustain proper rumen motility.

Results on intake are encouraging. Animals in pen-fattening programs normally consume at least 2.5% of their bodyweight (CPA 1998), and this level did not result in any noticeable metabolic problems. Any additional feed would be given in the form of poor-quality roughage like maize stover or wheat bran, improving the rhythmic movements of the rumen and aiding the proper formation of wastes. The high intakes of feeds containing lablab and mucuna hay suggest a high degradability for such diets. Legumes also have a good buffering capacity, necessary for appropriate microbial activity and crucial to the maintenance of a stable rumen environment.

Dry matter digestibility of the two forage legumes was high (≥70%). Any differences in production may be the result of different levels of maize grain and/or the possible associative effects of maize with a protein source. The mineral composition of the diets, which was not analysed in this experiment, may also contribute to production performance. Other factors like vitamins may have an effect.

Animals in production require bypass protein to be between 35% and 40%, so partitioning of nutrients between the rumen and the lower gut should be characterised.

Experiment 5: Yield and composition of milk from Jersey cows eating diets based on hay from lablab and mucuna

This experiment was designed to evaluate the effect of hay of lablab and mucuna on the yield and composition of milk from Jersey cows, as well as the economic benefits of using such diets.

Materials and methods

Animals

Nine Jersey cows in early lactation and in their second parity were used in this experiment. The cows were kept in individual 3 × 2 m pens with free access to clean tap-water, and were milked twice each day.

Diets and experimental design

Air-dried hay of mucuna and lablab was used in rations formulated to meet the minimum energy and protein requirements for lactating dairy cows, as follows:

Ration 1 — commercial dairy meal (16% CP)
Ration 2 — crushed maize grain and milled lablab hay mixed in the ratio of 1:1
Ration 3 — crushed maize grain and milled mucuna hay mixed in the ratio of 5 maize: 4 mucuna hay.

The ration with commercial dairy meal was used as the control diet. The hay was milled to about 5 mm long before mixing with crushed maize grain. The three treatment diets were randomly allocated to the nine lactating cows, with three cows per diet. The cows were allowed treatment diets equivalent to 0.5% bodyweight plus 0.1 × milk yield, and unlimited access to maize stover. Treatment diets were given in two equal meals in the morning and afternoon for 28 days. Milk samples were taken from each cow during the last seven days and sent for compositional analysis at the Zimbabwe Dairy Services Association in Harare. Milk recorded during the last seven days of the experiment was used in statistical analysis. The chemical composition of the rations used in these trials is shown in Table 5.

Results

Milk yield from cows eating a ration with hay from mucuna was significantly higher ($P < 0.05$) than the yield from cows eating lablab-based diets, as shown in Table 6. There were no significant yield differences between the mucuna-based diet and commercial feed. Protein, lactose and non-fat solids were significantly higher ($P < 0.05$) in milk from cows eating commercial feed and mucuna based diets compared with milk from cows eating lablab; differences between the commercial diet and the mucuna-based diet were not significant. Butterfat content was higher in lablab-based diets, although no significant differences were observed between the three diets. SCCs were below maximum legal levels of 1.0×10^6 cells/mL.

Results of a gross margin analysis (Table 7) show that using hay of lablab and mucuna increases profits in commercial dairy farming. Costs of producing lablab and mucuna hay were calculated as labour, chemical inputs and opportunity costs for 1 kg of hay at 5 t dry matter per hectare for lablab and 4 t/ha for mucuna. These are the estimated yields obtained at Grasslands Research Station during 2001–02, a season of poor rainfall distribution.

Discussion

Hay of mucuna and lablab forage is economic for commercial milk production. Farmers using the lablab-based diet made 76% more daily profit than those using the commercial diet, while those using the mucuna-based diet made 121% more. Farmers in Wedza welcomed the results and acknowledged them by increasing the cropping area allocated to these legumes. The high level of adoption of these technologies (Maasdorp et al. 2004) may be attributed to the comparable milk yields of the mucuna-based ration and the commonly used commercial feed, the convenience of using these legumes, and the ever-increasing cost of commercial feed.

With the abnormal economic situation in Zimbabwe, farmers will rely more on home-grown feeds than commercial concentrates. From November 2002 to November 2003, milk producer price increased 10-fold from Zim$77/L to $800/L, while the price of 15% CP commercial feed rose 27-fold from $55/kg to $1500/kg. This resulted in hyperdemand for mucuna and lablab seed for the 2003 season. Grasslands Research Station failed to cope with farmers

Table 5. Chemical composition of experimental diets testing the role of lablab and mucuna hay based diets in dairy feeding.

Plant material/nutrient being considered	Ration 1 Commercial	Ration 2 Lablab-based	Ration 3 Mucuna-based
Dry matter (g/kg)	890	893	891
Crude protein (g/kgDM)	147	140	155
Crude fibre (g/kgDM)	103	139	130
Acid detergent fibre (g/kgDM)	125	182	167
Dry matter digestibility (g/kgDM)	870	800	810
Dry organic matter digestibility (g/kgDM)	900	820	824

Table 6. Milk yield and composition and somatic cell counts of Jersey cows eating diets based on lablab hay, mucuna hay and commercial feed.

	Milk yield (kg)	Butter fat (%)	Protein (%)	Lactose (%)	Non-fat solids (%)	Somatic cell counts
Commercial feed (15% CP)	10.9 a	4.2 a	3.7 a	4.8 a	9.5 a	1.0×10^4
Lablab-based feed	7.0 b	4.4 a	3.2 b	4.5 b	8.7 b	1.2×10^5
Mucuna-based feed	9.0 a	3.9 a	3.6 a	4.8 a	9.5 a	3.7×10^3
Coefficient of variation	13.4	19.4	6.5	2.1	3.3	

Note: Means in the same column with different letters are significantly different ($P < 0.05$).

Table 7. Gross margin (Zim$/day) for dairy programs using lablab and mucuna-based diets.

	Milk yield (kg)	Milk producer price/L	Gross/L	Daily production cost	Daily gross margin	Maize grain (%)
Commercial ration	10.9	77	839	602	237	80
Lablab-based ration	7.7	77	593	177	416	50
Mucuna-based ration	9.0	77	693	170	523	56

seed requirements and is in the process of encouraging farmers to establish seed banks at farm level.

Using forage legumes in dairy diets reduces the cost of production and results in higher profits. Although these legumes require minimum attention during the growing season, the harvesting period is labour intensive. These legumes may not, therefore, be ideal in large-scale production without appropriate mechanisation. However, the Zimbabwean government is promoting the involvement of smallholder farmers in commercial dairy farming, and mucuna and lablab have a role to play.

Another crucial point is that research has concentrated on protein sources and paid less attention to energy sources in animal production. Maize is the main energy source used for animal production in Zimbabwe, but is also the main staple food of the people. As a result, both the farmers and the policy makers want to reduce the maize used in cattle diets as far as possible. Maize usage in dairy diets reduces by 24% in the mucuna diet and by 30% in the lablab diet, compared with traditional commercial feeding systems.

It is also worth noting that the Jersey cows eating lablab- and mucuna-based diets produced good-quality milk that met the expected minimum market standards. Mucuna and lablab also reduce external inputs and alleviate land degradation.

Conclusion

Forage legume based diets are ecologically and economically sustainable both in dairy and in pen-fattening programs for smallholder farmers in Zimbabwe. In the current economic environment, dairy farming is more profitable than pen fattening. Using bought protein is uneconomic in the Zimbabwean smallholder system, and farmers should replace commercial protein with forage legumes where possible. Future research should examine the long-term effects of using mucuna and lablab on the reproductive performance of cattle, perhaps focusing on the length and shape of the lactation curve and the effect on fertility.

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Animal Production from Legume-based Ley Pastures in Southeastern Queensland

R.L. Clem*

Abstract

As soils used for cropping in central and southeastern Queensland decline in organic matter and available nitrogen, the benefits of using legume-based ley pastures as an alternative to using fertiliser nitrogen are being more widely recognised. However, as well as providing increases in soil fertility for subsequent cropping cycles, ley pastures also need to provide adequate returns to farmers from livestock production. This study at Brian Pastures Research Station in southeast Queensland compared forage and animal production from eight tropical pastures, which included legumes identified in recent evaluation programs and being developed for use by farmers.

The pastures used were lablab (*Lablab purpureus* cv. Highworth), which is an annual legume that was resown each year; *Macrotyloma daltonii* CPI 60303 and *Vigna trilobata* CPI 13671, which are annual legumes that regenerate from seed each year; butterfly pea (*Clitoria ternatea* cv. Milgarra) and burgundy bean *(Macroptilium bracteatum* CPI 27404), which are perennial legumes; a grass pasture of green panic (*Panicum maximum* var. trichoglume cv. Petrie), creeping bluegrass (*Bothriochloa insculpta* cv. Bisset) and Queensland bluegrass (*Dichanthium sericeum*); and the same mixture of grasses with butterfly pea and with caatinga stylo (*Stylosanthes seabrana* cvv. Primar and Unica).

End-of-season yields ranged from 1 to 5 t/ha, with lablab and the grass–legume pastures producing the highest yields. *M. daltonii* and *V. trilobata* regenerated each year, but regular spraying for weed control was necessary. Burgundy bean persisted for three years and butterfly pea was even more persistent. Both butterfly pea and Caatinga stylo persisted and combined well with the grasses.

Lablab produced the most liveweight gain/ha, with growth rates from 0.60 to 0.86 kg/head/day. Growth rates on other legumes varied from 0.39 to 0.79 kg/head/day, and there were some differences in the duration of grazing. Liveweight gain/ha was similar for butterfly pea and burgundy bean and was higher than for *V. trilobata*, followed by *M. daltonii.* On the grass and grass–legume pastures, growth rates ranged from 0.39 to 0.71 kg/head/day, with legume-based pasture producing gains of 30 to 70 kg/ha more than the grass-only pasture over five years.

Beef cattle production and cropping are the major agricultural industries on large areas of central and southeastern Queensland, although the integration of livestock and cropping has been limited even on properties where both enterprises are practised. With long-term cultivation and cropping on clay soils, lower wheat grain protein levels are associated with a decline in soil nitrogen (Dalal et al. 1991). At the same time, higher quality forage is needed to increase cattle growth rates and reduce age at turn-off to meet more demanding beef markets. As a result there is increasing interest in, and more recognition of, the value of using legume-based ley pastures to maintain or restore soil fertility and to provide higher quality forage to improve livestock performance.

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* Department of Primary Industries, PO Box 395, Gympie, Queensland 4570.

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There are many similarities between this region and those to the north and south. In northern Australia, where research in the 1980s investigated the potential for using tropical legumes in leys in cropping and livestock systems (Jones et al. 1991), their commercial use was limited until the live-cattle export trade increased demand for high-quality pasture (Winter et al. 1996). In southern Queensland, although ley pastures based on lucerne (*Medicago sativa*) and annual medics (*Medicago* spp.) have been shown to arrest soil fertility decline and improve crop yield and protein content (Dalal et al. 1991), their adoption has been slow. While this slow adoption has been attributed to a number of causes (Lloyd et al. 1991; Weston et al. 2000), the areas now being sown are increasing.

In central and southeast Queensland until the 1990s, the use of leys was limited because well-adapted pasture legumes and the appropriate agronomy to allow reliable establishment and management (Keating and Mott 1987) were not readily available. There is now a good range of tropical legumes (Pengelly and Conway 2000) and grasses (Cook and Clem 2000) that can be used in leys, and the value of lablab (*Lablab purpureus* cvv. Highworth, Rongai and Endurance) is being further recognised (McCosker et al. 2000). Larger areas of lablab and butterfly pea (*Clitoria ternatea* cv. Milgarra) are now being sown.

To continue and increase the rate of adoption of leys in farming/livestock systems, the more complex issues of management now need to be addressed. These include the strategies necessary to maximise the accumulation of nitrogen in the ley and optimise its use during the subsequent crop, and to improve the value of grazing from the pasture phase. This paper reports some aspects of pasture and animal production from a range of forage and pasture types grown on a vertosol in the Burnett region of Queensland.

Materials and Methods

Site description

Experiments were located at Brian Pastures Research Station, Gayndah, Queensland, Australia (25°39'S, 151°45'E). The average annual rainfall at the station is 702 mm, but rainfall is highly variable, both annually and seasonally. On average, the highest maximum and minimum temperatures are in January (32.1°C and 20.2°C) and the lowest in July (21.6°C and 6.6°C) with approximately 20 frosts each year. Low moisture availability during the warmer months, low winter temperatures and frosting are the major climatic limitations to pasture growth (Fitzpatrick and Nix 1970).

Soils are brown to dark self-mulching clays of basaltic origin. Surface pH is 6.5 to 7.5 with an alkaline pH trend with depth. Soil phosphorus levels range from 40 to 80 ppm (Colwell 1963, bicarbonate extraction) and soil depth varies from 0.4 to 1.5 m (Reid et al. 1986).

All treatment paddocks had been cleared of trees and cultivated. The original vegetation was open woodland with *Eucalyptus tereticornis, E. melanophloia* and *E. crebra* being the main species; the predominant grasses were *Bothriochloa bladhii, Dichanthium sericeum* and *Heteropogon contortus*.

Design and treatments

Eight pasture treatments, each replicated twice, were sown into 16 paddocks of 2.5 ha each from 4 to 6 February 1998. Lablab was sown again on 7 December 1998, 4 January 2000 and 13 December 2000. The pasture treatments were:

1. Lablab (*Lablab purpureus* cv. Highworth)
2. *Macrotyloma daltonii* CPI 60303
3. *Vigna trilobata* CPI 13671.
4. Butterfly pea (*Clitoria ternatea* cv. Milgarra)
5. Burgundy bean *(Macroptilium bracteatum* CPI 27404)
6. Grass
7. Butterfly pea with grass
8. Caatinga stylo (*Stylosanthes seabrana* cvv. Primar and Unica) with grass.

Legume sowing rates were, in the grass–legume paddocks, caatinga stylo 3 kg/ha and butterfly pea 4 kg/ha and, in the legume-only paddocks, butterfly pea 7 kg/ha, burgundy bean 3 kg/ha, *M. daltonii* 4 kg/ha, *V. trilobata* 3 kg/ha and lablab 32 kg/ha. Lablab, butterfly pea, burgundy bean*, M. daltonii* and *V. trilobata* were sown into moist soil, while caatinga stylo and the grasses were surface-sown and rolled into the soil surface.

The grass was a mixture of 1 kg/ha creeping bluegrass (*Bothriochloa insculpta* cv. Bisset), 1 kg/ha Queensland bluegrass (*Dichanthium sericeum*) and 2 kg/ha green panic (*Panicum maximum* var. trichoglume cv. Petrie).

Grazing management

All pastures were grazed with Brahman crossbred steers at a range of stocking rates. On the grass and grass–legume pastures, the first grazing commenced on 11 August 1998 for 293 days to 12 April 1999 at a stocking rate of 1.25 ha/steer. Subsequent grazings, all at the same stocking rate, have been from 7 July 1999 to 26 April 2000 (324 days), from 28 November 2000 to 9 July 2001 (288 days) and from 13 September 2001 to 29 May 2002 (270 days).

The five forage legume-only treatments were grazed for the same period in year 1, but in later years grazing time has varied depending on forage availability (Table 1). Grazing in the three annual legume treatments (lablab, *V. trilobata* and *M. daltonii*) has been in late summer/early autumn. There was also a reduction in the area of these paddocks, as sorghum was sown into one-third of each paddock in 2000 and two-thirds of each paddock in 2001 as part of another experiment. In 2001, a group of 10 steers grazed the 0.8 ha for between 6 and 12 days.

The perennial legumes (Milgarra butterfly pea and burgundy bean) provided grazing earlier and over a longer period (Table 1) and again for 160 to 176 days from 13 December 2001 to 29 May 2002.

All steers were weighed at six-week intervals except when grazing the small areas of legume in 2001. Stock were removed from the pastures when weight loss was imminent (drafts 1 and 4) or as soon as weight loss was measured (drafts 2 and 3).

Pasture measurements

Seedling density was measured after emergence by counting plants in 100 quadrats in each paddock. Pasture yield and botanical composition and legume density were determined each year at the end of the growing season. In the annual forage paddocks, this was done by cutting 10 quadrats, counting the legume plants cut, and sorting legumes from grass and weeds. In the perennial pastures, these attributes were measured using the BOTANAL technique (Tothill et al. 1992).

In the paddocks of butterfly pea, caatinga stylo, burgundy bean, *M. daltonii* and *V. trilobata,* the amount of legume seed in the soil has been measured each year by taking soil cores following first rains in spring, and washing seed from the soil using the technique of Jones and Bunch (1988).

Table 1. Stocking rates (ha/steer) and grazing days for the annual and perennial forage types over four seasons.

Forage type	1998 (18/5–3/8/98)		1999 (3/11/98–12/4/99)		2000 (6/1–15/6/00)		2001 (28/11/00–9/7/01)	
	ha/steer	days	ha/steer	days	ha/steer	days	ha/steer	days
Lablab purpureus	0.5	77	0.62	81	0.42	101	0.08	12
Macrotyloma daltonii	0.62	77	1.25	130	0.83	161	0.08	6
Vigna trilobata	0.62	77	1.25	130	0.83	161	0.08	9
Clitoria ternatea	0.62	77	1.25	160	0.83	161	0.62	215
Macroptilium bracteatum	0.62	77	1.25	160	0.83	124	0.62	207

Table 2. Rainfall (mm) at Brian Pastures Research Station from 1997–88 to 2001–02, and the long-term average.

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Year
1997–98	**38**	**7**	43	**39**	126	**58**	120	120	**3**	103	75	**20**	752
1998–99	**22**	**26**	119	**21**	107	**90**	35	**51**	**49**	**5**	**30**	37	**592**
1999–00	84	**14**	33	107	118	**53**	**78**	**61**	**27**	**33**	**27**	**26**	**661**
2000–01	**5**	**3**	**0**	171	70	**66**	**7**	138	120	**32**	46	**1**	**659**
2001–02	46	**1**	38	**33**	155	**52**	**18**	164	**60**	5	49	70	**624**
Average (48 yr)	34	28	30	62	75	103	103	96	66	36	39	29	702

Note: Bold ≥ average. Long-term decile 5 is 670 mm/year.

Results and Discussion

Seasonal conditions

Rainfall has generally been near or below average over the five growing seasons (Table 2). Summer rainfall in 1997–98 was adequate for soil moisture build-up and successful establishment, but pasture yields in the first season, except for lablab, were low and grazing was restricted. Pastures have been maintained, but long dry periods have resulted in variable pasture yields.

Legume density and soil seed

Legume and grass establishment in all pasture types was satisfactory. Density of legumes at establishment ranged from 9 to 30 plants/m^2. Establishment of lablab was consistent across all years of sowing, but populations of other legumes have varied depending on plant survival and recruitment from seed (Table 3).

The annual legumes, *M. daltonii* and *V. trilobata,* have successfully recruited from seed, with large populations of seedlings emerging on several occasions each summer. The success of this regeneration is very dependent on control of weeds and recolonising grasses, and can be improved with strategic use of herbicide. Soil seed levels for *V. trilobata* declined after year 1 but have been maintained at moderate levels since. In contrast, *M daltonii* has maintained levels of 200 to 300 kg/ha (Table 4).

Of the perennial legumes, butterfly pea was more persistent than burgundy bean. Most of the original plants of burgundy bean had died by the end of the fourth year, but there was some regeneration from a moderate amount of seed in the soil in the 2001 summer.

The density of butterfly pea declined initially, but then increased following recruitment in 2001; the amount of soil seed, although low in years 1 and 2, had increased to 30–40 kg/ha by year 4.

Similarly, in the grass–legume pastures, the density of butterfly pea first declined but increased in 2002 (Table 3). Seedling recruitment of caatinga stylo was high in 2000–02 following heavy seeding (as indicated by soil seed reserves and seedling density).

Table 3. Legume density of lablab sown each year and changes in density of the other legumes sown in 1998 measured at the end of the summer.

	Legume density (plants/m2)				
	1998	1999	2000	2001	2002
Lablab purpureus	10	15	11	12	–
Macrotyloma daltonii	11	–	–	50	–
Vigna trilobata	30	–	–	20	–
Clitoria ternatea	13	9 (1)[a]	8 (1)	7 (6)	12 (3)
Macroptilium bracteatum	18	12 (5)	8 (5)	1 (9)	6 (2)
C. ternatea with grass	9	6	6 (2)	7 (6)	12 (4)
Stylosanthes seabrana with grass	16	11	12 (35)	7 (71)	37 (16)

[a] Numbers in brackets are seedlings.

Table 4. Changes in soil seed (kg/ha) of legumes for the range of pastures.

	Legume soil seed (kg/ha)				
	1998	1999	2000	2001	2002
Lablab purpureus	0	0	0	0	0
Macrotyloma daltonii	216	216	222	335	192
Vigna trilobata	200	27	16	42	22
Clitoria ternatea	0	7	0	46	33
Macroptilium bracteatum	43	23	15	6	13
C. ternatea with grass	0	0	0	26	124
Stylosanthes seabrana with grass	0	0	38	90	85

Pasture yields and composition

Pasture yields varied in response to rainfall and periods of moisture stress. Lablab produced high yields in the first season, when good subsoil moisture was available, and again in 2000–01 (Table 5).

Although the annual legumes (*M. daltonii* and *V. trilobata*) produced high yields in some years, the total legume yield and presumably the amount of nitrogen accumulated (Jones 1972; Vallis 1972) over four summers was lower than for lablab. These legumes successfully recruited from seed each year, however, and comprised a moderately high proportion of the total yield (Table 5).

All pure legume pastures were recolonised with grass or weeds to varying extents, but butterfly pea persisted well with over 50% legume in the pasture. Burgundy bean had a moderate percentage of legume in the pasture into the third summer, but then the proportion of the legume declined to 7%, after which its value for future grazing and any further nitrogen input would be negligible.

Pasture yields in the grass and grass–legume paddocks were high, and provided for longer periods of grazing than on the legume paddocks. In the grass paddocks, the percentage of green panic, a grass that requires high nitrogen to persist under grazing (Jones et al. 1995), declined from 80% to 15% of pasture yield, while the percentage of Bisset bluegrass increased to nearly 60%. In the grass–legume paddocks, green panic also declined; however, it remained at over 40% of yield and the increase in bluegrass was less. The legume component remained at 20% in the butterfly pea paddocks and increased to some 40% in the stylo paddocks (Table 5).

Steer liveweight gain

The forage legume paddocks were grazed for variable periods over the summer each year at stocking rates generally higher than for the grass–legume pastures (Table 1). Grazing days ranged from 77 on all forages in the first year to 215 on butterfly pea in 2001. Butterfly pea and burgundy bean paddocks were again grazed for 160–180 days in 2002. On the grass–legume pastures, grazing began in August 1998 at 1.25 ha/steer, and these pastures were grazed at this stocking rate for between 270 and 324 days each year.

In the paddocks sown to lablab, *M. daltonii* and *V. trilobata* in 2001, only one-third (or 0.8 ha) was replanted or allowed to regenerate to legume, as the other two-thirds was sown to sorghum. Six groups of 10 head each were used to graze these areas for 6–12 days in May 2001 after the crop had been harvested. This avoided the risk of animals breaking into the crop area, but liveweight gains on the legume areas were not recorded.

Steer liveweight performance and liveweight gain/ha varied with pasture type and season. On the forage treatments, liveweight gain/head ranged from 0.35 to 0.86 kg/head/day, while gain/ha has varied from 50 to over 200 kg/ha/year (Table 6).

Steers grazing lablab consistently gained at high rates of up to 0.86 kg/steer/day, and over four years lablab produced the most liveweight gain/ha.

Grazing of *V. trilobata* and *M. daltonii* commenced earlier in the summer than for lablab, but overall grazing days were fewer, with a range of 72–194 animal grazing days/ha for *M. daltonii* and 104–194 for *V. trilobata* compared with 130–240 for lablab.

Table 5. Total yield (kg/ha) and percentage legume (in brackets) for each forage and pasture type.

	1998	1999	2000	2001	2002[a]
Lablab purpureus	4155 (100)	2398 (100)	2566 (100)	4990 (100)	–
Macrotyloma daltonii	1314 (100)	4866 (57)	1940 (80)	4437 (87)	–
Vigna trilobata	1581 (100)	2268 (62)	2937 (65)	3253 (57)	–
Clitoria ternatea	1003 (100)	2270 (49)	2650[b] (53)	3494 (65)	3454 (32)
Macroptilium bracteatum	923 (100)	2058 (71)	2900[b] (35)	2285 (7)	2370 (3)
C. ternatea with grass	1009 (33)	3660 (5)	2792 (13)	3686 (25)	3903 (20)
Stylosanthes seabrana with grass	1960 (6)	5845 (7)	3853 (28)	3886 (24)	4328 (43)

[a] In 2002, these legume areas were sown to sorghum.
[b] These yields were estimated.

Table 6. Live-weight gain of steers and gain/ha for each of the forage and pasture types over four seasons (annual forages) and five seasons (perennial legumes and grass–legume pastures).

	1998		1999		2000		2001		2002		Total
	(kg/ha/d)	(kg/ha)	(kg/ha/d)	(kg/ha)	(kg/ha/d)	(kg/ha)	(kg/ha/d)	(kg/ha)	(kg/ha/d)	(kg/ha)	(kg/ha)
Lablab purpureus	0.60	92	0.86	112	0.73	176	0.86	124			505
Macrotyloma daltonii	0.40	50	0.66	69	0.35	67	0.66	48			234
Vigna trilobata	0.60	74	0.79	82	0.55	107	0.79	86			349
Clitoria ternatea	0.39	48	0.64	82	0.49	95	0.64	221	0.65	183	629
Macroptilium bracteatum 27404	0.56	69	0.63	80	0.40	59	0.67	222	0.67	171	601
Grass			0.44	104	0.52	135	0.57	132	0.57	124	495
C. ternatea with grass			0.42	98	0.52	135	0.68	157	0.63	136	526
Stylosanthes seabrana with grass			0.39	91	0.62	162	0.68	156	0.71	154	563

Growth rates of steers on *M. daltonii* were less than those recorded from other pastures despite high legume yields, and ranged from 0.35 to 0.66 kg/steer/day. These lower growth rates may be due to lower palatability of this legume. In comparison, *V. trilobata* was noticeably the most palatable of the legumes and gave high steer growth rates of 0.55–0.79 kg/steer/day.

Beef production from butterfly pea, which was being recolonised with grass, varied most, from a low of 48 kg/ha in 1998 to a high of 220 kg/ha in 2001. Butterfly pea is not favoured by short growing seasons such as that in 1998, but over the relatively long growing season of 2000–01 it maintained animals for 215 days at 0.64 kg/head/day. Burgundy bean, which is more palatable than butterfly pea, produced similar per animal performance and liveweight gain/ha, although the legume content of the pasture declined. In year 1, liveweight gain was higher from burgundy bean, possibly because of the high legume yield, its high palatability and its ability to regrow under severe defoliation (Dalzell et al. 1997).

On the grass–legume pastures, grazing periods were longer (270–324 days) at the lower stocking rate of 1.25 ha/steer than on the annual and perennial legume forages. Growth rates ranged from 0.4 to 0.71 kg/steer/day and were similar to growth rates on the butterfly pea and burgundy bean planted without grass. Beef production from the grass–legume pastures was slightly less than from the perennial legume pastures, but liveweight gain was probably restricted by forage availability in the first year of grazing, when steers gained only 120 kg/head/year. The range from 160 to 200 kg/head/year in years 2, 3 and 4 is similar to that from other tropical grass–legume pastures in southeastern and central Queensland (Mannetje and Jones 1990; Partridge et al. 1996). After four years of grazing, the grass–legume pastures provided a useful benefit in animal production over the grass-only pastures (Table 6). Except in the first year, presumably when the quality of grass was high following cultivation and mineralisation of nutrients, steer growth rates were higher on both the grass with butterfly pea and the grass with caatinga stylo.

Implications and Conclusions

There is potential for the forage and pasture types tested to provide useful grazing for beef cattle while being used as pasture leys. The pastures included an annual legume that was resown each year (lablab), annual legumes with potential for seedling recruitment (*V. trilobata* and *M. daltonii*), short-term perennial legumes that also recruit from seedlings (butterfly pea and burgundy bean), and two short-term perennial legumes (butterfly pea and caatinga stylo) sown with grass.

Under the seasonal conditions encountered, in which rainfall was near or below average, lablab was the most reliable and most easily managed, and also produced the most liveweight gain. Economic analysis would be needed to determine relative cost-effectiveness. A major cost in such a production system is the resowing of the lablab each year, but this may be offset against its consistent and reliable establishment, which is a critical element of any ley pasture system (Bellotti et al. 1991).

The annual legumes, *V. trilobata* and *M. daltonii*, successfully recruited from seed each spring. In the first season there was a high percentage of weeds, with legume contributing only about 60% of yield. With improved control of weeds in subsequent seasons, a higher proportion of legume was achieved. However, a chemical spray strategy that gave reliable weed control was difficult to develop under the varying conditions, since plant growth was dictated primarily by the amount and timing of rainfall events in spring and early summer. A range of chemicals was used, but the most successful approach was to spray with glyphosate as needed to control weeds (and kill legume seedlings) until a major rainfall event. Although this strategy killed some legume seedlings, there was little risk of re-establishment failing because of the high amount of soil seed. As the range of weeds with some tolerance to glyphosate increased — mainly phasey bean (*Macroptilium lathyroides*), which itself may have a role in ley pastures, and sour thistle (*Sonchus oleraceus*) — dicamba was added to the chemical mix. Given the difficulties of managing *V. trilobata* and *M. daltonii*, it is doubtful that they offer any advantages over the easily established lablab or the more perennial burgundy bean, butterfly pea and caatinga stylo.

Animal production of 60–120 kg liveweight gain/ha/year from all forage types compares favourably with production from the higher-producing extensive grazing areas, such as buffel grass on the fertile clay soils of the brigalow lands of Queensland (Mannetje and Jones 1990) and productive native pastures oversown with stylo (Partridge et al. 1996). This return and the benefits of improved crop yields and protein content (McCosker et al. 2000) following lablab are

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encouraging, given that with refinement in management there is potential to improve these benefits for many of the forage types.

In considering any possible improvement in ley pastures for animal production, it is also necessary to consider the characteristics that will maximise benefits to the subsequent crop phase. It seems desirable that any ley pasture should have a high proportion of legume, at least in the early years, to maximise N contribution. Choosing the species best suited to the ley phase will depend on many factors, including the desired length of the ley. For short (1–2 year) phases, lablab is well suited because of its easy and reliable establishment, high production, minimal weed problems and relatively easy management of grazing, and needs to be more widely promoted to farmers.

Planted in pure swards, the other legumes (butterfly pea, burgundy bean, *M. daltonii* and *V. trilobata*) established successfully and produced high legume yields, especially in the first two years. Summer- and winter-growing weed species required regular chemical treatment in both the perennial and annual legumes. This, and the need to adjust grazing times to match growth of the single-species forage in response to soil moisture, complicated management and compromised other objectives. Other disadvantages of using pure legume stands identified by Jones et al. (1991) are that the stands may not provide adequate mulch for control of soil temperatures and crusting, that nitrogen mineralisation is too rapid, and that the potential for rapid weight loss of cattle was high if no alternative feed was available when the legume deteriorated or became unpalatable. In the longer term, there is the possible threat of soil acidification (Noble et al. 1998), although this would not happen quickly in these well-buffered soils.

In the legume–grass leys, which also provided high animal production, weed invasion and grazing management were less serious problems. However the amount of legume, which is critical to the amount of N fixation (Hossian et al. 1995), varied considerably. In the case of butterfly pea, legume content declined from 33% to 5% and then increased to 20%, while for caatinga stylo, legume content increased from 5% to 40%. The amount of soil seed also increased to levels that should ensure some recruitment. In fact, the soil seed reserve of butterfly pea sown with grass was considerably higher than in the areas where it was not sown with grass, perhaps because of lower stocking rates over the period of seeding. This confirms the important role of grazing management in enabling seed-set adequate for the persistence of annual or short-term perennial legumes.

The preferred pasture to meet the objectives of leys would be one in which legume is a high percentage of yield in the early life of the ley, to maximise the amount of nitrogen fixed in the system. A minor grass component could increase to benefit from the nitrogen, reduce weed invasion, increase soil organic matter above that of legume alone, and add grazing value as the ley develops. The presence of a grass in the system also ensures that the resulting organic matter mineralises more slowly, at a rate commensurate with the needs of the ensuing crops.

Technologies identifying legumes for different lengths of ley, and defining their management requirements to achieve the desired early growth and later persistence, are now well into development. However, to achieve the desired legume–grass mix will be more difficult because it will require more precise control of grass establishment. Sowing at lower seeding rates is unlikely to be effective because of the high variability and range of establishment conditions that can be encountered. Sowing larger-seeded grasses is one option, but the range of desirable grasses is limited. Purple pigeon grass (*Setaria incrassata* cv. Inverell) is one such species, although its relatively low palatability concerns some farmers. Another alternative is to oversow grass into established legume, perhaps in the second year, but this is likely to increase the risk of failure because grass seedlings may not be able to compete with established legume plants for moisture. A further option is to sow less vigorous grasses (Jones and Rees 1997). Queensland bluegrass (*Dichanthium sericeum*) is one such grass that has been used with some success (Clem et al. 2001).

Selection of other grasses better suited to the ley phase, testing of options for establishment and management in crop–livestock systems, and refinement of legume management are needed so that the value of ley pastures to animal and crop production, and ultimately to the sustainability of the whole farming system, can be realised.

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Participative Methodology and Adoption of Technologies

Tropical legumes for sustainable farming systems in southern Africa and Australia,
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Identifying the Factors that Contribute to the Successful Adoption of Improved Farming Practices in the Smallholder Sector of Limpopo Province, South Africa[1]

T.S. Ndove,*,† A.M. Whitbread,§‡ R.A. Clark and B.C. Pengelly‡**

Abstract

A formidable challenge that faces the governments of many developing nations is the maintenance of food supply to an ever-growing population and the protection of the natural resource base. Despite the existence of many relevant and cost-effective technologies, and the continued focus of researchers on finding new technologies that enhance crop and livestock productivity, the smallholder farming sector remains relatively unproductive. Understanding the key factors that contribute to adoption of technologies that improve farm productivity is paramount if sustainable farming production is to be achieved within the smallholder sector. This paper reports on the key factors that have enabled a participative multidisciplinary R&D project to make significant impact in the adoption of fertiliser and legume technologies by a smallholder farming community in South Africa.

Using semistructured and group interviews, information was collected on the process of practice change resulting from interventions (farmer team and network development, training, on-farm experimentation, demonstrations) during the period November 2002 to January 2003. The study has revealed that farmers have adopted improved farming practices, such as fertiliser use, row planting, intercropping of legumes, and pest and disease management. Capacity building of the farmers associated with the project has resulted in the development of significant leadership and organisational capacity to sustain improvement of farm performance. Changing the focus from subsistence to producing for profit has been a great achievement within this community. Despite the success of the R&D project, the high age of the farmers (who are predominantly women older than 60 years) and frequent droughts are likely factors impeding continuity and sustenance of project achievements.

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* MSc candidate, University of Queensland, St Lucia 4067, Queensland, Australia.
† Extension officer, Department of Agriculture, Limpopo, P.O. Box 1273, Letaba 0870, Republic of South Africa.
§ Department of Plant Production Systems, Wageningen University, P.O. Box 430, 6700 AK Wageningen, The Netherlands.
‡ CSIRO Sustainable Ecosystems, 306 Carmody Road, St Lucia 4067, Queensland, Australia.
**Department of Primary Industries, G.P.O. Box 46, Brisbane 4001, Queensland, Australia,

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The most common worldwide challenge in the twenty-first century is the supply of the ever-growing population with sufficient food and fibre. Singh et al. (1991) stated that agricultural scientists and researchers have, over the past decades, developed improved methods and practices that can increase production. Although many of these new agricultural technologies have helped raise farm production and efficiency, the productivity of farmers in developing countries still remains poor, and adoption of improved technologies is less than desired. These have widened the gap between the performance of the new technologies at the experimental station and in the farmer's field. As noted by Singh et al. (1991), only the large-scale, wealthier farmers have adopted modern farming innovations, while the smaller and poor farmers have been unable to make use of the same technologies.

The Limpopo Province of South Africa depends economically on agriculture, mining and tourism. The majority of the population in this province lives in rural areas, where agriculture has been the main source of their local economies and development for many decades. Government, non-government, local and international research and development (R&D) organisations have been engaged in improving the farming practices and profit of the smallholder farmers; however, the level of adoption has remained low and unsustainable. Over the years there have been large R&D inputs to develop appropriate methods that can be used to achieve improved practices and outcomes for food security and profit. A recent popular method is the 'participatory' approach.

Although large-scale improvement in smallholder food security and profit has not been widely achieved, Singh et al. (1991) recorded that, where participatory methods were implemented, they led to improved adoption of R&D practices and achievement of increased production by farmers. Socioeconomic differences have been found to be important factors that influence the adoption of new technology (Lockie and Vanclay 1992). De Sousa Filho (1997) has also postulated that there is a need to study the determinants of technology adoption and diffusion of sustainable agricultural technologies and practices, particularly in the smallholder farming situation.

This study was aimed at a better understanding of the key factors contributing to the adoption of improved agricultural practices that impact on the achievement of increased smallholder production, profit and capacity.

Overview of Methodologies

Background to the study site

This multidisciplinary R&D project, operating from 1999 to 2002, was a partnership between the Australian Centre for International Agricultural Research (ACIAR) and South Africa's Limpopo Department of Agriculture. The project targeted one community called Dan in Limpopo Province with the aim of improving the dryland cropping and livestock production systems of the small-scale farmers. The main objectives of the project have been to increase the crop yield and to improve the quality and yield of livestock through the use of legume species that are adapted to the local environment. The community of Dan was used for a pilot study because it has the representative features of the Mopani District, which is one of the six districts of Limpopo Province.

Biophysical environment

Dan is situated at 23°55'S 30°16'E, 13 km east of Tzaneen town, and falls under the Greater Tzaneen Municipality of the Mopani District. The main soils used for crop production range from coarse-grained sandy soils to sandy loams derived from granitic parent materials. The organic carbon content is generally less than 1.0%, and the plant available nitrogen and phosphorus concentrations are severely limiting to plant growth. The soils are acidic with pH values below 5.8. The sandy nature of the soil results in a low effective cation exchange capacity and the leaching of nutrients, particularly N, S and K. Much of the cropping lands are susceptible to waterlogging during heavy rains, and subsoil drainage is poor due to an underlying dense clay layer.

The annual average rainfall is 759 mm (based on the available weather files at the nearby Letaba-Letsitele weather station). The rainfall pattern is strongly summer dominant with 86% of the rainfall received from October to the end of March. The minimum temperature of ≈6.5°C is reached in June and July and the maximum of ≈32°C in December and January.

Community structures

Dan has a reported population of 15 000 people. The cropping area is 200 ha with 300 farmers (with individual allocations of between 0.5 ha and 1.0 ha). Dan also has communal grazing land of 400 ha, with about 1000 head of cattle (individual ownership

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ranges between 1 and 100 head). The majority of the farmers are elderly women with an average age of 65. Their only source of income, apart from agriculture, is from government social grants that amount to R550.00 (A$110.00) per month. The majority of the farmers belong to the Dan Farmers Association.

Farming systems

Most of the farmers plant maize every season, and it is used as the staple food. Maize is harvested as immature cobs, 'green mealies', or at maturity and milled for home consumption. Cowpeas and groundnuts are commonly intercropped with maize. The cropping area is used as a communal grazing area between April and October. Any crop that is still standing after April will be grazed by livestock, and this makes it difficult to plant crops of long duration, such as perennial plants and ley legumes.

While the majority of farmers don't own livestock, grazing on cropping areas is open to any livestock owner. Land preparation is done by hired tractors and in many cases farmers plant late because tractors are not available. Broadcasting is the most common way of sowing seeds. While some farmers use newly purchased hybrid seeds, the majority of them still use recycled seed from previous harvests. Cowpea is usually planted by hand between the maize plants after the first weeding of the maize. Most of the farmers do not apply fertiliser; however, a growing number apply small amounts of inorganic and organic fertilisers. Organic fertilisers are usually applied in the form of kraal manure at a rate of between 0.5 and 1.5 t/ha. The produce from the fields is generally used for home consumption and very little is traded.

Land tenure

The land is communally owned, and farmers have permission to occupy (PTO) rights only. The traditional authority allocates and controls the land. The system has not made enough room to accommodate new entry for new residents or exit strategies for the old participants. There is no strict policy on fallow land, even if it remains unploughed over many years.

Survey methods used

This study was conducted between November 2002 and January 2003, was focused on the participants of the ACIAR project, and employed a case-study approach that used both qualitative and quantitative techniques. The case-study approach has enabled the use of a variety of methods and techniques that focus on processes rather than outcome, and more on discovery than confirmation (Burns 1997). Multidisciplinary participative research was used as the model in this study. This method is derived from the principles of action research, which are described by Zuber-Skerrit (1991) as being practical, participative and collaborative. In this methodology the researcher is not an outside expert conducting an inquiry with the 'subjects', but a co-worker doing research with the people and a practical problem. Semistructured interviews with open-ended and closed questions were used with key respondents. Group interviews were also used to inform, validate and triangulate the result of the semistructured interviews, by running four group interviews with some respondents (Burns 1997). The reason for this approach was that the farmers work in groups, and it remains important to validate the individual responses by going through the same questionnaire using group interviews. Secondary data obtained from baseline studies, combined with data from the Limpopo Department of Agriculture and the farmers' own records, were used to benchmark the farmers' practices before the start of the pilot project.

Sampling method

Of the 32 pilot project participants, a random selection of 22 of those who were available for both the interview sessions was chosen to participate in the study. The data gathered from the interviews were classified, tabulated and analysed in accordance with the objectives of the study. The main questions asked both in individual and in group interviews were aimed at gaining understanding of the factors that have impacted on the adoption or non-adoption of improved agricultural technology. The questions focused on soil fertility knowledge (soil fertility management, types of fertilisers used), agronomic practice (intercropping, weeding and pest management), capacity and organisational capacity, as well as economic questions (economic objective of farming, knowledge of profit and loss). With regard to practices, farmers were asked about their knowledge and where and when they acquired it. Unstructured interviews with key farmer informants and some other key participants were also conducted. Observation of farmers' practices was also done to gain more understanding of their knowledge and skills.

Results and Discussion

Summation of the project activities

After unstructured and semistructured interviews with the key farmer informants, some extension personnel and the researchers who participated in the ACIAR project at Dan recorded a chronological summary of key inputs between 1999 and 2002 (Table 1). These activities were confirmed by all the participants who were interviewed as a true reflection of the activities that the project has embarked upon. Activities such as the educational tours, meetings, and training sessions were repeated at intervals over three seasons, while others such as the baseline study and project introductions were done once. Table 1 also reveals that in 1999 most of the activities were geared at consultation with the stakeholders, which included farmers, extension personnel and community leaders. The purpose of the project was also introduced and negotiated with all relevant stakeholders.

Social classification of the respondents

All but one of the 22 respondents in the semistructured interviews were female. The average age of the respondents was 63 years, which is below the Dan farmers' average age of 65 (information obtained from the baseline study in 1999). Forty-five per cent of the respondents were in the 61–70 age range. The high age of the respondents limits the availability of

Table 1. Summarised timelines of project activities, 1999–2002.

1999	2000	2001	2002
• Introduction of the project (Local extension, farmers and farmer organisation)	• Farmers' meeting monthly. • Project team meets bi-monthly • Assessment and planning • Training need assessment	• Farmers' meeting monthly • Establish another soil fertility team • Project team meets bi-monthly • Training needs assessment	• Farmers' meeting monthly • Continuation of soil fertility team • Project team meets bi-monthly • Training needs assessment
• Community consultation (Met with farmer organisation, local extension personnel and other stakeholders)	• Soil fertility teams formed • Training sessions on soil fertility and the role of legumes • Establishment of farmers' experiment on soil fertility.	• Training on soil fertility, how to use different fertilisers, deficiency symptoms, application methods • Continuation of farmers' experiment on soil fertility. Comparing application of different levels of fertilisers and non-fertiliser application	• Training simple gross margin • Continuation of farmers' experiment on soil fertility. Comparing application of different levels of fertilisers and non-fertiliser application
• Meeting of project leadership with the farmers	• Demonstration on row planting, fertiliser application	• Demonstration on strip, inter-row and relay intercropping	• Follow-up on intercropping, soil fertility
• Baseline study done by a consultant	• Educational tours • Participative evaluation of the year	• Educational tours • Participative evaluation of the year	• Educational tours • Participative evaluation of the year
• Needs assessment based on the baseline report	• Annual project workshop • Establishment of technical on-farm experiment on legumes and intercropping	• Annual project workshop • Technical on-farm experiment on legumes and intercropping	• Project evaluation workshop • Technical on-farm experiment on legumes and intercropping

labour, and only a few can afford to hire labour when it is required.

The level of education ranges from very low to no education at all (Table 2). Sixty-three per cent of the respondents cannot read or write, while those who can are limited to the indigenous language. The creativity of the extension personnel therefore becomes the most important factor in transferring skills and technology. The role of extension personnel, with support from the researchers, has been very influential in this type of work with the farmers. On-farm experimentation, demonstrations and tours have been highly regarded by farmers.

Responses of farmers

Soil fertility management and fertiliser use

There has been a consistent increase in the use of inorganic fertilisers by the respondents from 1999 to 2001 (Table 3). In 2002, the majority of the respondents were using fertilisers. The knowledge of the farmers about the use of fertilisers has improved considerably and can be attributed to the demonstrations and on-farm experiments that farmers were participating in since 1999. The high price of the fertilisers and the consistent drought have emerged as the greatest deterrent to the use of fertilisers. However, respondents remain convinced that rainfall will improve in future and that their yields and profits will improve. Although lime is less expensive than inorganic fertilisers, only four respondents had used it. This low utilisation of lime may be associated with a lack of understanding of the benefit of lime when compared with nitrogenous fertilisers, from which crops may show instant responses. Although lime is less expensive per kilogram than inorganic fertiliser, the large amount of lime required for application (in excess of 500 kg/ha) and transportation costs or difficulties contribute to its reduced use. The consistent increase in the use of inorganic fertilisers from 1999 to 2001 may indicate that farmers have attributed the observed good performance of crops in demonstration plots to the use of fertilisers. This process of farmers' practice change in adopting fertiliser use has also been observed by Nkonya et al. (1997), who revealed that demonstration of technologies in the farmers' fields seemed to be most appealing to farmers.

Pest management

The respondents have observed an increase in the incidence of aphid infestation of legume crops such as cowpea and lablab. This was also supported by the extension and research team, who indicated that there were no aphid or beetle infestations on legumes warranting control measures until the use of exotic

Table 2. Social classification: age and educational achievement of respondents.

Age	No. of respondents	No schooling	Primary schooling	Adult literacy schooling
41–50	1	–	–	1
51–60	6	2	1	3
61–70	10	8	1	1
71–80	5	4	1	–

Mean of age: 63.

Table 3. Dan farmers using soil fertiliser amendments prior to and during the project period.

Amendment[a]	No. of respondents[b]	Before 1999	1999	2000	2001	2002
2:3:2	21	7	2	5	6	1
LAN	19	5	2	4	7	1
Urea	14	5	1	3	5	–
Lime	4	1	2	1	–	–
Kraal	4	2	2	–	–	–

[a] Amendments: 2:3:2 = 11:22:11% N:P:K; LAN = lime ammonium nitrate (34% N); Urea = 46% N; lime = calcium carbonate (±Mg); kraal = manure of various qualities.

[b] Multiple responses could be obtained from a total of 22 respondents.

legume cultivars (Table 4). The indigenous cowpea cultivars never had pest problems until the introduction of the exotic cultivars. Adequate legume growth depends, to a large extent, on the chemical control of these pests. This adds another economic burden to the already resource-poor farmers. The benefits of pest control measures, generally one spray per growing season, far outweigh the cost of spraying. The respondents, realising these advantages, seem to be prepared to use pest control measures, as indicated by the increasing use of chemicals. Besides poor soil fertility and droughts, the largest constraint on maize production is the maize stalk-borer. Increased pesticide use for control of maize pests may have also resulted from the need to control pests on legumes.

Intercropping and row-sowing practices

There has been an increase of 50% in the use of row sowing by respondents since 1999 (Table 5). The majority of respondents have adopted row sowing over their traditional method of broadcasting seeds. The on-farm experimentation and demonstrations of row planting have led to increased adoption of this practice. The farmers saw row-planting practices as compatible with other agronomic practices of band-placement of fertilisers and pest and weed control.

While farmers have traditionally practised intercropping in various forms, accompanying technologies such as weeding, fertiliser application and pest control measures were not always integral parts of the system. The respondents preferred strip intercropping over row and relay intercropping, as it seems make it easiest for them to do agronomic management practices such as fertiliser application, disease and pest control and harvesting when the same crops are grouped together in strips.

The beneficial effects of legumes have also become drivers of the adoption of intercropping. The capacity-building activities (Table 1) have led to an understanding that the benefit of the legumes to maize is derived from the supply of nitrogen. The educational sessions addressed the fact that nitrogen supply is not directly between legumes and maize, but occurs over several seasons through soil fertility build-up. The increase in the farmers' understanding of legume technologies has made this practice even more relevant. The fact that farmers have been intercropping for decades made it easy for them to adopt this practice, which was simply modified to further satisfy their original need to produce more crops.

Table 4. Pest control measures applied prior to and during the project.

Pest	No. of respondents[a]	Before 1999	1999	2000	2001	2002
Stalk-borer	17	3	1	3	8	2
Aphids	10	2	–	3	4	1
Cutworms	4	2	–	–	1	1
Beetles	1	–	–	–	–	1
Locust	1	1	–	–	–	–
No control	2	2				

[a] Multiple responses could be obtained from a total of 22 respondents.

Table 5. Sowing arrangement practices prior to and during the project.

Type of sowing arrangement	No. of respondents[a]	Before 1999	1999	2000	2001	2002
Strip-intercrop[b]	21	1	2	7	9	2
Row-intercrop[c]	3	–	1	1	1	–
Relay-intercrop[d]	5	–	–	2	2	1
Row sowing — sole crop	17	6	1	2	7	1

[a] Multiple responses could be obtained from a total of 22 respondents.
[b] Strip-intercrop: alternate strips of multiple rows (4–6) of legumes and maize.
[c] Row-intercrop: alternate single rows of legume and maize.
[d] Relay-intercrop: delay in the planting of the legume between rows of maize.

The importance of profitability as a driving force

Seventy-six per cent of the respondents have indicated their understanding of profit, and that profit can only be achieved when input costs are less than the product sales (Table 6). Taking into account their level of education and age, this is a remarkable change in their view of farming. However, they are also aware that soil fertility, water, and control of pests and diseases can improve the quantity and quality of their yield and improve their profit margin. Fifty-four per cent indicated that, despite their small cropping areas, their aim is to farm for food and to sell the surplus production. With an average landholding of 0.5 ha and frequent droughts, the production of these farmers is seriously limited. Reduced input costs and better rainfall patterns can improve both yield and profit for the farmers if other agronomic practices are done. Increased farmer understanding of economics, particularly profit and loss, has been achieved despite the persistent droughts causing serious crop losses.

Table 6. The end-point use of produce and the concept of profit.

	No. of respondents
Produce for food	10
Produce for food and selling	12
Knowledge of profit	16
No knowledge of profit	6

Conclusions

The adoption of improved technology seems to be influenced by many factors, ranging from environmental factors, farmer type and the methods used by extension agents, to socioeconomics. In this paper we have tried to determine the key factors that influence the adoption of improved agricultural technologies and practices.

The main barrier to adopting such technologies as fertiliser and hybrid seed use has been determined as the purchase cost. Despite the potential benefits of these technologies, farmers are reluctant to invest in them. As noted by Caswell et al. (2001), cost is a barrier to the adoption of improved technology. These authors found that there is a difference between farmers who do not want to adopt practices and farmers who fail to adopt due to barriers such as cost. Even the utilisation of inputs such as kraal manure, which is readily available for some farmers, was restricted by the costs of transportation.

Methods used by the extension personnel and researchers in building capacity for the farmers have contributed to the increase in adoption of most of the practices. The use of training sessions, on-farm experimentation, demonstrations and education tours have greatly influenced the farmers to adopt technologies such as fertilisers and intercropping, and agronomic practices such as pest and weed management. Despite the high age of the farmers, the consistent use of these different methods systematically over three years (Table 1) has gradually built confidence for farmers to adopt improved practices. The use of feedback loops in the form of regular assessment and planning sessions (Table 1) has enhanced the effectiveness of the methods used to impart knowledge and skills to the farmers.

The relevance of the new or improved technology to the farmers and the need of the farmers to improve their situation have been observed to be important factors of adoption. Most of the practices that were introduced were the result of farmers themselves identifying problems that reduce their yield, and demonstrating their willingness to improve their farming situation. The need of the farmers to learn is consistent with the principles of adult learning, which say that the adult should feel and recognise the need to learn (Malouf 1994)

Persistent drought has contributed much to the difficulties the farmers have faced in implementing some of practices learned. Although some of the agricultural practices were successful in experimental trials, at demonstration sites and on the toured sites, consistent failure due to drought has reduced the adoption of most practices. Environmental factors such as rainfall have been found to be very important in determining adoption and practice change, as all farmers have highlighted drought or poor rain distribution as the major constraint.

In this study, many factors that affect adoption of improved practices have been identified. The cost of the improved practices, the extension methods, the age of the farmers and poor rainfall have emerged as the main factors determining adoption. Further detailed studies need to be conducted in other farming communities. The farmers at Dan can also be used to motivate other farmers in other R&D programs in the region, because they have achieved so much under difficult conditions.

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Contrasting Adoption, Management, Productivity and Utilisation of Mucuna in Two Different Smallholder Farming Systems in Zimbabwe

B.V. Maasdorp, O. Jiri and E. Temba*

Abstract

As part of a project to address smallholder problems of soil infertility and feed shortage in sub-humid areas of Zimbabwe through integration of forage legumes in cropping systems, farmers with typically intensive mixed crop–livestock production were supplied with 5 kg of mucuna seed (*Mucuna pruriens* var. *utilis*) in October 2000. The aims were to assess the likelihood of adoption, evaluate mucuna production and use by farmers, and provide information for future research and extension. The two participating farming communities represented the two major smallholder farming systems in Zimbabwe, communal and resettlement, and were targeted because of their commitment to semicommercial ruminant livestock production. They were in the communal area of Dendenyore (cattle pen-fattening) and the Zana resettlement area (dairying). Total arable landholdings were 5 ha in Zana and an average of 2.7 ha in Dendenyore. Whereas the communal farmers of Dendenyore cropped primarily maize at a subsistence level, farmers in Zana achieved higher yields and also cash-cropped tobacco and paprika. Monitoring of the 37 farmers given seed occurred during 2000–01 and of these plus over 45 new growers in 2001–02.

Mucuna was produced and used more successfully, and there were more positive signs of adoption, by the communal area farmers (higher yields, more timely planting, higher seeding rates, better protection from invading livestock, increase rather than decrease in area planted, adequate rather than inadequate seed retention). There was no interest in using mucuna as green manure by these livestock producers, and only short-lived interest in intercropping it. They all used mucuna for pen-fattening rations or dairy feed. Attempts in Zana to make hay were not very successful, as harvesting was late (May) because of competition for labour from other crops. Mucuna hay was not easy to protect from marauding livestock and not easy to feed. Hay harvesting was later largely abandoned, and pod harvesting favoured. The communal farmers mostly harvested pods, let their livestock graze the residues in the field, fed seed and pods, and also sold seed for mucuna planting (including to some Zana farmers). Despite little soil amendment use on mainly depleted granite sands, mucuna yields were considerable, averaging 3 and 1.5 t/ha for pods and seed, respectively, in Dendenyore in 2000–01 with rainfall of 864 mm.

We concluded that mucuna had good potential for integration into smallholder systems in sub-humid areas, particularly to address problems associated with livestock feed. The cash-cropping resettlement farmers had more serious labour constraints than the communal farmers, and these reduced their capacity to grow and manage mucuna well. In contrast to the resettlement farmers, who were better endowed with resources, the communal farmers were much more interested in selling mucuna seed.

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* Crop Science Department, University of Zimbabwe, PO Box MP 167, Harare, Zimbabwe.

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Poor soil fertility and inadequate forage supplies are major constraints in the mixed crop–livestock systems typical of smallholder farming in Zimbabwe. Soils are largely infertile granitic sands that have commonly been subjected to prolonged monocropping of maize with minimal fertiliser use. The major sources of livestock feed are crop residues and natural grazing, which are insufficient in both quantity and quality, particularly in the lengthy dry season. Commercial feeds are largely unaffordable. Overstocking and degradation of communally grazed rangelands are a disincentive for interventions to improve their productivity.

Integration of forage legumes into the cropping systems might alleviate these problems, providing high N biomass for soil amendment and/or forage. This applies particularly in the wetter areas with higher potential for cropping (Natural Regions [NR] 2 and 3 with average annual rainfall of 650–1000 mm and 650–800 mm, respectively, falling mostly between November and March). Such legumes can be integrated as a cereal intercrop or in rotation as a ley or green manure. Setting aside of arable land as a weedy fallow is a common practice (Nyakanda 2003; Chuma et al. 2000) and would facilitate this use of legumes. One of the main reasons given for the use of weedy fallows in Nyakanda's survey was exhausted soil fertility. About 25% of farmers held the view that fallowing would result in some restoration, though chemical analysis and following crop yields did not support this. Interventions such as sowing legumes to increase the effectiveness of fallows therefore seem needed.

Despite the successful development of forage legume technologies, adoption in Africa and Asia has generally been poor (Thomas and Sumberg 1995; Horne and Stur 1997). This has been largely attributed to lack of involvement by farmers in development of research priorities (Horne and Stur 1997). With this in mind, full farmer participation was an integral part of a project on the introduction and integration of forage legumes into smallholder cropping systems. The project was conducted in two areas of contrasting tenure and land use, communal and resettlement, representing the two most common smallholder farming systems in Zimbabwe.

In the communal farming system, households are allocated arable land on a more or less permanent basis by traditional leadership, while grazing and woodland resources are used communally. Arable landholdings vary in size, but are typically 2 ha per household, and there are no restrictions on livestock numbers. This farming system is not sustainable and crop production is largely at a subsistence level.

Apart from the current (2000–03) land redistribution exercise, resettlement areas were created following Zimbabwe's independence in 1980, when central government acquired 3.3 million ha of land from large-scale commercial farmers to resettle households from densely populated communal areas (Gore et al. 1992). Model 'A' resettlement schemes comprise intensive village settlement with individual arable land allocation and communal access to grazing. In NR 2, each household has access to 5 ha of arable land and grazing rights for five livestock units. The original model 'A' blueprint, to provide for a reasonable crop rotation on the lighter, less fertile soils, was the cropping of only 3 ha and fallowing of the other 2 ha (Ivy 1983).

As the 2000–01 rainy season approached, it was thought that it was about time that farmers were provided with legume seed to grow as they wished. This would be the fourth growing season in which the project had contact with the target smallholder communities. After two seasons during the planning phase, 2000–01 was the second season of on-farm trials. Farmers were impatient for the project to get under way in 1999–2000, and had now been exposed to a year of legume fodder production and feeding trials. The adoption process needed to be facilitated and encouraged by supplying farmers with legume seed.

Mucuna was selected as the main legume in the intercropping and ley trials because seed of this large-seeded, well-adapted, productive legume was easy to produce in large yields, and it was readily available. Seed of the smaller-seeded forage legumes has gradually disappeared from the formal market in recent years, as large-scale farmers have stopped producing it because of increasing costs of production and diminishing demand, amongst other factors. Seed of *Lablab purpureus*, the large-seeded species grown in the project for the first animal feeding trials, was not readily available either, as it is not easy to produce a good seed crop unless intensive measures are taken to control pests during flowering and podding.

Mucuna seed was distributed to promote adoption of ley legume technologies. Further objectives, achieved through subsequent monitoring, were to gain information on productivity under farmer management, to assess the relevance of the legume technologies developed and the likelihood of forage legume adoption by farmers, and to identify influential factors, particularly constraints arising from farming practices and socioeconomic factors. This included eliciting farmers' perceptions and preferences about mucuna production and use, and assessing whether their needs are met by the available mucuna technology. Such information would be useful for decisions about future research and extension to improve the appropriateness and adoption of the technology.

Methods

Details of the study areas

This study was conducted in the neighbouring wards of Dendenyore and Zana in Wedza District, about 140 km southeast of Harare.

Dendenyore is in a communal area under cultivation since the 1930s, and Zana is part of a model 'A' resettlement scheme formed in 1986. They lie in NR 2B, which has less reliable rainfall than NR 2A. The region can be subjected to severe dry spells during the rainy season, and occasionally has relatively short rainy seasons (Ivy 1978). The area is about 1400 m above sea level.

Soils are mostly acidic sands derived from granite. Chemical analysis revealed no notable differences in fertility between Dendenyore and Zana sands; the averages for six sites are presented in Table 1. The soils have low concentrations of all major nutrients, a low cation exchange capacity and very low organic carbon content.

The population pressure in the communal area is considerably greater than in the resettlement area, with total land area and population for Dendenyore and Zana being 14 028 and 5 187 ha and about 15 000 and 1890 persons, respectively (Chigariro 2004). Average household sizes were similar, at five persons in Dendenyore and six in Zana.

Intensive mixed crop–livestock farming is conducted in both areas. Cropping is rain-fed. In Dendenyore, the main crop is maize (the staple diet), with yields averaging about 1 t/ha, although the potential is about 5 t/ha. Other, more minor field crops are millets, sorghum, groundnuts, sweet potatoes, sunflowers, cowpeas and soybeans. Production is at subsistence level, with any surplus marketed. In addition to these crops, the Zana resettlement farmers also produce cash crops of tobacco and paprika, and achieve maize yields of at least 2 t/ha. There was no fodder production before the inception of the project (Chigariro 2004).

The average total arable landholding is 5 ha in Zana, with about 3 ha cropped each year, and about 2.7 ha (0.8–5 ha) in Dendenyore, with about 2 ha (0.8–3.8 ha) cropped. Cattle are mainly kept for draught, manure and investment purposes. Herd sizes in Dendenyore are 0–4 in the poorest, 5–9 in the middle and >10 in the wealthier households (Pengelly et al. 2003). In Zana, farmers own 2–4 dairy cows in addition to other cattle. More households own goats, kept primarily as a ready source of cash income. In Zana, land preparation is mostly by tractor (with assistance from the District Development Fund), whereas Dendenyore farmers rely on draught animals.

Demographic characteristics differed between the two areas. The age of participating farmers ranged from 20 to 76 years in Dendenyore and from 20 to 65 years in Zana, while the male:female ratios for these farmers were about 1:2 and 3:1, respectively (P. Mazaiwana, pers. comm.).

The communities of Dendenyore and Zana were targeted for the forage legume introduction project, and consequently this mucuna adoption study, because of their pre-existing commitment to beef fat-

Table 1. Soil chemical properties of granite sands averaged over six sandy sites from Dendenyore and Zana.

Soil depth (cm)	pH	K[a] (cmol_c/kg)	Mg (cmol_c/kg)	Ca (cmol_c/kg)	Available P[b] (mg/g)	Total N (%)	C (%)
0–15	4.31	0.11	0.06	0.22	12	0.04	0.35
15–30	4.14	0.09	0.05	0.17	6	0.04	0.26

[a] Equivalent to meq/100g
[b] Bray P
Source: adapted from Jiri (2003)

tening and dairy enterprises, respectively. The Wedza Feeders Association was formed in the 1950s and has a total of over 200 members from nearly all 14 wards, including two resettlement areas. There were 65 pen-fatteners in Dendenyore. The Wedza Dairy Association was formed by Zana farmers in 1992, and 54 aspiring dairy farmers from Dendenyore have now also registered. Before the project, summer milk yields with spring calving were 4–6 L/day. Milk production in the dry season declines to as little as 1–2 L/day, limited by lack of adequate grazing and supplementary feeds. With legume feeding, however, these production levels increased to 5–17 and 2–6 L/day, for summer and winter respectively (Chigariro 2004). Similarly, Dendenyore farmers depended on bought feeds for pen-fattening, but have now reduced this input by about 25%.

The ratio of agricultural extension officers to farmers is 1:1200 in the communal area and 1:400 in the resettlement area (Chigariro 2004).

Seed distribution

Mucuna seed was issued to interested farmers in Zana and Dendenyore in October 2000. Fifteen farmers in Zana and 22 in Dendenyore were given seed, mostly 5 kg each (for an anticipated 0.1 ha). Farmers were given seed on the understanding that they would pass on a similar amount of seed from their own crop to another farmer. All the farmers who had hosted legume ley trials the previous season (five in Zana and four in Dendenyore) accepted seed. The remainder of the farmers given seed were identified by government extension staff.

Monitoring

Monitoring of the farmers and their mucuna crops was done by extension staff during the 2000–01 growing season, and more formally by researchers following harvesting in the dry season of 2001. Further monitoring was done in 2001–02, of the 2000–01 growers and 'new' adopters (i.e. those who grew mucuna in 2001–02 from seed they had been given or been sold by other farmers). In addition to monitoring in Dendenyore and Zana, extension staff reported on the diffusion of this legume technology to other wards within the district.

Agronomic practices were noted, including the system of mucuna integration, planting date, seeding rate, soil amendments used, weeding, date of harvest, and any problems encountered. The area planted was measured. Where the mature crop of pods was harvested (all Dendenyore farmers and a few in Zana) they were weighed (air dried). No systematic attempt was made to estimate hay and intercrop stover yields. Subsequently, use of the crop was monitored. Farmers were also asked about their future plans for growing and using mucuna.

Additionally, in May–June 2001 information was sought about the perceptions of farmers who had hosted trials for two seasons, and of those who had started to experiment with mucuna on their own. A simple questionnaire was developed, and 18 farmers were interviewed.

Results

Table 2 shows the number of farmers given seed by researchers, the total number of growers, and the number of those monitored.

A reasonable amount of rain fell in the 2000–01 season (864 mm), although there was a mid-season drought. In 2001–02, most of the season was drought, but about 300 mm fell in February, bringing the total to 733 mm.

Agronomic practice

Cropping system

In Dendenyore, mucuna was grown as a monoculture in both 2000–01 and 2001–02, except by one farmer in the first year. In Zana, about half the

Table 2. Numbers of farmers receiving mucuna seed, growing the crop, and monitored.

	Zana		Dendenyore	
	2000–01	2001–02	2000–01	2001–02
Number of farmers given seed	15	3	22	0
Number of growers	13	28	21	>61
Number monitored	10	6	13	11

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farmers intercropped the mucuna in 2000–01, but changed to monoculture the next year. 'Too much care needed' was a common observation about intercropping. In the second season, there was still no interest in using mucuna for green manure, even by second-year growers who were no longer so concerned with seed bulking.

Planting

Information about planting is presented in Table 3. Planting in Dendenyore was done at the beginning of the rains, but in Zana planting was delayed, in some cases even into January.

The area planted to mucuna varied considerably. The minimum area planted by first-time testers was 0.02–0.05 ha, while the maximum was 0.22 ha in Dendenyore and 0.48 ha in Zana. In general, Zana farmers allocated more land to mucuna than Dendenyore farmers. Among those growers who used mucuna in both 2000–01 and 2001–02, those in Dendenyore tended to increase the area planted in the second year, but those in Zana reduced it.

The seeding rate varied considerably, often being much lower than the recommended rate of about 50 kg/ha, especially in Zana.

Fertiliser use

Inorganic fertiliser or manure was applied to about 20% of monocultured mucuna crops in Dendenyore and 40% of such crops in Zana. The inorganic fertilisers used were Compound D (8:6:6:6.5% N:P:K:S), ammonium nitrate (34.5% N) and single superphosphate (8:12% P:S). In Dendenyore, application rates were 43–342 kg/ha fertiliser and 6–18 t/ha manure, and in Zana 13–144 kg/ha fertiliser.

Weeding

Little information was obtained about weeding practices, other than that in 2000–01 Dendenyore farmers weeded once, on average at 26 days (range 18–31 days) after planting. Experimental plots were weeded twice.

Harvesting of monocultured mucuna

In 2000–01 all farmers harvested in May, either all the herbage (all growers in Zana and one in Dendenyore), or pods only. Some Zana farmers extracted some pods thereafter. In the following season, with one exception, only pods were harvested and this was done even later: in June in Dendenyore and July in Zana. Only one farmer in each year, in Zana, harvested early enough (end of April) to make reasonable quality hay.

Mucuna yields

Pod and seed yields

Table 4 shows pod yields, excluding data from one waterlogged site. In 2000–01, the shelling percentage was 53% for monocultures and the intercrop in Dendenyore, where widely spaced maize was smothered by mucuna. In Zana, pods were only harvested for two intercrops and the shelling percentage was

Table 3. Planting of mucuna in Zana and Dendenyore in two seasons: date of planting, area, seed planted and seeding rate.

	2000–01		2001–02			
			Previous growers		New growers	
	Zana	Dendenyore	Zana	Dendenyore	Zana	Dendenyore
Planting date						
average	10/1	30/11	28/12	15/11	5/1	23/11
range	27/12–18/1	12/11–19/12	12/12–10/1	28/10–25/11	(*n* = 1)	10/11–14/12
Area planted (ha)						
average	0.24	0.10	0.17	0.15	0.38	0.06
range	0.05–0.48	0.05–0.22	0.04–0.40	0.10–0.18	(*n* = 1)	0.02–0.11
Seed planted (kg)						
average	4.8	5.0	5.0	7.5	15.0	2.9
range	2.25–10.0	all 5.0	3–9	5–10	(*n* = 1)	1–5
Seeding rate (kg/ha)						
average	30	61	43	48	39	48
range	6–67	23–96	13–75	29–59	(*n* = 1)	39–60

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36%. Shelling percentage was not determined for the 2001–02 monocultures; 53% was used for both sites.

Hay yields

With the exception of a single case, it was not possible to estimate Zana mucuna hay or intercrop stover yields because of prior grazing in the field and/or because hay was already in racks or had been partly fed. The single estimate was 285 kg hay, equating to 3.1 t/ha.

Use of the crop

All farmers used the mucuna, in various forms, as feed for ruminants. In both seasons in Zana, about half the farmers had their mucuna crop invaded and largely demolished by uncontrolled livestock. Most other farmers harvested the crop for 'hay', but only one farmer cut early enough (end of April) to make reasonable quality hay. The rest harvested after pod maturity and, in 2000–01, extracted some pods for seed retention, and in one case, all pods for feeding. More farmers proposed feeding pods or seed in 2001–02, but this was mostly not possible because of late planting, drought or livestock invasion. The single new grower monitored in 2001–02 had more success, allowed the pods to mature, and grazed the residues in the field.

In Dendenyore all the farmers harvested the pods in the field. Most then allowed their livestock in, rather than collecting the residues. In 2000–01, feeding pods (crushed or milled) or seed (whole or milled) were equally popular. The shelled pods, sometimes crushed, were also fed both to cattle and to goats. Where seed was fed, this averaged 101 kg per farmer. In 2001–02, use of the crop in Dendenyore was similar to the previous year, although most growers now proposed to shell the pods and feed seed and shelled pods separately.

It was observed that there were problems protecting mucuna hay (heaped or in hay racks) from marauding livestock. In an attempt to protect the hay, some farmers had resorted to storing it indoors (in sheds, barns and even in their bedrooms). It was also obvious that mucuna hay is not easy to feed unless it is milled.

Farmers were originally given seed on the condition that they pass on a similar amount to another farmer. This was done by most of the Dendenyore growers, with some even passing on seed to more than one farmer and in more than one season. In Zana, however, none of the growers monitored passed on seed (because not enough seed was being produced or harvested), with the exception of one new grower in 2001–02.

Table 4. Pod yields (kg) of monocultured and intercropped mucuna in Zana and Dendenyore in 2000–01 and 2001–02.

	2000–01		2001–02	
	Zana	Dendenyore	Zana	Dendenyore
Monocultures				
Per farmer				
average	n.a.	260	n.a.	80
range	nil or very little; 191 (*n* = 1)	83–575	nil;147 (*n* = 1)	8–146
Per hectare				
average	n.a.	2949	n.a.	863
range	nil or very little; 2098 (*n* = 1)	814–6188	nil; 383 (*n* = 1)	148–1448
Intercrops				
Per farmer				
average	27	241 (*n* = 1)	–	–
range	19–35 [a]	1215 (*n* = 1)	–	–
Per hectare				
average	450	–	–	–
range	190–710	–	–	–

[a] Not all collected

Dendenyore farmers were more anxious to sell some of their seed, whereas Zana farmers were less concerned about this. Fifteen of the 16 new Zana growers in 2001–02 bought seed from Dendenyore farmers.

Farmers' perceptions

Reasons for growing mucuna

The main goal of Dendenyore farmers was to reduce the amount of inorganic fertiliser bought for maize crops, while farmers in Zana had specifically planted it for animal feed. All farmers, however, anticipated higher maize yields following mucuna than after weed fallow, from which they expected little soil fertility benefit. Unfortunately, the poor rains in 2001–02 made it impossible for farmers to assess this.

Labour needs

The assessed labour requirement of mucuna technologies differed between the two localities. On average, 76% of the Zana farmers assessed the labour requirement as high and the remainder as medium. In Dendenyore, 20% classified mucuna production as labour intensive while about 80% assessed it as requiring low labour inputs. Table 5 shows farmers' assessments of labour inputs. Generally, planting, weeding and harvesting for hay coincided with many other activities, especially in Zana. The few growers of maize–mucuna intercrops said that the practice required too much care. No farmers grew mucuna on its own as green manure.

Table 5. Problems encountered with the cultivation of mucuna (percentage of farmers asked).

	Zana (%)	Dendenyore (%)
Planting is tedious	57	44
Weeding is difficult	76	34
Workload increased	88	24
Difficult to work on	45	23

Extent of future mucuna cultivation

Farmers indicated that they would be able to set aside about 0.4 ha for mucuna production. Following both seasons, most growers indicated that they wanted to increase the area planted to mucuna in the next season. Some expansion was apparently largely achieved in Dendenyore in 2001–02 (Table 3), with an average increase of 168% for those farmers monitored in both seasons. However, in Zana the area planted in 2001–02 by farmers monitored in 2000–01 declined by an average of 26%. In the two years of growing their own mucuna, few farmers had achieved an area of 0.4 ha (27% in Zana and none in Dendenyore).

Discussion

Because of the relatively small number of farmers involved, any conclusions drawn from this monitoring should be treated with caution. Nevertheless, valuable insights can emerge from a few carefully chosen case studies (Parton 1992), and some clear trends emerged.

The average mucuna pod and seed yields achieved by Dendenyore farmers in 2000–01 were 2949 and 1564 kg/ha, respectively. These are considerable yields for a dual-purpose crop growing with little soil amendment on infertile soils of low water-holding capacity.

In 2001–02, because of the bad drought, pod yields were only about 25% of those in the previous season. This is a similar yield reduction to that experienced in a CIMMYT seed-bulking plot near Harare in NR 2A (S.R. Waddington, pers. comm.). Timely planting by the Dendenyore farmers in 2001–02 (late October and November) ensured that good stands were established before the drought set in. It should be noted that, despite the drought, mucuna did produce some yield and was not a complete failure like many other crops. In contrast to the timely Dendenyore plantings, the 2001–02 planting in Zana was late (mid-December to early January), as in the previous season, and establishment tended to be poor. Zana farmers also had more problems with invading livestock, and mostly very little seed, if any, was harvested (in some cases not even enough for replanting).

The low seeding rates used by some farmers, particularly in Zana, were likely due to seed shortage, but also indicate that perhaps more advice is needed about plant spacing, since low densities would increase the weed burden. Farmers seemed prepared to weed their own mucuna crops only once, and this did not thoroughly eliminate weed competition.

Most farmers did not apply fertiliser or manure to their mucuna, and the amounts used by those who did varied widely. On a per hectare basis, small to reasonable amounts were applied. In the on-farm trials, mucuna had shown good responses (1999/2000) to

SSP and lime application (Jiri 2003). However, these findings had not been taken up by extension staff or farmers. It was noted that extension staff recorded ‘Fertilisers used: N/A’, possibly indicating a lack of appreciation of this potential of SSP and lime to improve mucuna growth. The few farmers who applied inorganic fertiliser tended to use Compound D and ammonium nitrate: these contain N, which should not be necessary for well-nodulated crops. Non-affordability and poor availability of SSP and lime may also be influential factors.

Farmers seemed to prefer growing mucuna as a monoculture to intercropping. Intercropping is not commonly seen as a soil fertility management practice (Omiti and Freeman 1999; Bellon et al. 1998, cited by Ayuk and Jera 2001). Chibudu (1998) also reported this intercrop to be unpopular, because the twining mucuna made maize harvesting difficult. The lack of interest in using mucuna as a green manure crop, despite the desire in Dendenyore to replace fertiliser, was more probably caused by the necessary trade-offs between use for green manure, use of hay or pods as livestock feed, and seed sales, rather than by the high labour requirement for incorporating green manure (Muller-Samann and Kotschi 1994). The main incentive to adopt legumes is the economic benefit from sales, rather than benefits in soil fertility (Muza and Mapfumo 1999).

In Dendenyore, farmers appear to have grown and utilised mucuna for livestock feed more successfully, preferring to let the crop grow to maturity and harvesting pods in May–June. The mucuna was fed to livestock either as whole or crushed pods, or milled or whole seed; shelled pods were also fed broken, whole or crushed, and the residue grazed in the field. By contrast, in Zana the intact crop was more often intentionally or accidentally grazed in the field or collected for hay. However, only in two cases monitored did farmers cut the crop early enough to make hay of reasonable quality. It seems possible that competition for labour because of the harvesting of other crops in April and May militates against earlier harvesting of the mucuna, reflected in the perception of Zana farmers that mucuna crops have a high labour demand.

Problems of access by uncontrolled livestock to mucuna as hay seem to be reduced by collecting and storing pods. Milling and bagging hay would also protect it from livestock and make feed rationing easier, but would further increase the labour needed. Cases of increased labour demands inhibiting technology uptake by smallholder farmers in Zimbabwe have already been documented (Huchu and Sithole 1994).

For the communal area farmers of Dendenyore, who hoped to sell some seed, mucuna may have a role as a direct source of cash income.

After the 2000–01 season, most growers indicated that they intended to increase the area planted to mucuna the next season. This seems to have been achieved in Dendenyore, but not in Zana, where there were few expansions and some reductions in areas planted in the second season. This is probably related to seed availability. In Dendenyore, but not in the cash-cropping Zana system, farmers produced and retained adequate seed in both seasons for planting the next year. Most Zana growers seem to have produced no seed at all for planting in 2002–03. Unless farmers in Zana are willing to buy seed from their neighbours in Dendenyore, this is not a sustainable system. It is usually very easy to produce mucuna seed from a forage crop, so this failure to sustain mucuna seed supplies has negative implications for the continued production and adoption of other ley legumes.

Baseline data was determined only for Dendenyore and Zana farmers within the project interest groups, who were therefore all actual or potential cattle owners with some fallow land. In very similar communal and resettlement farming communities, also in NR 2B, Nyakanda (2003) found respectively 36% and 63% of farmers to have weedy fallows, averaging 0.42 and 0.83 ha (11% and 14% of arable land). However, more communal area farmers than indicated by the proportion with fallow land might have enough land to plant legume leys, since one strategy to counteract risks (of drought, waterlogging, livestock damage, lack of labour for weeding, inadequate fertiliser etc.) is to cultivate as much land as possible (Carter and Murwira 1995; Nyakanda 2003).

In a season of reasonable rainfall, monocultured mucuna would produce, on average, yields of 2–3 t/ha pods with 1–1.5 t/ha seed, according to the 2000–01 data for Zana and Dendenyore. An area of just 0.1 ha is therefore likely to yield about 200–300 kg of pods with 100–150 kg seed, which at the rate of 2 kg/day of pods for cattle (Topps and Oliver 1993) could provide a high-protein feed input for 100–150 days for one animal. Hay yields of just 350 kg from 0.1 ha (3.7–11.8 t/ha in unfertilised trial plots; Jiri 2003) would feed a cow hay at 6 kg/day for about 60 days (C. Murungweni, pers. comm.).

Conclusions

This study revealed the high potential of mucuna for integration into smallholder farming systems in NR 2 of Zimbabwe, particularly as livestock feed. Farmers produced good mucuna crops and some successfully produced seed, which is essential to perpetuate the crop and to ease adoption by other farmers. The potential for mucuna to improve soil fertility, and farmers' perceptions and adoption of it for this purpose, were less clear: farmers had no opportunity to observe the impact of mucuna on following maize crops because of the drought of 2001–02.

Production and use of mucuna differ between the Dendenyore communal area and the Zana resettlement area, perhaps because of differences in their farming systems and their cash economies. The different reasons of Dendenyore and Zana farmers for growing mucuna clearly reflected the areas' different resource bases. It was also quite apparent that resettlement farmers, involved in cash-cropping of tobacco and paprika, had serious labour constraints. Although they wanted to also undertake dairying and replace bought dairy meal with homegrown feeds, Zana farmers' attempts to incorporate mucuna into their farming system were less successful than those of Dendenyore communal area farmers. This has implications for the adoption of ley legume technology in this sector. The ultimate way of using the crop for livestock feed, as hay (Zana) or pods/seed (Dendenyore), was also influenced by labour availability.

Dendenyore farmers also saw mucuna seed as a source of cash, in contrast with the cash-cropping Zana farmers. Synergy might be created between two such communities by encouraging farmers to consider marketing mucuna seed between them as a feed.

The most efficient way to feed mucuna to livestock remains to be determined, especially regarding labour demands, palatability and feed conversion (of hay, seed, and shelled and unshelled pods; whole, crushed or milled).

Only the first two years of farmer testing of mucuna were monitored. In Dendenyore, the number of farmers trying out this new crop tripled in the second year, confirming the relevance of mucuna leys to the communal farming system and the likelihood of wider adoption by communal farmers.

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A Socioeconomic Evaluation of an ACIAR-funded Project on the Use of Forage Legumes in Integrated Crop–Livestock Systems on Smallholder Farms in Zimbabwe

G.J. Manyawu,* O. Jiri,† B. Chigariro,§ P.R. Mazaiwana,§ R. Nyoka§
and D. Chikazunga‡

Abstract

A farmer participatory research project was initiated in 1998 in the Wedza District of Zimbabwe to improve soil fertility and crop and livestock production on smallholder farms in Natural Region IIb (750–900 mm annual rainfall). Based on legume technologies integrated into crop–livestock farming systems, the project ran for four years. By the end of the project there was widespread adoption of legumes in ley pastures, cereal–legume intercropping and livestock feeding systems. This rapid adoption resulted from the combination of good forage technologies, the better practices process and the participatory action research approach. The project had a large impact on the community, demonstrated by improved household incomes from the sale of milk, beef cattle and seed, and improved crop yields. Forage legumes fitted well into smallholder farmers' integrated crop–livestock systems, and *Lablab purpureus* and *Mucuna pruriens* were the most widely used legumes. Adoption was hampered by shortage of seed of the recommended varieties. We concluded that farmers should produce legume seed at a commercial scale to satisfy local and external markets. Farmers said that, for an even bigger impact, the project should help them to obtain crop inputs and better breeds of cattle. Farmers' comments at the end of the four years showed that the project still had a lot to accomplish. The ready adoption of the project results demonstrated that scientists should develop and run research programs in partnership or consultation with the end-users of the technology.

The purpose of this research project, initiated in 1998, was to improve soil fertility and crop and livestock production on smallholder farms through well-adapted and well-chosen legumes. Normally, crop and livestock production in these farming systems is integrated. Crops provide feed for livestock and livestock provide draught power and manure for the cropping system (Francis and Sibanda 2000). This aspect of the farming system was incorporated into the project.

The project was conducted in Wedza district and lasted four years. It was developed in association with smallholder farmers of Zana II and Dendenyore wards using farmer participatory research methodologies, sponsored by the Australian Centre for Inter-

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* Grasslands Research Station, Private Bag 3701, Marondera, Zimbabwe.
† AREX Head Office, Agronomy Institute, PO Box 594, Causeway, Harare, Zimbabwe.
§ AREX, Wedza Office, PO Box 30, Wedza, Zimbabwe.
‡ University of Zimbabwe, Agricultural Economics Department, PO Box MP 167, Mount Pleasant, Harare, Zimbabwe.

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national Agricultural Research (ACIAR), and implemented by a multidisciplinary team of researchers from Zimbabwe, in conjunction with some Australian scientists. Farmer-managed experiments were conducted to evaluate a range of tropical forage legume accessions in veld (grassland) reinforcement, ley pasture production and cereal–legume intercropping. The project employed the principles of the better practices process (McCartney et al. 1998; Clark and Timms 2000) to ensure a positive impact and continuous improvement of the research program.

In Zana II, the farmers agreed to test 30 species of legume in veld reinforcement as a communal effort. Mucuna (*Mucuna pruriens*) was also used in some on-farm trials to demonstrate the benefits, for soil fertility and fodder production, of using legumes in cereal rotations or intercropping systems. Dairy farmers from the same ward were also involved in experiments to test the use of lablab (*Lablab purpureus*) and mucuna seed or foliage as protein supplements for lactating cows during the dry season. Similar experiments were conducted in Dendenyore Ward. However, farmers in Dendenyore were mostly interested in beef cattle farming, particularly pen-fattening, and not dairying.

Our report describes the adoption of the technologies and their impact on soil fertility, on fodder, crop and livestock production, and on farmer's livelihoods.

Materials and Methods

Since 1999, diagnostic surveys to benchmark progress were conducted annually between February and March by research and extension staff from the project. In these benchmarking surveys, research and extension staff spoke with farmers to determine farmers' aspirations and achievements. Data from these exercises was largely descriptive.

In addition, a socioeconomic survey was conducted in February 2002 using a semistructured questionnaire to assess the levels of adoption of the new legume-based technologies and their impact on household income, capital developments and livelihoods. The questionnaire gathered information on household demography, resource endowments and field crop, fodder and animal production before and after the introduction of the project. It was given to 46 farmers in Dendenyore and 18 in Zana II. These farmers were chosen on the basis of their level of involvement in the project. In Dendenyore, 24 of the farmers were founding members of the project and 22 were farmers (hereafter referred to as adopters) who were recruited into the project when they adopted technologies introduced by the project. Similarly, in Zana II there were 15 founding members and three adopters. Five trained enumerators administered the questionnaire. Data from the questionnaires was coded and entered into the SPSS analytical program (version 7.5) for analysis.

Results and Discussion

Brief description of the farming systems in Zana II and Dendenyore wards

The total numbers of households in Dendenyore Ward and Zana II were 3000 and 75, respectively. At the inception of the project, there were 49 participating households at Dendenyore and 19 at Zana II. The average age of household heads in the two wards was 58, and the average educational level was to grade 7 in primary school. The average size of the household was bigger in Zana (9.7) compared to Dendenyore (6.2). All households in Zana were headed by men. In Dendenyore, 38% were headed by women. Although most households were headed by men, women carried out most of the farming operations in both wards.

Farmers in the two wards take farming seriously. Most are members of agricultural associations, such as the Zimbabwe Farmers Union, the Livestock Feeders Association, the Dairy Association and other commodity associations for tobacco, mushroom, paprika, maize and soybeans. These associations are a vital source of information on agricultural production and marketing.

When farmers at both sites were asked to rank the most important sources of income, they rated crop production, livestock production and off-farm income as equally important.

Total land holdings of the average farmer in Zana II were almost double those in Dendenyore (Table 1). The difference exists because Zana II is a relatively new resettlement area where farming started in 1986. Dendenyore is an old communal settlement where most of the land has been continually subdivided through family inheritance since the 1950s. Up to 75% of the land in both wards was devoted to crop production. While farmers in Zana II had less land under fallow, there were indications in the past two years that some farmers were beginning to devote more land to fodder production.

Table 1. The mean farm size (ha) and the pattern of land use on properties owned by farmers involved in the ACIAR project.

	Dendenyore	Zana II
Total land size	2.7	5.0
Total land under crop	1.5	3.0
Total land fallow	0.6	0.9
Total land under pasture before 1999	Negligible	0.3
Total land for pastures after 1999	0.4	0.4

Table 2. Farmer rankings of the most important crops grown in Dendenyore and Zana II Wards.

Crops	Dendenyore	Zana II
Maize	46 (1)	18 (1)
Beans	27 (3)	3 (5)
Groundnuts	44 (2)	–
Paprika	–	17 (2)
Tobacco	–	15 (3)
Soybeans	–	6 (4)
Bambara nuts	26 (4)	–
Sweet potatoes	13 (5)	–

Crop production

Farmers from Zana II concentrated on crop production, with tobacco the most important crop followed in descending order by paprika (*Capsicum annuum*), soybean (*Glycine max*), sugar beans (*Phaseolus* spp.) and maize. Farmers derived this rank order by assessing incomes obtained from these crops and their contribution to household food security.

Farmers at Dendenyore also carried out intensive crop production, supplemented with beef production and horticulture. The most important crops were, in descending order, maize, sugar beans, groundnuts (*Arachis hypogea*), Bambara nuts (*Voandezia subterreanea*) and sweet potatoes (Table 2). Up to 56% of the farmers in Zana II and 79% in Dendenyore intercropped sugar beans with maize. Other legumes that were mixed with maize were mucuna and lablab.

All farmers indicated that they practised crop rotation and that they grew at least one legume, such as Bambara nuts, soybean, forage legumes, sugar beans and cowpeas (*Vigna unguiculata*), to improve soil fertility through biological nitrogen fixation and to reduce costs of N fertilisers.

Livestock production

Farmers in both wards rear beef and dairy cattle, with a few sheep and goats (Table 3). Cattle were by far the most widely kept livestock. About 87% of the farmers in Zana II were involved in commercial dairying. Most of the milk was sold at the Wedza Dairy Center and to neighbouring farmers. The milk was produced from exotic (Jersey) and indigenous (Mashona) beef crosses. In Dendenyore, farmers only milked their multipurpose indigenous beef cattle for subsistence; otherwise, the cattle were kept to provide draught power, manure, meat and income.

In each ward, a group of farmers attended initial meetings to outline problems that needed to be investigated in crop–livestock systems of production. This same group of farmers was asked to host and manage on-farm research trials from 1999. As these farmers gained experience, they helped in technology diffusion in the wards and in distributing pasture seed to neighbours. Fields belonging to host farmers were accessible to all farmers in the program; there were no restrictions. Host farmers also explained their role in the continuous improvement of the project and how this led to a sharper focus in resolving production problems. Neighbouring farmers who copied technologies from host farmers were termed ‘adopters’.

The farmers hosted the experiments as individuals or in groups. At Zana II, rangeland research was hosted by a group of farmers, whereas research on

Table 3. Cattle ownership by average households in Dendenyore and Zana II Wards.

Ward	Cattle type	Year		
		1999 mean (s.d.)	2000 mean (s.d.)	2001 mean (s.d.)
Dendenyore	Beef	7.7 (6.0)	7.4 (5.3)	7.3 (4.4)
	Dairy	2.5 (1.6)	2.4 (1.6)	2.3 (1.3)
Zana II	Beef	13.1 (11.9)	11.8 (11.7)	12.4 (10.9)
	Dairy	1.5 (1.3)	2.6 (1.7)	4.6 (1.6)

intercropping and screening of legumes for ley pasture production was hosted by individual farmers. At Dendenyore, all the research was hosted at individual farms, but in some instances (for example, in evaluating legumes suitable for leys) the farmers came to work at experimental sites in groups.

Adoption of crop production technologies

The main reasons why farmers were adopting the use of legumes in their cropping systems were to improve soil fertility and the yield of subsequent maize crop, and to provide fodder. Results of the survey showed that mucuna and lablab were the most widely grown legumes in Zana II and Dendenyore, and that they were increasingly being adopted by farmers inside and outside the project area. The farmers were impressed with the drought tolerance of lablab and mucuna. The number of farmers who grew lablab increased by 20% in Zana II and 68% in Dendenyore, and the numbers who grew mucuna increased by similar proportions. The area sown to these legumes also increased progressively (Table 4) as farmers gained knowledge about how to grow them.

Most farmers adopted the use of these legumes both in homestead gardens and in the main fields. Many of the adopters were getting seed of the two legumes from host farmers at prices that ranged from Zim$5 to $45/kg (US$0.09–0.82). Initially, seed was provided by the project free of charge, and the project continued to provide free seed to at least five farmers each year. It was project policy that each year a hosting farmer or adopter who received free seed in the previous season should pass on at least 5 kg of seed to another new farmer. At the time of the survey, no arrangements had been made to market the seed to commercial seed companies. However, there was overwhelming demand for seed of the forage legumes and some farmers showed interest in producing seed at a commercial scale.

Adoption of livestock production technologies

Although the number of beef cattle reared in the two wards did not change (Table 3), the feeding practices of the farmers did. Farmers increasingly used forage legumes to replace commercial concentrates. In 2001, on average, 5.9 beef and 1.8 dairy cattle per farm at Dendenyore and 8.8 beef and 1.2 dairy cattle per farm at Zana II were fed lablab or mucuna as hay, fresh material or ground seed to substitute for commercial concentrates such as ‘Super 10’.

About 31% of the farmers at Zana II and 16% at Dendenyore used commercial supplements. The majority, 67% and 82% respectively, relied on maize stover and 2% used groundnut tops, pods from indigenous trees and maize meal as supplementary feed during the dry season. Some 71% of the Dendenyore farmers and 45% of Zana II farmers said that the amount of forage legumes grown was sufficient for their cattle herds. The other Zana II farmers indicated that they did not produce sufficient forage because they devoted less land to pastures. They appeared to get better returns from cash crops such as tobacco and paprika.

Table 4. Production statistics for lablab and mucuna at Wedza.

Parameter measured	Dendenyore Ward		Zana II Ward	
	Mean	s.d.	Mean	s.d.
Lablab				
area (ha) sown in 2001	1.13	0.44	0.85	0.58
area (ha) sown in 2000	0.96	0.35	0.70	0.52
area (ha) sown in 1999	1.06	0.37	0.44	0.33
Forage yield in 2001(kg DM/ha)	976.92	580.45	766.67	560.57
Forage yield in 2000(kg DM/ha)	1026.82	1052.51	1058.33	1330.21
Forage yield in 1999(kg DM/ha)	929.33	633.43	400.40	270.83
Mucuna				
area (ha) sown in 2001	0.98	0.36	0.69	0.50
area (ha) sown in 2000	0.80	0.43	0.65	0.38
area (ha) sown in 1999	1.06	0.26	0.49	0.36
Forage yield in 2001(kg DM/ha)	1100.36	1746.28	644.62	736.44
Forage yield in 2000(kg DM/ha)	1937.50	2431.81	345.00	353.20

Impact of the project

Crop practices

The project had a huge impact on cropping practices. Farmers reported that, on average, maize grown after a legume yielded 4 t grain/ha, whereas maize under continuous cultivation yielded 2 t/ha. Although previous research by Manyawu et al. (1995) and Alemseged et al. (1991) indicated that intercropping maize with legumes depressed maize grain yields by 18–20%, evidence collected in the current survey demonstrated that in Wedza the yield reduction was only 3%. Farmers were therefore changing their cropping practices to include legumes in their cereal rotations. Some farmers even favoured the idea of intercropping maize with lablab because it was less aggressive than mucuna.

Livestock production

The majority of farmers indicated that the project had a direct impact on their incomes and livelihoods. In Zana II, improved milk yields increased farmers' incomes. The higher yields resulted from better quality feeds introduced by the project. Table 3 shows that the number of dairy animals increased in Zana II, and Table 5 shows the increase in milk yields.

Table 5. Average daily milk production (L/cow/day) at Dendenyore and Zana II.

Year	Dendenyore		Zana II	
	Mean yield	s.d.	Mean yield	s.d.
2001	2.94	2.4	5.10	2.2
2000	2.94	2.1	4.60	2.1
1999	2.91	2.4	6.56	2.0
1998	1.50	0.9	2.06	1.7

Farmers in Zana II were selling a litre of milk at Zim$60 (US$1.09) at the Wedza Dairy Center. An average farmer in Zana II who had two dairy cows that produced 5 L/day was selling up to 300 L of milk per month, realising Zim$18 000 (US$327). The farmers also indicated that improved feeds introduced by the project had increased milk fat content. Considering that per capita annual income in Zimbabwe is about Zim$1340, the current income from milk may be sufficient to sustain an ordinary dairy farmer in Wedza.

Returns were higher (1:1.9) when farmers used forage-based diets, as opposed to concentrate-based diets (1:0.7). Up to 78% of the farmers in Zana II indicated that income from milk sales was the main cash benefit they were enjoying from the project. The additional income helped farmers to meet their daily household expenses and acquire some farm inputs.

In Dendenyore, beef farmers were increasing their profits by using home-grown leguminous fodder to substitute for commercial concentrates in cattle fattening diets. Because of the low cost of the home-mixed diets, farmers were able to feed their livestock more effectively and cheaply. Gross margin analysis by Murungweni et al. (2004) showed that the farmers made a profit of Zim$931.80 (US$16.90) on a steer when they used forage-based diets. Farmers who used commercial concentrates made a loss of Zim$2619.00 (US$47.62) on every steer.

Generally, farmers felt that feeding legumes improved the health status of their livestock, and these sentiments were echoed by neighbours who admired the cattle. Good nutrition also improved conception and, consequently, total milk yields. Draught cattle remained in good condition up to the end of the dry season.

Indirect benefits

Farmers indicated that they were getting indirect savings on fertiliser by growing legumes, because subsequent crops required less N fertiliser. Farmers also noticed that growing mucuna in rotation with maize was cost-effective in eradicating *Striga* (witchweed). When legumes were used in cattle-fattening diets, the amount of maize grain in the supplementary diet was reduced by 30%. A few farmers said they roasted and ground mucuna seed to make a beverage similar to coffee, thereby saving money on coffee.

Constraints

Limitations of legume technologies

Despite the benefits outlined above, some dairy farmers in Zana II reported that milk from dairy cows that were fed mucuna had a tainted taste and turned sour sooner than usual. Dairy cows sometimes took time to get used to the legume, and some animals even suffered from mild diarrhoea at the onset of the feeding period. The farmers also added that lablab was unsuitable in some instances because it succumbed to aphids during droughts. It was prone to damage and death of seedlings at establishment because of cutworms and also to a variety of insect pests at flowering. This made it less suitable than mucuna because farmers had to buy expensive pesticides and other chemicals to control the infestations. Hence, researchers need to find better suited legumes and develop appropriate methods to process herbage from mucuna before it is fed to livestock.

Most farmers complained that mucuna smothers maize when it is intercropped, causing severe yield reductions. Researchers need to identify less aggressive varieties of this legume and/or devise appropriate intercrop planting methods that will favour the grain crop.

The shortage of seeds of lablab and mucuna was also said to be a major limitation to the adoption of legume-based technologies on a large scale.

Shortage of resources

Farmers indicated that they were having problems in getting enough money to buy fertilisers that could be applied to planted legumes. They mentioned that their first priority is to find enough fertilisers for cash crops. Many said that the project should set up a credit scheme to provide loans for fertilisers and lime to be used in pasture development. Normally, the farmers do not have enough money to buy these fertilisers.

At both Dendenyore and Zana II, more than 87% of the farmers suggested that the project should start a livestock finance scheme to provide loans to farmers who wish to buy better breeds of dairy or beef cattle. Many said that local (indigenous) cattle do fully capture the advantages of using cultivated pastures because of their low milk production potential, small body weights and slow growth rates. Farmers wanted better breeds of cattle, especially exotics, which they would cross with local breeds.

A Dutch-sponsored project (BTZ) operating in Wedza District bought motorised chopper–grinders for farmers under its program. Farmers on the ACIAR project wanted similar machines to chop forages for ensilage and to mill grain or legume seed for use in mixed rations. Local business people do not allow the farmers to process legume seed or forages in their hammer mills.

Level of participation by farmers in the project

Farmers expressed the opinion that, in some instances during the current phase of the project, researchers designed experiments and farmers only participated in evaluating the promising technologies (consultative participation). The project staff responded that there was a need to balance the two approaches, because it is not possible to have all experiments in the full collaborative participation mode. This issue requires further discussion.

Conclusion

The impact of the project was demonstrated by improved household incomes from the sale of milk, beef cattle and seed, and by improved crop yields. Widespread adoption of legume-based technologies on this project confirmed that participatory action research and the better practices process are powerful tools that should be used in developing appropriate technologies in smallholder farming communities. In projects of this nature, scientists will have to place increased importance on developing and running research programs in partnership with the end-users of the technology.

Forage legumes fit well into the integrated crop–livestock systems that prevail on smallholder farms in Natural Region II of Zimbabwe. Farmers must attempt to produce seed of the legumes at a commercial scale in order to satisfy local demands and external markets. When seed of the appropriate legumes is readily available at an acceptable price, the rate of adoption of the technologies is likely to be even greater. Farmers' comments at the end of the survey indicated that the project still has a lot to accomplish before it ends. For an even bigger impact, the project should help the farmers to obtain crop inputs and better breeds of livestock.

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Using the Agricultural Simulation Model APSIM with Smallholder Farmers in Zimbabwe to Improve Farming Practices

A.M. Whitbread,* A. Braun,† J. Alumira§ and J. Rusike§

Abstract

Computer simulation models can serve as a platform for achieving change in a farming system. Such models represent crop and animal production processes to assist farmers, researchers and agricultural managers. This paper presents examples of using a simulation model, APSIM, with farmers to analyse farm decision making, to assess the impact of climatic risk on productivity and profitability, and to set priorities for participatory research. At the Linking Logics II workshop held at ICRISAT, Bulawayo, Zimbabwe in October 2001, a team consisting of a modeller/soil scientist, a sociologist, an economist, a participatory methods expert and local NARES (national agricultural research and extension systems) extension officers spent two days with more than 20 local farmers at Zimuto Siding near Masvingo in Zimbabwe. The scenarios and simulations developed during these meetings are presented. Important fertiliser, manure and crop management choices were explored for poorer and wealthier groups of farmers, and as a result, the farmers were able to consider a broader range of management decisions for the next season.

Resource-poor farmers are the focus of many research and development projects in the developing world. Poor adoption of technological innovations from many agricultural research projects has resulted in greater emphasis by funding agencies on farmer adoption and adaptation of technologies. This has led many researchers to operate in a participatory research context, recognising that the inputs and outputs of the biophysical 'production system' of crops, pastures, animals, soil and climate operates together with the 'management system', which is made up of people, values, goals, knowledge, resources, monitoring opportunities and decision making (Keating and McCown 2001). Both the biophysical and the human systems are characterised by complexity, diversity and dynamism (McDougall and Braun 2003).

In the semi-arid regions of southern Africa, smallholder farmers face serious social challenges to maintaining food security, exacerbated by low soil fertility and highly variable rainfall. In these environments, water and nutrient use efficiency are low (Mapfumo and Giller 2001), and technical options for improving soil fertility and production are limited by a range of factors, which often include the poor resource endowment of farmers and their aversion to risk. The approaches used by farmers to manage biophysical risk include utilising the spatial variability of their landscape and on-farm resources (Giller et al. 2004), adapting the timing of operations such as planting and fertilising (Harrington and Grace 1998), diversification, keeping reserves, and a range of other

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* CSIRO Sustainable Ecosystems, 306 Carmody Road, St Lucia, Queensland 4067 Australia.

† Paideia Resources PO Box 462, Nelson, New Zealand.

§ International Crop Research Institute for the Semiarid Tropics, PO Box 776, Bulawayo, Zimbabwe.

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marketing and financial strategies outlined by McConnell and Dillon (1997) and Anderson and Dillon (1992). Simulation models such as the Agricultural Production Systems Simulator (APSIM) are proving useful for capturing the interactions between climatic conditions, soil types and nutrient dynamics in cereal-based farming systems in Africa and Australia. In Africa, the development of the APSIM model has been pursued in collaboration with the International Maize and Wheat Improvement Center (CIMMYT), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and their NARES partners since 1985; a number of publications outline this work (Keating et al. 2000, 2003; Shamudzarira et al. 1999; Shamudzarira and Robertson 2002; Carberry et al. 2002b).

Keating and McCown (2001) used APSIM as an example of how systems simulation models could be used to integrate 'hard' biophysical systems and 'soft' systems approaches to intervention in social management systems. In this context, APSIM can enable scientists, extension officers and farmers to explore the consequences in the farming system (e.g. grain yield, gross margin, soil fertility) of management actions and strategies and of seasonal and long-term climatic conditions. This can lead to a series of 'what if' scenario analysis sessions and information on trade-offs.

Keating and McCown (2001) summarised the evolution of the use of computer-aided farming systems analysis and intervention over the past 40 years. Many modelling efforts have continued because of their 'potential' benefits in aiding agricultural developments, but models have not been widely used to help make land management decisions. These authors criticised many modelling efforts (decision support systems, expert systems) for their lack of a systems perspective, and especially for not engaging the end user. Doyle (1990) found that 'the failure of systems researchers to liaise with farm decision makers has meant that [farmers who have been exposed to modelling] are rightly suspicious of computer generated predictions of optimal resource use'.

That the use of simulation can be relevant and significant to farmers in certain situations is found in the Australian FARMSCAPE experience reported by Carberry et al. (2002a). FARMSCAPE (Farmers, Advisors, Researchers, Monitoring, Simulation, Communication and Performance Evaluation) is a program of participatory research with 'elite' Australian farmers and their advisors, who work with researchers in their own farming operations.

Can this use of simulation with elite farmers in the developed Australian farming environment be relevant to smallholder farmers in southern Africa? While modelling has been extensively applied in Africa to interpret on-farm experiments, assess the climatic risk of technologies, analyse trade-offs and find best-bet options, Dimes (2002) and Carberry et al. (2004) describe a process of engaging smallholder farmers directly with simulation models in semi-arid Zimbabwe. They conclude that, in an action research framework, intervention strategies can successfully incorporate aspects of simulation.

The objective of this paper is to present our experience with a small group of smallholder farmers in Zimbabwe, using the APSIM modelling system and a multidisciplinary group of scientists, as was part of a larger workshop approach called Linking Logics II. The Linking Logics workshop was a joint venture of the Consultative Group on International Agricultural Research (CGIAR) system-wide programs on Participatory Research and Gender Analysis and on Soil, Water and Nutrient Management; the CGIAR research centres; ICRISAT; and CIMMYT. The joint venture workshop explored complementarities between farmer participatory research approaches and computer-based simulation modelling in soil fertility management at the smallholder level. Carberry et al. (2004) describe their experiences at Tsholotsho, Zimbabwe, and this paper outlines a similar exercise with a farming community at Zimuto in Zimbabwe.

Background

During the Linking Logics II workshop, a team containing a modeller/soil scientist, a sociologist, an economist, a participatory methods expert and local NARES extension officers spent two days with smallholder farmers from the village of Zimuto Siding. Most of the 20 farmers who attended the meetings were participants in a farmer research and learning group, which had just been established in the village by ICRISAT with the objective of testing soil management technologies and improving farm management decisions and performance. The objective of the exercise was to explore how APSIM could be used as an educational and decision-making tool. Previous work by ICRISAT in the region gave confidence in the ability to simulate the actual yields of maize achieved by farmers under various management systems (Keating et al. 2000; Shamudzarira et al. 1999). The Zimuto Siding farmers had no prior exposure to simulation modelling, but some of them had been involved in previous on-farm research and development work with ICRISAT and the Department of Agriculture.

The climate at Zimuto Siding (19°51'S, 30°52'E) is subtropical with a unimodal rainfall pattern from October/November to March, when most of the rain falls as sporadic heavy convectional storms, and a long dry spell from April to September. The mean annual rainfall for the Zimuto area (derived from 1961–98 rainfall records at nearby Makoholi Research Station) is 631 mm, with a range of 200 mm to 1200 mm.

The soils are largely derived from granite, with four major categories recognised on the basis of soil moisture-holding capacity, drainage, waterlogging, weed burden, and soil fertility on a typical catena. All these parameters increase downslope from dry topland granitic sands (Lithic Ustirhents/Lithic or Umbric Leptosols) of the upland ridges and valley slopes (Typic Kandiustalfs/Haplic Lixisols), to the hydromorphic Vlei-margin and valley bottom Vlei soils (Typic to Aquic Ustipsamment/Luic Aarenosols and Plinthic Lixsols) adjacent to watercourses. Size and texture of soil particles range from fine/medium-grained sands over medium to coarse-grained sandy loams at the Topland sites, to medium to coarse-grained sandy loams for the vleis and vlei margins. The vleis and vlei margin are significantly more acidic than the topland soils, and this increase in acidity appears to be associated with significant increases in organic carbon in the top 15 cm of a profile (J. Dimes, pers. comm.)

The APSIM model, described most recently in Keating et al. (2003), was used to run the scenarios developed during discussions with farmers. Daily weather records (1961–98) from Makoholi Research Station were used as the climate files for the APSIM runs. In all simulations, the soil described in Table 1 was tilled on 20 October and again at sowing. Farmer tillage practice varies with the availability of draught power, and tillage usually takes place in October or November. The units of measurement used were those chosen by the farmers (bags/acre, where one bag is equivalent to 50 kg of hulled grain maize).

APSIM initialisation

The soil type in Table 1 was used for all simulations, and represents an infertile, sandy profile typical of both the field sites discussed above. The soil type is a shallow sandy soil (1 m deep) with plant available water capacity (PAWC) of 59 mm. The pH is 6.0, increasing to 6.5 at 0.75 m depth. Specific details of the lower limit (LL15), drained upper limit (DUL) and organic carbon for the soil profile are in Table 1. The crop lower limit (LL15) measures the amount of water left in the soil at a suction of 15 bar and represents the lowest limit at which plant roots can remove soil water. The DUL is the amount of water the soil holds after drainage has ceased. The difference between the DUL and the LL15 is the theoretical plant available water held by the soil. Further details of the characterisation methods can be found in Dalgliesh and Foale (1988).

In order to trigger the sowing event (dates of sowing specific to each simulation), rainfall of at least 10 mm over 10 days and a stored PAWC of 50 mm or more was required. A grass weed was also sown at the same time as the maize to mimic the effect of weeds on the maize crop. The weeds were removed by tillage at 20 days after sowing. Density of maize was 5 plants/m^2, and weeds were sown at 4 plants/m^2.

Results of the Zimuto Siding meetings

Five men and 16 women attended the two-day workshop, held in a school building at Zimuto Siding. All the men and nine of the 16 women were heads of households. The farmers collectively identified and ranked the main agricultural problems they faced (Table 2).

Table 1. Lower limit (LL15) and drained upper limit (DUL) expressed as volumetric water percentage, and organic carbon (O.C.) of the soil used for the Zimuto APSIM scenarios.

Depth (cm)	0–15	15–30	30–45	45–60	60–75	75–100
LL15	0.04	0.07	0.13	0.13	0.18	0.22
DUL	0.14	0.15	0.20	0.22	0.22	0.24
O.C. (%)	1.0	0.9	0.7	0.5	0.5	0.4

All farmers at the meeting used a maize-based farming system. Food produced was usually enough to feed the family, but rarely was there a surplus to sell. Only four of the farmers had no cattle, which are important for manure, draught power, milk and meat, and for paying for funerals, weddings etc. Some of those without cattle collected leaf litter from forested areas, or ant-hill soil, to fertilise their fields, but labour constraints (often due to HIV/AIDS-related illness) made this practice less common. All farmers said that labour was limiting.

Table 2. Assessment of the main agricultural problems facing the farmers at Zimuto.

Problem	Rank (out of 10)
Lack of draught power	6
Poor soil fertility — sandy soils	2
Expensive inputs (seeds and fertiliser)	1
Very little available manure for use as a fertiliser	1

The richer farmers sometimes had surplus maize to sell or exchange for labour, and those with draught cattle were able to exchange draught power for labour. The poorer farmers without their own draught power were forced to use the draught animals of other farmers, and late planting was often a consequence. Lack of implements was also noted as a serious problem. Overall, the farmers felt that if a household possessed cattle and implements the other problems were much less important.

Wealth ranking

Through discussion, it quickly became clear that there were important differences in the relative wealth of the farmers present. Through a series of participatory wealth ranking exercises, the farmers categorised households in the area into three generalised resources/wealth groups (Table 3). At no time were farmers asked to say which wealth group they belonged to. Indicators of wealth identified by farmers included livestock ownership (numbers and types), amount of land cultivated, farm implements, draught power, and labour availability.

Poor households. Resource-poor farmers struggle to remain self-sufficient in maize in all but very good seasons with high rainfall. These farmers are forced to supplement their income by selling their labour (herding cattle, planting, weeding and harvesting) and other income-earning enterprises (trapping termites, making clay pots and wares). The average household size was 5–11 people (with 3–9 children). The children usually attended school, but paying fees was cited as

Table 3. Resources available to poor, average and rich farmers at Zimuto Siding, Zimbabwe.

		Poor	Average	Rich
Farmed land (contours[a])	Total	1–2	5–10	>10
	Farmed/season	0.5	1	3–4
Draft power		_	Shared	Owned
Implements	Wheelbarrows	_	_	_
	Scotch carts	_	_	_
	Ploughs/harrows	_	Shared	_
Animals	Cattle	0	2–4	5–40
	Donkeys	0	0	4–6
	Goats	0	1–5	6–10
	Sheep	0	0–1	4–10
	Chickens	0	7–10	15–50
Labour	Family	_	_	_
	Hired	_	_	_
Agricultural inputs	Seed	_[b]	_	_
	Fertiliser	_[b]	_	_
Timeliness	Cultivation	Late	Sometimes late	On time
	Planting	Late	Sometimes late	On time

[a] One contour = ~ 1 acre.
[b] Small quantities can be purchased at a local shop.

an important problem. Most of these families were headed by females (usually a widowed mother or grandmother). If there was a husband at home, he was said to be sick, elderly or irresponsible. Low maize production was caused by factors mostly out of the control of the poorer farmers (a small amount of land available for planting, inadequate or inappropriate inputs, hired draught power that resulted in late ploughing and delayed planting, labour constraints at critical times such as weeding and harvest).

Average households. The farmers in the average category are also forced to supplement their income from the farm by selling labour and other products. Since this group commonly owns poultry and other small animals, the sale of eggs and meat provides important income. The average family size is similar to that of the poor farmers, and about 60% of households are headed by females. Some 'average' families receive remittances from family members who work in cities, either in Zimbabwe or abroad.

Rich households. Rich farmers have more diverse income sources, ranging from primary production (livestock and surplus grain) to off-farm income from outside activities (salaries, remittances, pensions, businesses). Labour for farming activities comes from the extended family or is bought. Rich households are considerably smaller than those of poor and average farmers, with 4–6 people. Some rich farmers are able to purchase Vlei land areas. Commonly, it is the richer farmers that own the majority of the cattle. As a result, some of the communal grazing areas are being fenced to contain their stock and exclude others' stock. Some farmers are buying more cultivable land in order to increase their grain harvests.

Development of APSIM scenarios

Farmers were divided into three groups. Each group was asked to represent one of the wealth groups that had been characterised by the whole group. The six men attending the meeting represented the rich farmer category, and the 16 women were divided randomly into two groups to represent the poor and average farmers. The wealth grouping a farmer belonged to for this exercise did not necessarily reflect their actual wealth, but each was asked to act as if they belonged to that category. This was to avoid embarrassment, and to encourage frank exchange. The groups further discussed farming-related problems and drew resource maps of typical poor, average and rich households (Figure 1). Only the poor and rich scenarios developed are reported here. The average scenario was discarded because of its similarity to Agritex (Department of Agricultural Extension) recommendations for maize production in this district and because it did not seem to reflect an authentic view of local farmers. The farmers considered that a minimum yearly maize requirement of 12 bags (600 kg) per family was the minimum food security threshold.

Figure 1. Resource map drawn by farmers representing the poorest group in Zimuto Siding, Zimbabwe, and illustrating a 'poor' farmer's enterprise with home buildings, compost heap, well, fields, firewood and people (drawn and labelled in English and Shona, the local language).

Scenarios for poor farmers

The major constraints to maize production and food security identified by the poor were related to labour and fertiliser. Since no cash was available to purchase inorganic fertiliser, the poor farmers were forced to collect leaf litter and manure from the communal forested areas as a fertiliser source for maize. This required substantial labour inputs. The farmers wanted to investigate the trade-off between col-

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lecting leaf litter as a low-quality fertiliser and using cash to buy fertiliser. They estimated that in the time it took to make 1 t of low-quality manure from leaf litter, approximately 15 kg N fertiliser/ha could be purchased. The farmers also wanted to know the effect of sowing date (1 or 15 November) on these scenarios. The following scenarios were then simulated before the next day's meeting.

1. Low-quality manure, 1 t/ha, applied 15 October
   - Sowing window starting 1 or 15 November
   - P, N and C in applied manure (dry weight basis) = 0.76%, 0.5% and 25% respectively (C:N = 50).
   - PO_4-P, NH_4-N, NO_3-N in applied manure = 10, 10, 10 ppm
2. 15 kg N/ha fertiliser applied as NH_4NO_3 at sowing
   - No manure applied.
   - Sowing window starting 1 or 15 November.

The application of 15 kg N/ha at sowing (1 November – 15 January) produced higher grain yields than the manure treatment in 13 out of the 18 years (Figure 2). There was little difference in the grain produced between the two sowing times, and only the results for the earlier sowing time are presented in Figure 2. In 1986 and 1998, the application of manure produced slightly higher grain yields, but in 1983 and 1992 there was no grain production because of lack of rainfall, regardless of the treatment. When climatic conditions were good, the treatment receiving 15 kg N/ha produced much more grain than the low-quality manure treatment.

The poor farmers generally have no animals and have to collect manure from the field and combine it with many types of low-quality residues, such as leaf litter. The composition of this manure is usually very poor (C:N ratio = 50), resulting in very little N for the crop and often in the immobilisation of any soil nitrate, further depriving the maize crop. As the purchase of inorganic N fertiliser requires cash, the farmers decided that it was better to work for a richer farmer for cash or fertiliser, rather than spend time collecting manure. Overall, the small application of 15 kg N/ha resulted in food security in 10 of the seasons, compared with only three seasons in which the manure was applied (Table 4).

Scenarios for rich farmers

The farmers representing the rich group were most concerned with the effect of manure and its quality on maize yield. They said that large amounts of manure were available each season because of the large numbers of cattle owned. This group wanted to know whether applying manure as collected from the field or kraal (low-quality C:N ratio = 50) was better than composting this manure to form a higher quality manure (high-quality C:N ratio = 25). They insisted that 5 t manure/ha be applied, because they believed that such a large amount of manure would be available from the many cattle owned by rich farmers. However, based on local extension officer and researcher experience, it is unlikely that so much would be available.

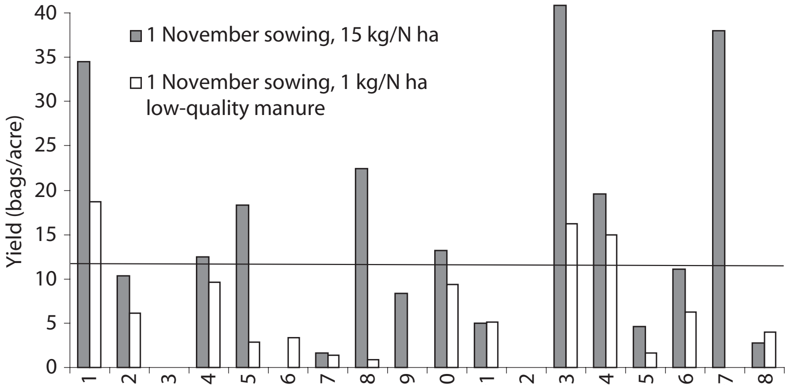

Figure 2. Maize grain yield of the scenario planted in the sowing window from 1 November to 15 January with 15 kgN/ha or 1 t/ha of low-quality manure applied at planting. Note: horizontal line represents minimum yearly maize requirement for a family.

1. Low-quality manure, 5 t/ha, applied 15 October
   - P, N and C in applied manure (dry weight basis) = 0.76%, 0.5% and 25% (C:N = 50)
   - PO_4-P, NH_4-N, NO_3-N in applied manure = 10, 10, 10 ppm
   - Sowing window starting 1 or 15 November.
2. High-quality manure, 5 t/ha, applied 15 October
   - P, N and C in applied manure (dry weight basis) = 0.76%, 1.0% and 20% (C:N = 20)
   - PO_4-P, NH_4-N, NO_3-N in applied manure = 10, 10, 10 ppm
   - Sowing window starting 1 or 15 November.

The higher quality manure generally resulted in higher maize yield. Grain yield exceeded the family threshold of 12 bags/acre in 10 of the seasons where the high-quality manure was used (Table 4). If the low-quality manure was applied annually, there were only three occasions when this threshold was satisfied (Figure 3). Total grain yield over the 18 seasons was slightly higher at the earlier sowing time (1 November) regardless of the manure quality (Table 4), and only the yields for this sowing time are shown in Figure 3.

Soil fertility was positively affected by both treatments. Plant available soil nitrate nitrogen increased from a negligible amount at the beginning of the simulation to 99 kg nitrate nitrogen/ha on the high-quality manure treatments and 20 kg nitrate nitrogen/ha on the low-quality manure. As expected with large yearly applications of manure, the soil organic carbon improved from the starting value of 1% to 1.2%, regardless of manure quality and sowing date.

Table 4. Seasons between 1981 and 1998 that maize production exceeded food security minimum (12 bags/acre), and cumulative grain produced during this period.

Sowing date	Number of years >12 bags/acre		Total grain (1981–1998) (bags/acre)	
	1 Nov–15 Jan	15 Nov–15 Jan	1 Nov–15 Jan	15 Nov–15 Jan
Poor farmers				
1 t/ha low-quality manure	3	2	100	83
15 kg N/ha	8	9	243	251
Rich farmers				
5 t/ha low-quality manure	3	3	161	149
5 t/ha high-quality manure	10	10	266	257

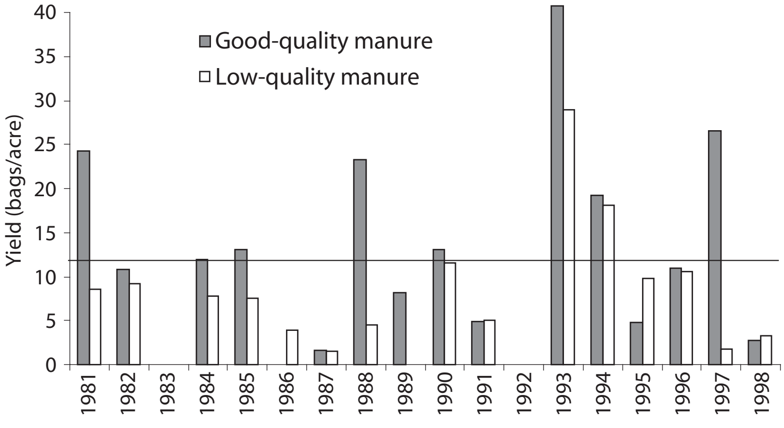

Figure 3. Maize grain yield of the scenario planted in the sowing window 1 November to 15 January, with 5 t/ha of good–quality and low-quality manure applied yearly.

Presentations of the simulations to farmers

Before the farmers were shown the simulation outputs, they were asked to identify the years in which the best and worst climatic seasonal conditions resulted in the highest and lowest maize yields. The farmers indicated that the lowest yields had occurred during 1983 and 1992, which were serious drought years. There was general agreement that 1993 was a good season with high yields. These best and worst years corresponded well with the simulations, and the range of yield levels we presented was within the farmers' own experiences of maize production. We presented the results of the simulations as hand-drawn histograms on flip charts.

There is very little difference in total grain production between the poor farmers' treatment, in which 15 kg N/ha was applied at planting, and the rich farmers' treatment with 5 t/ha of high-quality manure. Obtaining 5 t/ha of manure would require a very large input of labour and, because the collected manure would probably be of low quality, a period of composting to narrow the C:N ratio to 20 would be likely. This would be an additional labour cost. Over the long term, the increasing organic matter content of the soil receiving the manure applications may leave the system more fertile, but this should be weighed against the labour costs.

Several poverty alleviation strategies emerged from the scenario analysis:

- Farmers who were currently selling labour should pay more attention to their own fields to enable timely planting. Some suggested the use of minimum tillage to avoid ploughing delays.
- Farmers representing the poor group suggested that labour should be sold to meet immediate needs and fund small fertiliser purchases.
- All groups suggested that taking production windfalls from good years to invest in assets, such as animals and education, is a good long-term strategy.

Conclusions and Recommendations

The use of simulation modelling in the field with farmers is a relatively new concept, and one the authors believe can facilitate the integration of hard and soft sciences to improve farm management intervention. In Australia, the APSIM model has been used extensively with commercial farmers through the FARMSCAPE projects (Keating and McCown 2001; McCown et al. 2002). However, its use in participative research with smallholder farmers in Africa has been limited. In the experience described in this paper, the APSIM model was able to achieve a number of outcomes that would not have emerged from discussion of field trial results, local knowledge and farmers' experiences alone.

During a series of facilitated discussions, the Zimuto farmers identified labour and resources as key constraints on soil fertility management and the improvement of maize yields (Table 3). Scenarios developed for each of the wealth rankings (poor and rich) and simulated using APSIM helped farmers make decisions about investment in soil fertility to achieve household food security through increased maize harvests. The farmers were then able to discuss ways to more profitably direct their labour efforts. The choice between collecting poor-quality manures and using this labour to buy small amounts of fertiliser could be weighed up in terms of potential maize yields. The fertiliser option was clearly superior.

The value of sharing hard data, such as long-term weather records and simulated grain yields, with farmers as an input to discussions of trade-offs and climatic risk management was also evident. Such data can be effectively presented in tabular or histogram form, depending on the researchers' ability to summarise data concisely. The farmer's memory of the best and worst seasons is a powerful starting point for discussing the implications of such data.

Simulation models such as APSIM are unlikely to be used by farmers directly. An expert user (consultant, scientist, researcher) might use the models in consultation with the farmer as one tool for farm analysis. Using simulation modelling to conduct preliminary investigations of issues that require research could also lead to more-focused field trials.

Whether the exercise at Zimuto resulted in any practice change by the farmers was not further investigated. Other work, reported in Pengelly et al. (2003) and Dimes et al. (2003), demonstrates that on-farm participative experimentation can change practices. The use of simulation tools in on-farm experimentation and participatory research is suggested as a sensible progression of this work.

In using simulation models in the field, the authors learnt the following lessons:

- Good preparation is essential, but there is also a need to be flexible and adapt the process on the spot.
- Target options to different groups (for example, farmers at different wealth levels).

- Keep the simulations simple enough to be run quickly by the modeller and understood by the farmers.
- Where long-term climatic records are available, the element of risk can be brought into discussions of profitability and production.
- Establishing credibility in the simulation output (in the eyes both of the farmers and of the researchers) requires some field validation. Even the least competent models can represent nil yields in dry years, so it is important to ensure that the simulations represent reasonable and sensible responses to changes in inputs.

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