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Potential and prospects of legume-based pastures in the tropics

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Abstract

This paper consists of two parts. First the N fixation, C storage and animal production of legume-based pastures are reviewed; then the adoption of pasture legume technology is discussed in terms of technical, biological and socio-economic constraints. Different forage production systems and their place in livestock production systems are described. The prospects for legume use in Australia, south-east Asia, Africa south of the Sahara and Latin America are discussed in relation to forage and animal production systems.

Tropical legumes fix as much N as temperate ones. Measured amounts of N added to pasture systems range from 30–290 kg/ha/yr for herbaceous legumes in mixtures with grasses to 575 kg/ha/yr for a pure stand of *Leucaena leucocephala*. Soil N increments under tropical legumes were up to 140 kg/ha/yr in Australia and 128 kg/ha/yr in Costa Rica.

Legume-based tropical pastures store more C than pure grass or native pastures. In Colombia, an improved grass-legume mixture had accumulated 237 t/ha C to a depth of 1 m over 6 years compared with 186 t by a grass-only pasture.

The highest cattle liveweight gain recorded from an irrigated pure stand of *L. leucocephala* was 2000 kg/ha/yr in the Kimberleys, Western Australia. On herbaceous legume-grass pastures the highest liveweight gain measured was 937 kg/ha/yr on *Brachiaria brizantha —Arachis pintoi* in the humid tropics of Costa Rica. Maximum milk production on tropical grass-legume pastures without concentrates is around 10–12 kg/cow/d. However, due to high carrying capacities, milk yields per ha of about 8000 kg/ha/yr have been recorded in north Queensland and in Malaysia.

There is reasonable adoption of legume-based technology in tropical Australia and parts of south-east Asia and Latin America. However, many countries, particularly in Africa, have such a low development status that problems related to land tenure, infrastructure and social justice need to be solved first.

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Introduction

Tropical pasture legumes came into general use only after 1960. Before then, there were isolated trials with leguminous cover crops e.g. *Centrosema pubescens, Pueraria phaseoloides, Lablab purpureus, Calopogonium mucunoides, Stylosanthes guianensis, Neonotonia wightii* and *Indigofera* spp. in Australia (Williams 1983; Eyles and Cameron 1985) and with a large range of species in Hawaii (Hosaka and Ripperton 1944). In addition, in northern Australia, there were extensive areas of *S. humilis*, an accidental introduction from Brazil nearly one hundred years ago (Humphreys 1967).

Since that time, a substantial research effort by CSIRO, QDPI and NTDPIF in Australia has increased the range of legumes which can be grown successfully and has developed management systems to maintain them in pastures. Dr T.H. Stobbs played a very important role in this work, particularly in relation to the pasture-animal interface (e.g. Stobbs 1975, 1976; Chacon and Stobbs 1976; Chacon *et al.* 1976)

This Stobbs memorial lecture reviews legume-based tropical pasture technology and its adoption in northern Australia, south-east Asia, Africa south of the Sahara and Latin America.

The potential for tropical pasture legumes

Nitrogen fixation

Tropical pasture legumes are as effective in N fixation as temperate legumes (Vallis 1985), the amount of N a legume fixes being largely a function of its dry matter production, irrespective of the species. This was shown in field studies by Jones *et al.* (1967) and Vallis and Gardener (1985), and can be calculated from data from a sand culture experiment by Henzell (1962). However, total amounts of biologically fixed N added to tropical pasture systems are moderate. Estimates of N fixation by tropical pasture legumes have been 30 and 170 kg/ha/yr for average and 290 kg/ha for good legume growth in tropical and subtropical Australia (Henzell 1968); 30–80 kg/ha/yr for *S. hamata* in the dry tropics of Queensland (Vallis and Gardener 1984); and 67–117 kg/ha/yr for *Stylosanthes* spp. in the cerrados of Brazil (Cadisch *et al.* 1993). The highest levels of N production in tropical legume systems have been recorded for *Leucaena leucocephala* in Queensland. Hutton and Bonner (1960) measured 576 kg/ha N in leaves and twigs during one growing season and Ferraris (1979) 480 kg/ha/yr in total top growth, with 390 kg/ha/yr in leaf growth.

In a review of the literature, Vallis (1985) reported additions to soil N under tropical legumes up to 140 kg/ha/yr in Australia. In the humid tropics of Costa Rica, Ibrahim (1994) measured annual additions to soil N of 128 kg/ha by *Arachis pintoi* grown with *Brachiaria brizantha* under grazing over 3 years. Tropical legume-based pastures obviously enhance soil fertility.

The transfer of N from the legume to associated grasses takes place from: exudation of N from the legume roots; decaying nodules; and mineralisation of organic matter, arising from dead plant material; and from faeces and urine of animals grazing the pasture. Mineralisation of organic N is a function of the N concentration of the organic matter and its degradability, which in turn depends on the leaf:stem ratio and the tannin content. The exuded or mineralised N is immobilised by microbes and becomes available to associated grasses only after degradation of the microbial biomass.

Carbon storage

Legume-based pastures also play a role in the emission and storage of greenhouse gases. Three of the greenhouse gases [CO_2, CH_4 and nitrous oxides (mainly N_2O)] have relevance to grasslands. Grasslands play a beneficial net role in the storage of carbon (C), but, when grazed, they have a net emission of CH_4. Their role in relation to the release of N_2O may be important, but this is as yet not clearly quantifiable and depends on the level of N in the system. Most information is available about C storage, which will be dealt with briefly.

Forests and grasslands are important C stores, with probably little difference between them (Goudriaan 1990; Minami *et al.* 1993). Most of the C stored by grasslands can be attributed to soil organic matter. The total amount of C released by burning grasslands is of the order of 4–7 Gt/yr, but this is previously stored C and compensated for by regrowth. Furthermore, if the material was not destroyed by fire, most of it would decompose within a year, releasing the same amount of C to the atmosphere (Hall and Scurlock 1991; Minami *et al.* 1993).

Large areas of rain forest have been cleared in central and South America and south-east Asia. This land is used for plantation agriculture, arable cropping and grasslands. Clearing of rain forest destroys the above-ground C accumulated in the standing timber and, when the land is used for arable cropping, there is a greater net loss of C from the soil than when the land is used for pastures (Detwiler 1986; Veldkamp 1993). However, the soil C dynamics under pasture depend on the type of grassland vegetation.

In the llanos of Colombia, Fisher *et al.* (1994) measured C storage of 237 t/ha under a 6-year-old *A. gayanus-S. capitata* pasture compared with 186 t/ha under unimproved savanna with about half of it in the 40–100 cm deep soil layer. At another site, the soil under unimproved savanna held 197 t/ha C, that under *B. humidicola* alone 223 t/ha and under *B. humidicola-A. pintoi* 268 t/ha. In Queensland, Henzell *et al.* (1966) measured C accumulation of about 5 t/ha over 6 years in the top 30 cm under a *Desmodium uncinatum* pasture on a sandy soil of initially low fertility, but fertilised at different rates of P and K and micro-elements. P fertilisation had a large positive effect on soil C accumulation. Ibrahim (1994) measured 47 t/ha C in the top 10 cm of soil under grazed *B. brizantha – A. pintoi* pastures, which had been established 3 years previously, in the Atlantic Zone of Costa Rica. This amount of soil C was comparable with that found under rain forest. In Peru, Ayarza *et al.* (1987) also measured C accumulation under a grazed *B. decumbens-D. ovalifolium* pasture.

Animal production

The contribution of legumes to animal production from tropical pastures has been extensively documented in Australia and to a lesser extent in Latin America, but there is a dearth of published records from south-east Asia and particularly from Africa. The highest recorded liveweight gains of cattle on tropical legumes were 2000 kg/ha/yr on a pure stand of irrigated *L. leucocephala* in the Ord region of Western Australia (Pratchett and Petty 1993). On herbaceous legume-grass pastures, the highest liveweight gain recorded was 937 kg/ha/yr on *B. brizantha – A. pintoi* on fertile soil, grazed at 6 an/ha, and 534 kg/ha/yr at 3 an/ha in the humid Atlantic Zone of Costa Rica (Hernandez *et al.* 1995). In north-east Queensland with comparable annual rainfall, but a distinct dry season, grass-legume pastures grazed at 3 an/ha produced 550 kg LWG/ha/yr (Teitzel *et al.* 1991).

In areas with poorer soils and drier climates, large increases in animal production can be obtained by sowing legumes, e.g. *Stylosanthes* spp., into native pasture, or by replacing the existing pasture with grass-legume mixtures. Shaw and 't Mannetje (1970) reported a 4-fold increase in liveweight gains on black speargrass (*Heteropogon contortus*) pastures in central coastal Queensland when oversown with *S. humilis* and fertilised with superphosphate. Both the introduction of *S. humilis* and the use of fertiliser increased liveweight gain per animal and allowed increased stocking rates. The biggest responses were obtained when both treatments were combined. Oversowing of *S. hamata* cv. Verano in speargrass pastures in the dry tropics of north Queensland and fertilising with superphosphate, allowed carrying capacity to be increased 10-fold and the fattening period of cattle to be halved (Edye and Gillard 1985).

In a 10-year experiment at the Narayen Research Station in south-east Queensland, breeding cows grazing unimproved native speargrass pasture at a stocking rate of 0.17 cows/ha produced 155 kg of calf per cow mated and 26 kg of calf per ha. This compared with means of 199 kg of calf per cow mated and 118 kg of calf per ha on a pasture of *Panicum maximum* var. *trichoglume*, *Chloris gayana* and *Macroptilium atropurpureum* cv. Siratro with superphosphate at stocking rates of 0.50 and 0.68 cows/ha (the differences between stocking rates were either non-significant or inconclusive) (Coates and 't Mannetje 1990).

In a 4-year experiment in north Queensland, Holroyd *et al.* (1983) compared the reproductive performance of beef cows, and the growth rate and weaning weight of their calves, on unimproved native speargrass pastures grazed at 0.25 cows/ha with those on native pasture oversown with *S. humilis*, fertilised with superphosphate and grazed at 0.5 cows/ha. Higher conception rates and earlier calving were recorded on *S. humilis* in one year only, but calf growth rates and weaning weights were significantly higher on *S. humilis* (means over 4 years of 0.84 vs 0.74 kg/d and 184 vs 166 kg, respectively). The fertilised legume-based pasture produced 2.4 times more cow and calf liveweight/ha (383 vs 160 kg/ha/yr) over the 4 years than native pasture.

The benefits of legume-based pastures have also been demonstrated in south America. CIAT (1989) measured 660 and 803 kg LWG/ha/yr on pastures of *Andropogon gayanus-C. macrocarpum* and *B. dictyoneura-D. ovalifolium*, respectively, over a period of 5 years.

On legume-based (*S. guianensis, M. atropurpureum* cv. Siratro, *D. intortum*) ley pastures in Malawi, Thomas and Addy (1977) obtained little response in animal production from legumes during the wet season. However, in the dry season, the animals on *C. gayana* plus legumes gained an average of 26 kg, the same as animals supplemented with cottonseed cake, while those on *C. gayana* alone lost 1 kg.

The effect of legumes in pastures on beef production in wet-dry climates can be attributed to higher carrying capacity, longer period of weight gain into the dry season and reduced losses of liveweight during the dry season ('t Mannetje and Jones 1990). In the humid tropics, with reduced seasonal effects on pasture production, the main effect of legumes on animal production is improvement of feed quality, as grasses have high growth rates, combined with low digestibility and low crude protein concentrations (Wilson 1994).

There are few papers on the effect of tropical pasture legumes on milk production. Stobbs (1971a) and Stobbs and Thompson (1975) reviewed experimental results from around the world and concluded that milk production of Jersey cows on tropical grasses did not exceed 10–12 kg/d. Pure stands of *M. atropurpureum* cv. Siratro or *D. intortum* yielded 7.7 kg/cow/d compared with 9 kg/cow on N-fertilised *Digitaria decumbens* (Stobbs 1971b). However, Hamilton *et al.* (1970) reported a milk yield per cow of about 12 kg/d on *L. purpureus* compared with 9 kg/d on *C. gayana* and *Setaria anceps*. The milk yields on *L. purpureus* were also maintained at a higher level for longer than those on the grasses. Dale and Holder (1968) obtained a mean of 18 kg/d milk production per cow from *Medicago sativa* hay and concentrates compared with 8 kg/d on stall-fed *Pennisetum clandestinum* and *Neonotonia wightii*. Stobbs (1976) recorded similar milk yield of Jersey cows (16 kg/cow/d) during spring from *Trifolium semipilosum* and *T. repens* grown with *Paspalum dilatatum*.

L. leucocephala has a positive effect on milk (and beef) production when fed as a supplement to cows grazing N-fertilised grass. Jones (1994) reviewed results from Latin America and Samford, Queensland, concluding that the average increase in milk production attributable to *L. leucocephala* was 14% (range 2–33%). There are contrasting reports about the removal by pasteurisation of a taint in milk produced by cows eating *L. leucocephala*.

In Latin America, Lascano and Avila (1991; 1993) reported milk production from grass-legume mixtures 13–20% higher than from grass alone. Animals with a higher genetic potential for milk production showed 18% higher milk production as a result of legume inclusion in the pasture, compared with 10% by crossbred cows of lower potential.

Milk production per cow on legume-based tropical pastures is generally lower than on legume-based pastures in temperate climates, but not always. For example, Cowan *et al.* (1975) obtained a milk yield of 8300 kg/ha/yr on a pasture of *P. maximum* var. *trichoglume* and *N. wightii* on the Atherton Tableland, north Queensland. In Malaysia, Hassan *et al.* (1989) reported that Sahiwal X Friesian cows on *B. decumbens* and *L. leucocephala* produced 7760 kg/ha/yr of milk.

Hamilton *et al.* (1970) concluded that the low milk production per cow from tropical grasses and legumes was primarily due to low intakes of digestible nutrients, associated with the low digestibility of the herbage.

Adoption of new technology

Legume species and cultivars have been developed for all soil types and all except the driest climates (Oram 1990; 't Mannetje and Jones 1992; Cameron *et al.* 1993). The required management for sustainable pastures is also reasonably well understood.

The 'green revolution' increased food crop yields in south-east Asia and parts of Latin America. Although the tropical pasture revolution of the 1960s (Henzell and 't Mannetje 1980) increased animal production in Australia ('t Mannetje 1984; Wildin *et al.* 1986), it had little impact outside Australia. This is due to the lack of adoption of new cultivars and inappropriate pasture management. However, there are other significant problems in many developing countries in addition to the technical, biological and socio-economic constraints referred to below. Policy makers and research leaders concerned with livestock production often concentrate their efforts on animal health and genetics, and ignore animal nutrition, particularly from forages (Pamo 1993).

Technical constraints

Intensive, large-scale forage cultivar development occurs in only a few centres e.g. in Queensland (CSIRO and Department of Primary Industries), Colombia (CIAT) and Brazil (EMBRAPA). In several other countries, there is active local cultivar development. These programs require large inputs of scientific personnel, laboratory, glasshouse and field experiment facilities (see Jones *et al.* 1984), limiting the involvement of most developing countries. These countries must introduce existing cultivars or germplasm from the large centres, for limited evaluation.

The selection of a cultivar does not ensure its adoption. Seed or planting material must be produced and an infrastructure is needed for quality control and distribution. These are lacking in most developing countries (Griffiths 1993).

Biological constraints

In the 1960s, Queensland was the main region for cultivar development, and seed was transferred to research institutes in other countries (Jones *et al.* 1984), as well as for large-scale plantings, particularly to South America. This often led to failure in the importing countries because the cultivars were poorly adapted to local soil conditions or were eliminated by pests and diseases not present in Queensland.

Many early cultivars in Queensland failed because they could not tolerate the variable grazing pressures that occur on farms. Farmers often overgraze pastures for reasons beyond their control (e.g. droughts) and do not use fertilisers because of cash flow problems.

Another reason for failure has been the emergence of pests or diseases not present at cultivar release, e.g. anthracnose (*Colletotrichum gloeosporioides*) on *Stylosanthes* spp; rust (*Uromyces appendiculatus*) on *Macroptilium atropurpureum* cv. Siratro; and psyllid (*Heteropsylla cubana*) on *Leucaena leucocephala.*

Pasture research in tropical countries currently aims to develop legume cultivars which are: tolerant of the prevailing pests and diseases; able to cope with low soil fertility; and more 'farmer proof', *i.e.* resilient to improper management for a period of time. Cultivars of *Stylosanthes* spp. are tolerant of low soil P and pH, and cultivars of *Arachis pintoi, Vigna parkeri, Chamaecrista rotundifolia* and *Desmodium ovalifolium* can tolerate heavy grazing (Cameron *et al.* 1989).

Socio-economic conditions for pasture improvement

't Mannetje and Jones (1992) and 't Mannetje (1993) listed socio-economic factors as the main causes of the lack of adoption of the new pasture technology, despite the fact that there are technologies which suit a range of input levels.

The adoption of pasture improvement in existing farm systems is governed by the following conditions ('t Mannetje 1993):

- the demand for improved animal production;
- the value and marketability of animal products;
- the motivation of producers;
- land tenure; and
- the availability of resources.

Demand for improved animal production. Animal proteins play an important role in the human diet, and in most developing countries, there is a demand for more and better food. Demand for food is increasing through increased human population, and increasing purchasing power in many tropical countries is leading to increased demand for food of animal origin.

Although 64% of the world's cattle, 100% of the buffaloes, 51% of the sheep and 94% of the goats are kept in tropical countries, production of meat and milk in the tropics is only 36 and 18%, respectively, of total world production (FAO 1991). This is due to inadequate nutrition, health care and management of the animals. In order to increase animal production for meat, milk, draft purposes and manure, the feed supply must be improved, *i.e.* forage production and quality need to be increased.

While achieving this aim, the need to conserve natural resources, particularly the land and its vegetation, must be kept in mind. Increasing food production in developing countries is usually achieved by bringing new land into production. Rangelands in Africa are converted to crop lands and rain forests in Latin America and Asia are cleared for cropping and animal production. Therefore, grassland research and development should aim at sustainable intensification of production on already cleared land, with higher yields per animal and per hectare, without polluting the environment or degrading the land. Legumes can play an important role in increasing production and soil protection of degraded pastures.

In Australia, key markets in south-east Asia and Japan require younger, more tender beef, which demands faster growing animals and therefore better pastures.

Value and marketability of animal products. Attractive economic returns, comparing favourably with ranching, can be achieved by traditional livestock husbandry in developing countries, producing saleable products, draft power and manure (Scoones 1992). However, nomadic herdsmen and small farmers in Africa, south-east Asia and Latin America are usually subsistence producers with only incidental access to markets and often a total lack of product handling and processing facilities, as described for Namibia by Sartorius von Bach and Van Zyl (1993). Animals have a value for investment, but this can be counterproductive. As animal numbers are more important than their production, stocking rates of rangelands, particularly near urban centres, often exceed carrying capacity, thus reducing productivity. Animal products other than meat and milk, although valuable, often have no market value at all, e.g. draft power, dung. Therefore, subsistence producers are unlikely to have finance for pasture improvement, even if other restrictions such as land tenure, did not apply.

Large-scale producers must market their outputs. Prices on local, national and international markets are determined by supply and demand. Local demand depends on consumers' incomes. In most developing countries, prices for animal products tend to be low and there is little incentive to invest in pasture improvement.

Motivation of producers. The lack of adoption of new pasture technologies by pastoralists is a function of skills and attitudes. Crop growers regularly cultivate the soil and either purchase seed or retain part of the harvest to plant the next crop. A new crop cultivar is therefore easily introduced. There is an infrastructure for seed production and distribution. However, managers of traditional and extensive pastoral systems do not cultivate the soil; they accept the existing pasture as a permanent resource. They neither possess nor have access to cultivating equipment, and in developing countries, there are usually no trained extension officers to assist them in such a revolutionary exercise.

Pasture improvement requires a complete change in attitude and awareness of the potential yield improvement through using more productive species and cultivars, or the management needed for sustainable forage production. Farmer involvement in research and extension (the participatory approach) would be the most effective and efficient way to achieve this attitude change. Adult learning techniques should be employed with the farmer considered as an adult learner and the extension officer as a facilitator in the learning process (Jiggins 1993).

Land tenure. Land tenure can be a severe limiting factor, as producers are unlikely to invest money into lasting pasture improvement if they have no guarantee of continued use of the land. Most grazing lands in Africa and many in India and China are subject to common grazing by privately owned herds. This system works well with low population pressures and therefore low animal numbers in a region. However, as human and animal populations increase, grazing pressure on the land increases with no controls, and land condition deteriorates. Unfortunately, non-farmers living in urban areas invest in animals and employ herdsmen to graze them on the common rangelands. This leads to severe overgrazing with low production and accelerated erosion. When land is owned or leased by the family who uses it, the stocking rates are more likely to match the carrying capacity and be sustainable.

Availability of resources and knowledge. A serious impediment to pasture improvement is the lack of finance and knowledge of new technologies by both farmers and the extension service. Firstly, extension workers need training in forage production and utilisation and in extension methods. Then, an extension framework needs to be developed as outlined by Jiggins (1993).

An important consideration is the cost of pasture improvement and the expected return on investment. Costs are high and the financial situation of the farm determines how attractive it is to apply the technology. Although a high return may be achieved in the longer term, cash flow is negative in the short term (Wickstced 1986). Some farmers do not have sufficient cash reserves and credit facilities are not always available. There is also an element of risk, e.g. the improvement may fail or product prices may decrease.

It is necessary to foster applied local research and extension on pasture improvement. However, national research and extension facilities in many developing countries, particularly in sub-Saharan Africa and Latin America, are inadequately financed and staffed. In addition, the International Research Centres, ILCA (now ILRID) and CIAT, receive reduced financial support, and are reducing research efforts. In a review of research outputs in eastern and southern Africa, Jutzi and Tothill (1993) showed that: research was mostly concerned with improvement of feed supply and rangeland improvement for cattle in ecologically favoured areas and for large-scale livestock production; research outputs were not discussed in terms of locally prevailing production systems; and very little of the knowledge gained had been generated on-farm.

Seed production and trade should be encouraged and policy makers and bankers should be educated on the possibilities and benefits of improved forage production. At least, grassland scientists in developing countries are now well aware of the need for forage seed production. A system of subsidies to encourage the development of an infrastructure for pasture improvement and to assist farmers in the adoption of proven technology in developing countries could contribute immensely to increased food production and more sustainable land management. Alhassan and Barnes (1993) advocated loans in kind (materials, seeds, fertilisers) for Ghana. The success of such policies for smallholders has been shown in Thailand with seed production (Manidool 1990; Phaikaew *et al.* 1993) and in Vanuatu with beef production (Macfarlane *et al.* 1993).

The place of forage production systems in livestock production systems

Forage production systems

Perkins *et al.* (1986) distinguished **extensive** forage production systems (no managerial inputs such as irrigation or fertiliser with minimal controlled grazing); **semi-intensive** forage production systems (inputs such as fertiliser, weeding and irrigation primarily applied to the main cash crop, which also benefit associated forage); and **intensive** forage production systems (inputs applied for the sole purpose of forage production). Based on this classification for Indonesia, 't Mannetje and Jones (1992) recognised 5 forage production systems, each with its typical level of input:

- extensive permanent grassland: (a) privately owned or leased land; and (b) communally grazed and cut land and roadsides;
- semi-intensive permanent forages: (a) understorey of tree crop plantations; (b) forage from shade trees in plantations; (c) paddy field bunds and edges of crop fields; and (d) perennial forage in alley cropping;
- semi-intensive annual forages: (a) forage crops sown after harvest of food crops; and (b) crop residues;
- intensive permanent forages: (a) improved grasslands; and (b) protein banks; and
- intensive short-term forages: (a) fodder crops; and (b) fodder crops on special areas.

Hay or silage is not widely used in developing countries and it is not likely to be so in the future. However, conservation is used successfully in some situations. For example, some commercial dairy farmers are using silage of elephant grass (*P. purpureum*) and some smallholders are using dried grass for feed in the dry season (Ranjhan 1986).

Livestock production systems

Livestock production systems can be grouped conveniently into 3 categories: pastoralism; livestock-crop systems; and crop-livestock systems ('t Mannetje and Jones 1992).

Pastoralism can be divided into 3 main subgroups: nomadism; ranching; and intensive dairying. Nomadism is widely practised in semiarid and arid areas of Africa, India and China. Ranching is used in northern Australia, South America and southern and east Africa, but is of very little importance in south-east Asia and west Africa. Commercial dairying is generally restricted to areas with good access to large urban centres.

In the livestock-crop production system there is some dependence on crop residues for feed, but livestock are more important in the farming system than cropping. This system prevails in many parts of Africa.

The crop-livestock system is typical of southeast Asia and parts of Africa, where the crop can be an annual such as rice or a long-lived tree such as coconut or oil palm. The food or cash crop is the major and essential part of the farming system.

How the different forage production systems mentioned above fit into these different livestock production systems is summarised in Table 1. This table illustrates that there are potentially more ways of incorporating forages from different sources into dairying and crop-livestock systems than into systems such as nomadism or ranching.

Prospects for tropical pasture legumes

In view of the requirements for the adoption of pasture improvement technology outlined in the previous part of this paper, it is of interest to compare the actual with the expected situation in the main tropical regions of the world.

Table 1. Forage production systems used in different livestock production systems.

	Livestock System				
Forage production system	NOMADISM	RANCHING	DAIRYING	LIV. CROP	CROP. LIV
Extensive permanent grassland					
privately used	—	+	+	—	—
communally used	+	—	—	+	+
Semi-intensive permanent forages					
understorey tree crops	—	—	+	—	+
forage from shade trees	—	—	+	—	+
forage in alley cropping	—	—	+	—	+
edges of crop fields	+	—	+	+	+
Semi-intensive annual forages					
after harvest crop	—	—	—	+	+
crop residues	+	—	+	+	+
Intensive permanent forages					
improved grasslands	—	+	+	—	—
protein banks	—	+	+	+	+
Intensive short-term forages					
fodder crops	—	+	+	+	+

Tropical Australia

The main animal production system is pastoralism with a predominance of ranching for beef and sheep with limited areas of dairy production. The forage production systems available are extensive permanent grasslands, improved grasslands, protein banks and fodder crops. Adoption of improved pastures is predominantly determined by the market for beef, the main products being: manufacturing beef exported to the USA; store cattle for feedlots; live cattle exported to south-east Asia; and high quality pasture-fed beef for the Asian and domestic markets.

The extensive permanent grasslands are the savannas and pure (treeless) native grasslands. In areas with more than about 650 mm annual rainfall, native grasslands are being oversown with *S. scabra* and *S. hamata* cv. Verano (McIvor *et al.* 1983; Edye and Gillard 1985; Middleton *et al.* 1993). *L. leucocephala* is used increasingly in protein banks to supplement cattle, and also as the main feed supply for finishing cattle (Clem *et al.* 1993; Pratchett and Petty 1993). In addition, *M. atropurpureum* ('t Mannetje and Jones 1990), especially the new rust-tolerant cultivar Aztec (Bray 1988), *D. intortum* cv. Greenleaf (Lowe and Hamilton 1985) and *Lotononis bainesii* (Cameron *et al.* 1989) are used in subtropical areas for beef and dairy production, whereas *C. rotundifolia* cv. Wynn (Cook 1988; Partridge and Wright 1992) and *Aeschynomene americana* cv. Glenn (Bishop *et al.* 1985) are grown in dry regions with poor soils and wet to waterlogged soils, respectively. There are also some 100 000 ha of ponded pastures consisting primarily of *B. mutica, Echinochloa polystachya* and *Hymenachne amplexicaulis* (Wildin 1993). Although N fertiliser has given good responses in experiments with ponded pastures, very little is applied. The question is, therefore, whether a regular N supply might not be necessary in the long run. The use of *Sesbania rostrata*, which grows in inundated areas, might be considered (Torres *et al.* 1995).

In subtropical regions of Australia, temperate legumes (*Trifolium repens, Medicago sativa*) are used in dairy pastures (Moss and Lowe 1993).

In tropical Australia, there is a good infrastructure; seed production and distribution are well organised; and there is a good extension service supported by strategic and applied research.

The prospects for legume use are favourable, but there is a danger that the combination of *Bos indicus* X *B. taurus* cattle and urea-molasses supplements will result in overgrazing of native pastures. The crossbred cattle survive under harsh conditions, whilst the legume and the supplement allow high dry matter utilisation, thus putting the native grasses under high grazing pressure. The heavy grazing pressures, used to encourage a high proportion of *Stylosanthes* in the pastures, have resulted in the demise of perennial grasses and weed invasion (Miller and Stockwell 1991).

Latin America

As in tropical Australia, the main animal production system is ranching for beef production with some dairying. Both domestic and export markets are important. Exports are limited, however, by the presence of foot-and-mouth disease in many countries south of the Panama Canal. The forage production systems are extensive permanent grasslands, improved grasslands, protein banks and fodder crops.

Work at CIAT and national research organisations has generated a good body of knowledge on pasture improvement and a range of grass and legume cultivars for the various agro-ecosystems in Latin America (Pizarro *et al.* 1985; Toledo and Formoso 1993). Successful legumes are: *S. capitata, S. macrocephala*, and *S. guianensis* (var. *pauciflora*) for the tropical savanna zone; and *Centrosema acutifolium, D. ovalifolium* and *S. guianensis* for the humid regions, whilst temperate legumes are used for subtropical areas (Toledo and Formoso 1993).

Seed production, processing and distribution involving smallholder farmers are being developed in several countries in Latin America (Ferguson *et al.* 1985, 1993; Ferguson and Sauma 1993; Silvester-Bradly and Ferguson 1993).

The main socio-economic constraints to pasture development are political instability, lack of social equity and poverty (Toledo and Formoso 1993). There is a reasonable infrastructure and every country has a research and extension capability. Grasslands and animal production in much of Latin America are blamed for most deforestation. The focus is on bringing new land into production rather than intensifying production per hectare. Increased animal production from legume-based pastures would eliminate the need for further deforestation. However, there are political and fiscal reasons why deforestation in several Latin American countries is not being curtailed.

South-east Asia

The crop-livestock system with food and cash crops is the main livestock production system in south-east Asia. Many farmers own one or two draft animals (cattle or buffaloes) and one or two female animals for breeding. Much animal production has no direct marketing value (e.g. draft power) and many farmers have no land available for forage production. Roadsides and grazing reserves are the main permanent extensive forage production systems, with rice field bunds and crop field edges as important semi-intensive forage resources.

However, good opportunities for improving forage production have arisen from extensive research in Thailand, Malaysia, Indonesia and The Philippines. *S. hamata* cv. Verano and *S. humilis* are used widely in the dry tropics of Thailand (Topark-Ngarm 1985); *L. leucocephala* is used in many countries (Gutteridge and Shelton 1994); and in Bali, Indonesia, the 'Three Strata Farming System' is being adopted (Nitis *et al.* 1990). 't Mannetje and Jones (1992) have pointed out that the greatest potential for improvement lies in the use of shrub or tree legumes, backyard or homelot forage production, making better use of bunds between rice paddies, forage under plantation crops and use of annual legumes with or after food crops. Recent progress in improving animal production by shrub legumes or by forages under plantation crops has been reported in publications edited by Devendra (1990), Shelton and Stür (1991) and Gutteridge and Shelton (1994). A small but increasingly important system with the potential for improvement is that involved in the supply of milk to urban areas (Hassan *et al.* 1989).

Seed production is also well developed in parts of Thailand (Kowithayakorn and Phaikaew 1993; Phaikaew *et al.* 1993).

Major socio-economic constraints are the poverty of small farmers and lack of knowledge on how to improve forage production. Extension services need upgrading and staff require training. In particular, there are major problems in improving communal grazing reserves (Raghavan 1990). Governments can also encourage improvements, as in the case of woody legumes in Indonesia (Rangkuti *et al.* 1990) and The Philippines (Trung 1989) and through the development of "mini-farms" in Malaysia (Chin 1989). Effective and sustained educational and 'follow-up' schemes to support farmers adopting any improved practice are important (Nitis *et al.* 1990). Although the constraints imposed by socio-economic factors must be recognised, they are not impossible to overcome (Perkins *et al.* 1986).

Africa south of the Sahara

The livestock production systems are pastoralism (nomadism, ranching), livestock-crop systems (transhumance) and crop-livestock systems. The forage production systems are permanent extensive grasslands, usually in communal use, and private lands mostly used for cropping. The first call on private lands will always be for food crops.

Forty percent of Africa is infested with tsetse fly, which causes trypanosomiasis, thus preventing the large-scale development of livestock production. This concerns the area of Africa with the best rainfall conditions. Eradication of the tsetse fly would open up land for increased animal production, but would expose the area to possible degradation.

The Sahelo-Sudanian region, immediately south of the Sahara, has experienced a large human and animal population increase, putting a great deal of pressure on the rangelands, which are over-exploited by grazing, fuel collection and, increasingly, arable cropping (Leloup 1994). The frontier of cultivation is moving from the better watered south to the drier north. As fertiliser use is extremely limited, soil fertility is being degraded in much of Africa, because arable cropping systems remove more nutrients than are returned (Smaling 1993; Stoorvogel *et al.* 1993). This unsustainable land use is advancing the frontier of land degradation from north to south.

Land tenure reform in developing countries is a prerequisite to sustainable development (Motsamai 1993). However, this is not an easy matter as several examples of land use reform efforts in Africa have shown. Merafe (1990) reported how the Government of Botswana introduced the Tribal Grazing Land Policy in 1975. Major land reform was introduced, which prescribed that tribal land be divided into commercial, communal and reserved areas. However, the scheme has not lived up to expectations due to lack of appropriate management, combined with drought.

Therefore, in much of Africa, forage production can be improved only on private lands. It should be possible to integrate food cropping with forage production in the form of alley cropping and to use forage crops in rotation with food crops (Sumberg and Atta-Krah 1988; Okigbo and Sabiiti 1993; Reynolds and Jabbar 1994). Saleem *et al.* (1985) showed the benefits of integrating *S. guianensis* with crops in various ways in terms of soil fertility, crop yields and better quality feed for animals on fallow land.

In the humid zone of Nigeria, fodder banks are receiving a great deal of attention (Saleem and Suleiman 1986; Peters *et al.* 1994a, 1994b). Although the use of fodder trees in Nigeria is technically quite feasible, the practical application on farms still meets with difficulties. Francis and Attah-Krah (1989) reported about farmer-managed trials with *L. leucocephala* and *Gliricidia sepium*, either interplanted with crops as alleys or planted in pure stands. Although establishment was generally successful, the rate of adoption was poor. The authors blamed sociological, institutional and edaphic factors as the reasons for the limited success. These included poor soil fertility, the incompatibility of established cropping patterns and rotation practices with the planting of trees on farms, the division of labour and organisation of decision making within the household. Many livestock improvement schemes in Africa have failed because of a lack of knowledge and understanding of the complexity of African pastoral production systems (De Leeuw and Milligan 1986).

Socio-economically, the biggest problems in Africa are poverty, insecurity and ethnic wars, apart from communal land use.

Conclusion

The value and importance of legume-based pastures for N fixation, C storage and increased animal production are well documented.

There is reasonable adoption of new technology in tropical Australia and parts of south-east Asia and Latin America. However, many countries, particularly in Africa, have such a low development status that more pressing socio-economic problems, related to land tenure, infrastructure and social justice, need to be solved before the development and application of new technologies will be possible.

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