Adoption of tropical legume technology around the world: analysis of success

H.M. SHELTON[1], S. FRANZEL[2] AND M. PETERS[3]
[1] *School of Land and Food Sciences, University of Queensland 4072, Australia*
Email: m.shelton@uq.edu.au
[2] *World Agroforestry Centre, United Nations Ave, PO Box 30677-00100, Nairobi, Kenya*
[3] *Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia*

Key points

1. Examples of successful adoption of forage legumes are reported from all continents, where they delivered profitability and often provided multipurpose benefits to farmers.
2. Factors vital to successful adoption were: meeting the needs of farmers; building relevant partnerships; understanding the socio-economic context and skills of farmers; participatory involvement with rural communities; and long-term involvement of champions.
3. Organisation of seed supply, achieving scale-up and forming partnerships to implement adoption are key features.
4. Legumes remain an important but under-exploited resource for tropical farming systems. The alternative to legumes will be greater and more costly use of N-fertilisers and purchased protein concentrates.
5. The R&D organisations will need to provide long-term support and greater investment for legume technologies to deliver benefits to farmers. Support will be needed for training and education programs to overcome declining availability of forage legume expertise and lack of awareness of opportunity for use of tropical forage legumes.

Significance of tropical legumes in agriculture

Legumes with their associated nitrogen fixation have long been realised to have a large potential contribution to animal production in the tropics. Australian scientists in CSIRO led the early research into forage legumes for grazing (Coleman and Leslie 1966). They understood that tropical grasses were of lower quality than their temperate counterparts, and that the introduction of adapted legumes into tropical grazing systems would simultaneously address the problems of: a) low N status of leached tropical soils; and b) low dietary protein intake by grazing ruminants. The search for adapted tropical forage legumes commenced in earnest after 1950, and by 1990, >17 000 accessions of >20 genera had been introduced into Australia, largely from central and South America but also from Asia and east Africa. This early Australian enthusiasm for tropical legumes was not shared internationally. Coleman and Leslie (1966), when reviewing the IX International Grassland Congress held in Brazil in 1965, noted 'an anti-legume complex', which they said was 'due to the failure of legumes to provide a stable pasture under grazing either in association with grasses or in pure stands.' Nevertheless, scientists based at International Agricultural Research Centres, such as ILRI, ICRAF, CIAT and ICARDA, initiated introduction and evaluation programs for herbaceous, shrub and tree legumes. A large number of germplasm accessions was collected and conserved in gene banks (Maass and Pengelly 2001). It is timely to review the impact of forage legumes on agricultural systems over the past 50 years. Fittingly, the genesis of this paper was the XIX International Grassland Congress in Brazil in 2001, where the view was expressed that adoption of tropical legume technology may be less than anticipated.

Has the original promise of tropical forage legumes been realised?

Reviews of the uptake of tropical forage legumes around the world have revealed that the original promise of legume technology has not been fully realised (Thomas and Sumberg 1995; Elbasha *et al*. 1999; Peters and Lascano 2003). Pengelly *et al*. (2003) concluded that 'despite 50 years of investment in forage research in the tropics, forage adoption has been relatively poor across all tropical farming systems'.

In Africa, Sumberg (2002) reported that fodder legumes have not achieved their potential in sub-Saharan Africa despite 70 years of R&D promoting forage legumes. He queried the long-held view that the introduction of legumes into mixed farming systems was the key to their upgrade. A similar situation existed in Latin America and the Caribbean. Between 1980 and 2000, of 14 legume cultivars that were released, none was well adopted (Peters and Lascano 2003). Miles and Lascano (1997) reported that 'the impact of *Stylosanthes* spp. (stylos) on tropical American livestock production was not proportional to the research literature generated over the past 30 years or so'. In the southern USA, the impact of tropical forage legumes has also been relatively small (Williams *et al*. 2005; Sollenberger and Kalmbacher 2005).

However, in spite of the overall consensus that adoption has been lower than expected, there have been many examples of successful uptake of forage legumes. There are good examples of successful adoption of legumes in regions of Asia, especially the use of *Stylosanthes* spp. in India (Ramesh *et al*. 2005), China (Guodao and Chakraborty 2005) and Thailand (Phaikaew and Hare 2005). Multipurpose tree legumes have played an important role in south-east Asia where *Leucaena leucocephala* has been a significant forage species in the Nusa Tenggara Timur (NTT) Province of Indonesia (Piggin 2003), and in the Batangas Province of the Philippines. *Gliricidia sepium* (gliricidia) is widely used in Indonesia and the Philippines, and leguminous cover crops in the rubber and oil palm plantations of Malaysia have been widely used since the 1800s. In Australia, tropical legumes have also had a significant impact, although only a small number (<10) of the >70 legume cultivars that have been officially released by government agencies since 1910 have made a noteworthy impact on the pastoral industry.

Reasons cited for poor adoption

Lack of perceived benefits of legumes

There is an emerging view in developing countries that grasses are being adopted more quickly and more strongly than legumes. Legumes were regarded as less resilient than grasses under cutting or grazing, benefits were largely long-term in nature, and grass-legume systems were more complex to manage (Peters and Lascano 2003). Similarly, in east Africa, the rapid adoption of grasses, such as *Pennisetum purpureum* (napier grass) in cut-and-carry systems, contrasted with the lack of adoption of herbaceous legumes (Omore *et al*. 1999).

Miles and Lascano (1997) and Andrade *et al*. (2004) reported that farmers in Latin America did not appreciate the benefits of legumes. Therefore, for adoption to occur, even of the best cultivars, they argued that targeted education programs, successful demonstrations and favourable profitability were needed. The objective of targeting low-cost improvement of grass pastures to improve dry season feeding, which worked well in Australia, was not successful in Latin America. Sumberg (2002) suggested that legumes were not just limited by adoption constraints, but that, even under favourable circumstances, scientists need to accept that they may not be able to reliably deliver economic benefits to African farmers, where there is no tradition of planting legumes for fodder.

Failure of technology

In many instances, lack of adoption could be related to failure of the technology for technical or socio-economic reasons, *i.e*., the technology did not live up to expectations and/or was not targeted at the appropriate production system.

In Latin America, a major reason for failure of the Australian *Stylosanthes* cultivars Schofield, Cook and Endeavour in commercial pastures was devastation by the anthracnose pathogen. That the cultivars did not persist under grazing was another significant disadvantage. This led to widespread disappointment among farmers, extension workers and consultants (Andrade *et al*. 2004). Lack of persistence was also cited as a reason for lack of adoption of forage legumes in Africa (Boonman 1993). In Florida, the slow uptake of *Aeschynomene americana* and *Desmodium heterocarpon* was due to an underestimation of the difficulty of establishing and maintaining the legumes in *Paspalum notatum* (bahia grass) pastures. Farmers found that neither legume was dependable when grown with this competitive grass (Sollenberger and Kalmbacher 2005).

Socio-economic factors contributed to the lack of adoption of intercropping and legumes in communal grazing. Attempts to promote intercropping of maize with legumes in east Africa failed due to the high cost of technology, variable rainfall and lack of interest in innovation by older farmers (Ndove *et al*. 2004). Similarly, Maasdorp *et al.* (2004) found that promoting the multipurpose use of *Mucuna pruriens* (mucuna) failed due to lack of interest in green manuring or intercropping, due partly to labour constraints of the cash-cropping farmers. Elbasha *et al*. (1999) reported that legume adoption in west Africa was constrained by lack of extension information, credit and seed, high costs of fencing, shortage of labour, insecurity of land tenure and land scarcity, livestock diseases, invasion by weeds and fire damage. Where land tenure is uncertain, most researchers report failure of adoption. Farmers were simply not interested in investing in their land when they had no assurance of being able to reap the benefits. Pasture improvement technology applied to communally grazed lands by government-supported projects, usually suffered from a lack of interest by the pastoralists involved (Pengelly *et al*. 2003).

Failure in approach

Failure of the key stakeholders to form effective partnerships between farmers and public and private institutions was often cited as a reason for lack of adoption (Miles 2001), leading to ineffective release and follow-up procedures. Andrade *et al.* (2004) stated that, while the release of *Stylosanthes macrocephala* cv. Pioneiro overcame deficiencies of earlier stylo cultivars, the cultivar was not promoted. With no extension support, there was no interest from private seed companies, as they did not see a large market.

Lack of establishment of a reliable seed-production and supply system to ensure that high quality seed was available at a reasonable price was regularly cited as a key reason for adoption failure, *e.g*. for *Stylosanthes* in Latin America (Peters and Lascano 2003), *Vigna unguiculata* (cowpea) in Nigeria (Kristjanson *et al.* 2004) and *Aeschynomene americana* (aeschynomene) and *Desmodium heterocarpon* (carpon desmodium) in Florida (Sollenberger and Kalmbacher 2005). Andrade *et al*. (2004) reported that, of 3 Australian and 10 South American *Stylosanthes* cultivars released into the South American market, seed is available for only two — Mineirão (*S. guianensis* var. *vulgaris*) and

Campo Grande (a mixture of *S. capitata* and *S. macrocephala*).

Lack of a participatory approach was also cited as a reason for ineffective promotion of legume technology. Douthwaite *et al*. (2002) criticised the International Research Centres for basing their approach on scientific enquiry independent of social factors, rather than on a 'learning selection model' that builds on farmer and group experiences.

Are there any success stories?

Difficulties with promotion and use of forage legumes, and the consequent low adoption rates, are of great concern to the R&D community. Without improved levels of adoption, and explicit demonstration of the relevance and benefits of forage legumes, the good will and support of funding and donor agencies will diminish (Shelton *et al.* 2000), preventing the realisation of much potential advantage for rural communities.

Our analysis of 19 successful case studies (Table 1) revealed that greater adoption success has been achieved in Asia and Australia than in Africa, USA or Latin America, although Brazil had some notable successes. *Stylosanthes* species and tree legume species dominated the success case studies, while species that delivered multipurpose benefits, such as *V. unguiculata* in west Africa and *Pueraria phaseoloides* (kudzu) in Brazil, were also important. *Arachis* spp. were successful in niche environments and were being adopted in three of the case studies.

Authors of the papers on successful legume adoption prioritised the adoption factors that they considered were important to success. Based on their expert opinion and knowledge of each case study, they were asked to allocate 100 points among a list of possible adoption factors to reflect the relative significance of the factors. This subjective analysis indicated that five key factors were important. The most important was that the technology met a need of farmers. The other factors (which were similar in their priority) were: the socio-economic situation of farmers was conducive to adoption; partnerships between relevant stake-holders (government, private, farmers) were in place; there was long-term committment by key players; and a farmer-centred research and extension program was implemented.

The gross economic benefits were naturally highest where large-scale adoption had occurred, *e.g.* from adoption of *Stylosanthes* in west Africa, southern China or northern Australia, *Leucaena leucocephala* (leucaena) in Queensland, and *P. phaseoloides* in the Amazon of Brazil (Table 1).

Reasons for success

The technology met a need of farmers

Adoption of legumes occurred when the technology met farmers' needs, although the particular need to be met varied among farmers and regions. Examples include:

- *West Africa* — *V. unguiculata* was adopted because it provided multiple benefits, *e.g*. grain for human consumption, fodder for livestock and opportunity to rotate with cereals to reduce the impact of the parasite *Striga hermonthica*, which causes loss of grain yield (Tarawali *et al*. 2005b).
- *East Africa* — Farmers lacked adequate protein for their stall-fed dairy cows and goats, but did not want to spend scarce cash on expensive concentrates. They preferred instead to plant fodder shrubs (primarily *Calliandra calothyrsus*, *Leucaena trichandra* and *Morus alba*). The shrubs required only small amounts of labour for planting and harvesting, and farmers found that they could establish tree legume hedges along pathways and field boundaries, and create soil conservation bunds along contours (Franzel *et al*. 2003).
- *Northern Australia* — Graziers found that dryland annual cropping on fertile clay soils was economically marginal due to uncertain rainfall and variable grain prices. In contrast, good cattle prices and the prospect of an agreeable lifestyle change for ageing farmers encouraged them to move to a lower-cost but profitable cattle-fattening enterprise. This led to the large-scale adoption of both *L. leucocephala* (Mullen *et al*. 2005) and *Clitoria ternatea* (butterfly pea) (Conway 2005).
- *Gulf Coast of the USA* — There was a market for high quality hay for the horse and dairy industries. New varieties of *Arachis glabrata* cvv. Florigraze and Arbrook (rhizoma peanut) were well adapted, the equipment for vegetative propagation was available, and it was profitable compared with alternative land uses (Williams *et al*. 2005).
- *India* — Establishment of *Stylosanthes* to produce leaf meal was a cheap but profitable option for infertile acid soils in arid zones (Ramesh *et al*. 2005). Establishment was simple with no special equipment required. In southern China, there was also a need for high-protein leaf meal for the large numbers of livestock in the region (ruminants and non-ruminants). *Stylosanthes* was well adapted and met this need (Guodao and Chakraborty 2005).
- *Nusa Tenggara Timur Province of Indonesia* — There was serious land degradation (erosion and weeds) in Amarasi and Sikki Districts in the 1930s. The high population densities required a change from swidden agriculture to sedentary agriculture. Alternatives, such as hand-made terraces, failed as they were too labour intensive and difficult to construct. In Amarasi District, farmers found that they could rotate *L. leucocephala* with corn to improve fertility and thus corn production, and the *L. leucocephala* could be used to feed tethered cattle and housed goats (Piggin 2003). *Lantana camara* (lantana) was largely eliminated as a weed problem by the system and *L. leucocephala* provided wood for a variety of uses.

Table 1. Summary of tropical forage legume success stories.

Country or Region	Species	Principal uses	Area planted (,000 ha)	No. farmers	Seed production	Estimated gross benefit (US$,000/yr)	Reference
Africa							
West Africa	*Vigna unguiculata*	Multipurpose — food, fodder, soil fertility	1400	~350 000	Not available (n.a.)	n.a.	Tarawali *et al*. (2005b)
West Africa	*Stylosanthes* spp. *Centrosema pascuorum, Aeschynomene hystrix*	Legume fodder banks and soil fertility restoration	19	27 000	n.a.	16 500 by 1997	Tarawali *et al*. (2005a) Kristjanson *et al*. (2004)
East Africa (Kenya, Uganda, Tanzania, Rwanda)	*Calliandra calothyrsus, Leucaena trichandra, Morus alba, Sesbania sesban*	Cut-and-carry for dairy cow and goat production, fuelwood, erosion control	~4 M m of hedges	>40 000	n.a.	2220	Franzel and Wambugu (2005)
Asia							
Southern China	*Stylosanthes guianensis* (cvv. Graham and CIAT184)	Leaf meal, agroforestry, green manure, erosion control	>200	>30 000	20 t/yr not including seed sold by farmers	22 315	Phaikaew *et al*. (2004) Guodao and Chakraborty (2005)
Thailand	*Stylosanthes humilis* (cv. Khon Kaen), *Stylosanthes hamata* (cv. Verano), *Stylosanthes guianensis* (cv. CIAT184)	Forage for cattle, dairy cow and buffaloes; cut-and-carry and grazing; roadside, communal and private pastures	>300	~12 000	4500 t since 1976	~750	Phaikaew and Hare (2005)
India	*Stylosanthes scabra, Stylosanthes hamata, Stylosanthes guianensis*	Revegetation of wastelands for erosion control and fodder	>250	>5000	800 t/yr	>160/ha for stylo seed	Ramesh *et al*. (2005)
Indonesia (Nusa Tenggara Timur)	*Leucaena leucocephala*	Erosion control, forage for cattle, wood production	70–93	n.a.	n.a.	n.a.	Piggin (2003)
Indonesia (Lombok)	*Sesbania grandiflora*	Cut-and-carry forage	n.a.	65 000	Transplanted seedlings	n.a.	Hasniati and Shelton (2005)
Nepal	*Arachis pintoi*	Cut-and-carry forage, cover cropping, erosion control, ley farming	n.a.	~20 000 since 1999	Vegetatively propagated	n.a.	Robertson (2005)

Table 1 (cont). Summary of tropical forage legume success stories.

Country or Region	Species	Principal uses	Area planted (,000 ha)	No. farmers	Seed production	Estimated gross benefit (US$,000/year)	Reference
Australasia							
Queensland, Australia	*Leucaena leucocephala*	Grazed pastures	100	400	~10 t/yr	20 000	Mullen *et al.* (2005)
Queensland, Australia	*Clitoria ternatea*	Grazed pastures	100	500	300 t/yr	~900	Conway (2005)
N. Territory, Australia	*Centrosema pascuorum*	Hay and pellet production	5 sown yearly	100	35 t/yr	2844	Cameron (2005)
N. Australia	*Stylosanthes scabra, Stylosanthes hamata*	Grazed pastures	~1500 naturalised up to 3000	n.a.	n.a.	~30 000	Rains (2005)
Latin America							
Brazil	*Stylosanthes capitata S. macrocephala* (cv. Campo Grande)	Grazed pastures	>150	n.a.	>500 t since 2001	n.a.	Fernandes *et al.* (2005)
Brazil (Acre State in Amazonian region)	*Pueraria phaseoloides*	Grazed pastures, reclamation of degraded areas	480	5400	25 t/yr	~33 000	Valentim and Andrade (2005a)
Brazil (Acre State in Amazonian region)	*Arachis pintoi* (cv. Belmonte)	Grazed pastures, reclamation of degraded areas	65	~1000	100 t/yr of vegetative material	~4000	Valentim and Andrade (2005b)
Colombia	Forage peanut (*Arachis pintoi*)	Grazed dairy brachiaria pastures	3	100	n.a.	n.a.	Lascano *et al.* (2005)
USA							
Florida	*Arachis glabrata*	Hay production, grazed pastures, ornamental turf	8	n.a.	Vegetatively propagated	7000	Williams *et al.* (2005)
Florida	*Aeschynomene americana, Desmodium heterocarpon*	Grazed pastures	65 and 14	750 and 200	60 and 4 t/yr	2400 and 540	Sollenberger and Kalmbacher (2005)

The analysis indicated that success could be achieved when the technology led to profitability, on-farm environmental benefits such as fertility improvement or weed control, and other multipurpose benefits — often there was a combination of several benefits. However, most successful examples of adoption of forage legumes were unambiguously profitable for the adopter. Farmers normally choose profit, food and income security before environmental protection (Peters *et al*. 2001). However, many scientists and government development personnel continue to justify the extension of forage legume technology by promoting natural resource management benefits, including off-farm benefits such as carbon sequestration and watershed management. The fundamental need for the legume technology to be firstly profitable and then afford delivery of on-farm environmental services as a secondary priority, cannot be emphasised strongly enough.

The technology matched farmers' socio-economic situation and skills

It is necessary to begin with an understanding of the production system in which the legume will be promoted. From the survey, examples of legume technology matching farmers' socio-economic situation and skills include:

- *Eastern Indonesia* — Farmers found that planting of *L. leucocephala* was compatible with local farming systems. It could be interplanted into maize patches without decreasing maize yield, and then rotated with maize as a soil fertility-building exercise (Piggin 2003). In China, production of leaf meal from *Stylosanthes* planted into young rubber plantation forests or horticultural systems provided an income stream for a large and inexpensive workforce, especially women (Guodao and Chakraborty 2005).
- *Queensland*, *Australia* — Graziers needed an intensive, highly productive pasture beef-fattening system, capable of delivering similar weight gains to feedlots in order to meet different market options. Those graziers with previous dryland cropping experience had less difficulty in establishing hedge-rows of *L. leucocephala* than graziers without this experience (Mullen *et al*. 2005).
- *Asia* — The introduction of well adapted *Stylosanthes* spp. into communal grazing lands in north-east Thailand was an easy low-cost strategy that delivered multiple benefits (improved livestock diets and improved land fertility) and was therefore well suited to the socio-economic conditions of the region. While many argue that it is not feasible to improve forage on communal lands due to lack of management (Cramb 2000; Pengelly *et al*. 2004), it was possible in Thailand due to government sponsorship of the improvement. Nevertheless, due to overgrazing and changed land use, the benefits of this oversowing strategy have been less than would be achieved on private land (Phaikaew and Hare 2005). In India, State and Federal Governments and NGOs also had long-running programs (25 years) of support for revegetation of village commons and watersheds (Ramesh *et al*. 2005).
- *Nepal* — In the mid-hill farming areas, small farm size and intensive cropping practices, coupled with back-yard dairy production, created the socio-economic environment for immediate interest and adoption of *Arachis pintoi* (forage peanut). Farmers in the region were accustomed to vegetative propagation, and there were many niche environments where *A. pintoi* could be planted (Robertson 2005). In Lombok, Indonesia, rice farmers needed to improve the diets of goats and cattle fed rice straw. They found that *Sesbania grandiflora* (sesbania) was tolerant of waterlogging and grew extremely well along the rice bunds without reducing yields of the rice crop. The side branches and leaves were easily harvested for fodder and the main stem was eventually cut to provide timber and poles. Nursing mothers also found *S. grandiflora* to be a nutritious vegetable.

The experiences reviewed in Table 1 also confirm that simple innovations are more quickly adopted than complex ones, *e.g.* a new variety of *Stylosanthes* was more readily accepted in north-east Thailand (Phaikaew and Hare 2005) or in northern Australia (Rains 2005) than a new farming system such as the *L. leucocephala* system in Indonesia (Piggin 2003) or Australia (Mullen *et al*. 2005). After 20 years of R&D into suitable *Stylosanthes* cultivars for the Brazilian savannas, Campo Grande was finally released in 2000. This cultivar overcame earlier difficulties with lack of persistence, susceptibility to anthracnose disease and poor seed production, and by 2004, more than 500 t of seed had been produced and sown on almost 150 000 ha of grass pastures (Fernandes *et al*. 2005).

Partnerships between stakeholders (government, private, farmers) were evident

All successful case studies have involved the formation of critical partnerships between the significant stakeholders (Williams *et al.* 2005; Conway 2005). In Nusa Tenggara Timur in Indonesia, local village heads, NGOs, church groups, the Dutch Administration and government departments all showed great committment to *L. leucocephala* adoption (Piggin 2003). Local administrators instituted new regulations creating a favourable policy environment for adoption to proceed. These included: (a) enforcement of tethering to replace free grazing; (b) provision of credit only to those who agreed to plant *L. leucocephala*; (c) promotion of erosion-control programs; (d) regulations requiring the obligatory planting of *L. leucocephala* (1932 and 1948); and (e) promotion of cattle husbandry in livestock distribution schemes.

Partnerships that integrated a mechanism for supply of good quality seed at a reasonable price were essential for success (Kristjanson *et al.* 2004). Similarly, where successful adoption involved vegetatively propagated species such as *Arachis* spp. (Robertson

2005; Williams *et al*. 2005; Lascano *et al*. 2005), an accessible supply of planting material was essential. In some developing countries, legume seed production was achieved by contracting smallholder farmers to produce the seed for government or NGO groups. This approach was first used in the 1970s in north-east Thailand to produce seed of *Stylosanthes humilis* (Wickham *et al*. 1977), and was consolidated by continuing support from the Thai Government for a further 25 years (Phaikaew and Hare 2005). Approximately 4500 t of seed have been produced since the scheme commenced (Phaikaew and Hare 2005). Seed is now exported as well as being purchased for local programs, and there are farmer-to-farmer seed sales. Seed producers exported 3 t of *S. guianensis* CIAT184 and 8–9 t of *S. hamata* cv. Verano in 2002 and 2003 (Phaikaew *et al*. 2004). A 'Thai club of seed producers' was formed to handle production and marketing. The Department of Land Development assists with monitoring of seed quality and testing, seed marketing, and seed packaging and storage. Successful contracting of seed production to smallholders has also occurred in India, where Government has supported *Stylosanthes* seed production (Ramesh *et al.* 2005); in Bolivia, where the NGO Empresa de Semillas Forrajeras SEFO — SAM has supported production of a variety of legume species for export (G. Sauma, personal communication); and in Benin, where purchase of *M. pruriens* seed from farmers by the NGO Sasakawa Global occurred (Douthwaite *et al*. 2002). However, partnerships that link smallholder seed production with the private sector should be sought to provide long-term continuity of seed supply.

For broadacre plantings, such as are found in Latin America, USA and Australia, seed production is normally handled by specialist private seed merchants (Conway 2005; Williams *et al*. 2005; Mullen *et al.* 2005). Lack of a reliable seed supply has limited adoption of *Stylosanthes* spp. in Brazil, *Centrosema pascuorum* in the Northern Territory of Australia and *Arachis pintoi* in Colombia (Lascano *et al*. 2005). Andrade *et al*. (2004) reported that release of new *Stylosanthes* cultivars with high seed-yield potential was vital, in order to gain the support of seed producers in Brazil. The seed company that marketed the *Stylosanthes* variety *Mineirão* from 1996, found that low seed yields, and consequent high market prices, led to a relatively large number of buyers purchasing small amounts of seed. Consequently, from 2000, the seed firm mixed Mineirão and Campo Grande (1:3) as a strategy to facilitate sales of Mineirão.

Partnerships with researchers were also an integral part of the successful case studies. Researchers needed to be available to solve problems and progress the technology. In Kenya, researchers have introduced new species (*Leucaena trichandra* and *Morus alba*) to reduce farmers' dependence on *Calliandra calothyrsus* (calliandra). Diversification is important for minimising the effect of a pest or disease attack on any one species, and also for providing a more balanced feed ration (Franzel *et al*. 2003). In Australia, the beef industry is supporting the breeding of a psyllid-resistant *Leucaena* spp., and research into the management of subclinical DHP toxicity, which was recently observed in Queensland cattle herds (Mullen *et al.* 2005). Cramb (2000) agreed that successful adoption occurred where there was a timely formation of a 'flexible' coalition of key stakeholders, whose interests converge sufficiently that their joint resources focus on achieving the adoption outcomes.

Long-term committment of key stakeholders

Most successful case studies have occurred over a long time period, *e.g*. 10–50 years (Shelton *et al*. 2000). In central Kenya, 10 years elapsed between the start of the first on-farm trial and the wide-scale uptake of fodder shrubs by farmers. Elbasha *et al*. (1999) noted that realisation of benefits from the use of tropical legumes took at least 15 years in west Africa and at least 20 years in Australia. Kristjanson *et al*. (2004) indicated that 20 years were needed to extend the results of *Vigna unguiculata* research in Nigeria. Strategies that have immediate and profitable short-term benefits will be favoured. This was the case with milk production systems in Kenya, where adoption of *Calliandra* occurred relatively quickly as dairy producers responded to the immediate increase in milk yield and the opportunity to reduce their use of expensive concentrates. In Brazil, *Arachis pintoi* was quickly adopted in the Amazon due to the introduction of environmental regulations preventing more clearing of forested lands.

Successful adoption was also associated with dedicated champions who were willing to commit their time to achieving a successful outcome (Williams *et al*. 2005; Conway 2005; Mullen *et al*. 2005; Ramesh *et al*. 2005). Examples include north-east Thailand, where interest in the promotion of *Stylosanthes* commenced in the 1970s with Thai, New Zealand and Australian input. This was followed by World Bank support, and now Japanese support. A key factor was the continuing support from the Thai Department of Livestock Development, and consistent support from key individuals. Such sustained donor support is critical to ensuring the success of the technology.

Farmer-centred research and extension programs were implemented

Many workers have pointed to the need for a close interactive working relationship with farmers in order to achieve adoption. Horne *et al*. (2000) were critical of the lack of participatory involvement with farmers during 40 years of forage development programs in south-east Asia. They proposed an intensive interactive program of discussion, interviews and on-farm trials jointly conducted with farmers to identify the best solutions to problems identified by the farmers. Tuhulele *et al*. (2000), reporting experiences using Participatory Rural Appraisal (PRA) tools, found that careful selection of participating farmers was important and that good facilitation and communication skills with farmers were essential. However, a flexible approach is necessary so that farmer innovations can be absorbed into the technology recommendations and passed on. Further improvements occurred as farmers experimented with the technology, *e.g*. in Kenya, researchers encouraged farmers to conduct their own experiments, called 'farmer-designed trials', in which farmers planted *Calliandra* as they wished. Several important lessons emerged from these trials, and were incorporated into extension recommendations, including planting in different niches and planting *Calliandra* between rows of *Pennisetum purpureum*, and between *Grevillea robusta* trees along field boundaries.

Braun and Hocdé (2000) referred to the need to change the orientation of existing R&D structures and to develop sustainable community-based research capacity. This has happened in northern Australia, where graziers have the major say in establishing priorities for research expenditure in the northern Australian beef industry (via the Northern Australia Beef Research Committee). A network of *Leucaena* growers has formed 'The *Leucaena* Network', and has played a major advocacy role promoting research, negotiating with government agencies regarding environmental issues, and conducting training courses for growers.

Within the participatory framework, it was important to ensure that accurate and practical information on the technology was readily available and was transmitted to farmers using an appropriate vehicle. Wortman and Kirungu (2000) considered that smallholder farmers in sub-Saharan Africa were influenced by government extension services, neighbours, relatives, schools and radio. Ndove *et al*. (2004) reported that adoption of legumes in maize cropping systems was assisted by training, demonstrations, tours and on-farm experiments. In Australia, the five most important information sources for graziers were rural newspapers, local Department of Agriculture, national radio, neighbours and stock and station agents (Anon. 2004).

Issues and opportunities for the future

Relevance of tropical legumes to future livestock production

The future of the tropical ruminant livestock sector seems assured with predictions of continuing strong demand for livestock products due to population increase (Kristjanson *et al.* 2004), and to an increasingly prosperous middle class in developing countries. It will be the integrated crop-livestock smallholder systems of Africa and Asia, and to a lesser extent Latin America, that will be the major suppliers of meat and milk (Delgado *et al*. 1999). However, production systems will need to intensify to meet demand for higher quality products, while remaining environmentally sustainable. In Africa, there is a move from pastoralism to sedentary farming, requiring greater inputs and a more sustainable production system (J. Lenné, personal communication). In Asia, smallholder livestock farmers are moving from herding systems to tethering systems, or to intensive penned animal systems that require cut-and-carry forage (Fujisaka *et al.* 2000). Most are planting high-yielding grasses to supplement dry season crop residues, and many now purchase feed concentrates to supply protein, energy and minerals, thereby improving productivity, especially milk production. As production systems intensify, the inability of farmers to adequately feed their livestock year round will be even more important. The outstanding value of legumes in general, and of *Calliandra* in particular, is needed to meet this dry season feed gap, with the additional benefit of increased intake of associated poor quality roughage (Shelton 2004b). It is not surprising that tree legumes figure strongly among the successful case studies. They are multipurpose, and their superior rooting depth delivers excellent water use efficiency and drought tolerance (Shelton 2004a).

Similarly, the broad-scale grazed tropical grass pastures in Australia, southern USA, and central and South America will be neither productive nor stable unless their N-nutrition is maintained. Declining N status leads to reduced productivity, reduced pasture vigour and weed invasion. While use of inorganic N is feasible in southern USA (Sollenberger and Kalmbacher 2005), it is less economically attractive in Australia, Africa and Latin America.

There is an emerging and significant role for legumes as a protein supplement to reduce reliance on expensive concentrates (Franzel *et al*. 2005), which often account for a high proportion of direct costs. Related to this is a rapidly increasing demand for legume hay and leaf meal. This is happening in India (Ramesh *et al*. 2005), China (Guodao and Chakraborty 2005) and Latin America (Peters and Lascano 2003).

Are we short of adapted legumes?

A considerable amount of adaptation research has already been completed (Pengelly *et al.* 2004), although there remains a continuing need for germplasm evaluation and genotype x environment studies to better understand the range of environmental niches for legume accessions (Peters and Lascano 2003). Databases are available, *e.g*. the CIAT Forage Database (Barco *et al*. 2002) and SoFT (Selection of Forages for the Tropics) (Pengelly *et al*. 2005). The web sites of FAO (http://www.fao.org/) and PROSEA (Plant Resources of Southeast Asia) (http://www.prosea.nl/) have species information; and documentation describing the characteristics of a large number of tropical forage legumes is available (Horne and Stür 1999). Data on forage adaptation and farmer preference have been linked to a GIS system, based on biophysical and socio-economic data for different regions (Peters *et al.* 2000). It is hoped that it will be possible to extrapolate the forage adaptation data to new regions, by inputting information on production system, market access and social preference into the GIS-based tool.

There are many accessions of legumes currently in world germplasm banks, although this resource is under threat due to lack of adequate funding (Maass and Pengelly 2001). It is vital that the capability to identify new varieties to meet the continuing challenges of pests and diseases is retained, and that there is access to new accessions for niche environments. On occasion, discarded accessions have become relevant, due to the changed circumstances of farmers, *e.g.* the success of *Clitoria ternatea* cv. Milgarra as a ley legume to restore nitrogen fertility in cropping lands in central Queensland occurred many years after it was first evaluated (Conway 2005).

In recent years, there has been increasing interest in indigenous species as an alternative to introducing exotic species. There are many reasons for this trend: (a) farming communities have detailed knowledge of their use and value; (b) there are ecological and conservation advantages in using indigenous species; and (c) there is a risk of unwanted weed invasion from exotic species. Indigenous forage tree species have generally been used for subsistence feeding rather than commercial systems. Exotic species are usually more vigorous, and produce higher yields than indigenous species, as they have been carefully selected for use as forage and removed from the challenge of pests and diseases present in their native range (Shelton 2004). Roothaert and Franzel (2001) noted that most fodder tree screening programs in Africa involved exotic species, but that the local species offer great potential. The challenge is to find trees that can be propagated easily, are highly nutritious and can be pruned intensively.

Seed production strategies

Most authors of successful case studies cite the need for readily available cheap seed or planting material of good quality. The use of smallholders for contract growing of seed has worked well in many developing countries. Small-scale production of legume seed has successfully matched the skills and resources of smallholder farmers, and has often involved rural women in seed harvesting and cleaning. Nevertheless, in Kenya, despite high adoption of fodder trees, seed marketing is still problematic. Commercial firms have not shown interest in marketing seed, and individual seed growers find it difficult to link with potential buyers, who are usually smallholder farmers interested in buying minute quantities. Many NGOs give away free seed and this is a disincentive for farmers interested in selling seed. However, researchers can facilitate seed marketing in several ways: a) by helping producers to produce high quality seed; b) by helping producers link with merchants in areas of high demand; and c) by helping merchants to sell seed in small packets (Russell and Franzel 2004). There is a need to improve the linkages between smallholder seed production and the private seed sector, to ensure long-term continuity of seed supply. Improved levels of adoption will help overcome the problem of low market volume for legume seed, thus encouraging private seed merchants to make investments.

In developed countries, a reliable supply of high-quality affordable seed is similarly crucial to successful adoption (Conway 2005; Mullen *et al.* 2005; Rains 2005; Sollenberger and Kalmbacher 2005). A number of constraints continue to hamper seed production and distribution from private seed companies including: variable environmental conditions affecting production; variable economic conditions affecting demand (especially export demand); and declining R&D into new varieties. Miles (2001) reported that EMBRAPA (Centro da Empresa Brasileira de Pesquisa Agropecuária) and Unipasto (an association of Brazilian pasture seed firms) are collaborating to ensure pasture seed supply in the region.

Who is best qualified to implement adoption projects?

There is considerable debate concerning the respective roles of farmers, technology researchers, socioeconomists and other stakeholders in the adoption process, and the relative contributions that can be made by a traditional scientific approach and by participatory approaches. In reality, the prime movers of adoption programs will vary. It is often not the local extension service, but may be a farmer organisation, a university, or locally or internationally funded R&D agencies (Braun and Hocdé 2000). A major problem for all those wishing to promote the use of forage legumes is declining resources, and especially the declining number of pasture scientists in national and international agencies trained in tropical pasture science R&D. Andrade *et al*. (2004) report that CIAT and national research agencies in Latin America have reduced their forage research budgets. The number of Australian pasture researchers has declined dramatically over the past decade. Given the increased demand for livestock products, the clear evidence that poor animal nutrition is the major factor limiting productivity, and the need to ensure sustainability of more intensive production systems, national and international agencies will need to increase their investment in education, training, research and extension of tropical pastures if the potential is to be realised.

Scale-up and sustainability

Scientists and development workers are often involved in developing and demonstrating technologies at a small scale. Scaling-up to large numbers of farmers involves working across villages, districts and provinces. This requires alliances with a multitude of institutions working with farmers, many of which will have limited expertise on forages. The use of expert decision support systems such as SoFT — a database and selection tool for identifying forages adapted to local conditions in the tropics and subtropics, and the linked GIS-based CaNaSTA (Crop Niche Selection for Tropical Agriculture) may assist in this regard. However, these computer tools cannot replace the long-term experience of forage agronomists. Fliert *et al*. (2000) stated that participatory activities are often characterised by intensive guidance processes, which may limit capacity for up-scaling. Tuhulele *et al*. (2000) recommended an intensive process of interaction with participating farmers using Participatory Rural Appraisal (PRA) approaches, but these approaches can create problems in up-scaling to new regions due to the heavy involvement of farmers and researchers in the process of promoting the technology (Horne *et al*. 2000). Some technologies, *e.g*. maize varieties, spread easily across an area, while many fodder legumes require more facilitation because they are 'information-intensive' and involve the learning of new skills. The building of partnerships and coalitions of a range of stakeholders, such as government agencies, NGOs, church organisations, community groups, farmer groups and schools, is the key to successful up-scaling (Franzel *et al*. 2003).

Sustaining scaling-up and the adoption process is not always possible. *Mucuna* was adopted by >10 000 hillside farmers in Honduras and several thousand farmers in Guatemala and southern Mexico. It was used as a relay crop with maize, delivering benefits for soil fertility, soil structure and weed suppression (Peters *et al*. 2001). However, due to farms becoming smaller and tenure less secure, much of this policy was reversed. Growth in the cattle industry reduced the area of land available for landless peasants to use the *Mucuna-Zea mays* rotation, and *Zea mays* became less attractive relative to other crops and off-farm employment opportunities (Neill and Lee 2001). In Florida, the availability of cheap nitrogen for use on N-fertilised grass and other more profitable land-use options has diminished grazier interest in use of forage legumes (Sollenberger and Kalmbacher 2005). Market failures and problems with the legume technology can cause the technology to fail. For these reasons, the long-term sustained involvement of researchers to address technical problems is crucial for successful adoption.

Computer modelling

There is much controversy over the role of computer tools for promoting adoption. Pengelly *et al*. (2003) argued that simulation modelling combined with socio-economic research would improve adoption. A simulation model assessing year-round feeding strategies for smallholder crop-livestock systems is being developed by ILRI and their partners (Domingo 2004). The software enables forecasting of livestock performance under varying feeding and management conditions. A similar strategy is being pursued by ACIAR in southern Africa, south Sulawesi and Indonesia, where an integrated livestock, crop, horticultural and economic model of smallholder systems is being developed.

However, there is concern that the use of computer tools as an aid to generate adoption options for forages in smallholder crop-livestock systems is a high-risk strategy. It may not be possible to achieve a credible, robust model for the smallholder farmers of Africa, Asia and Latin America, because of lack of technical information for the diversity of situations and the high skill levels and sustained committment needed to develop and support effective models. While it is concluded that computer modelling will be an important contributor to improved adoption outcomes, it is vital that development workers continue to engage with rural communities in relevant and practical ways, especially since the number of professionally trained forage scientists is declining.

Conclusions

Although adoption of tropical legumes worldwide has been less than anticipated, there have been notable adoption successes, especially in Asia and Australia, and to a lesser extent in Brazil. Where data were available, the economic returns from adoption have been significant. Successful legumes have included *Stylosanthes*, tree legumes and niche legumes, such as forage *Arachis* species. Their characteristics varied greatly, but with some exceptions, they demonstrated persistence, vigour and longevity under grazing or cut-and-carry systems, ease of establishment (with the exception of *Leucaena*), and either high seed yield or ease of vegetative propagation. They delivered profitability and multipurpose benefits to farmers, including on-farm environmental benefits.

Meeting the needs of farmers was the most significant factor leading to successful uptake of tropical forage legume technology. Other factors vital to successful adoption were: (a) the building of a coalition of relevant partnerships; (b) understanding the socio-economic context and skills of farmers and their farming systems; (c) a participatory involvement with the rural communities involved; and (d) the long-term involvement of champions who ensured the process did not stall and that problems were resolved.

Nitrogen is the key sustaining element in tropical farming systems, and as ruminant production systems are intensified, there is great potential and opportunity for exploiting tropical forage legume technology. Leaf meals, in particular, will become more common in the future. The alternative to legumes will be greater and more costly use of N-fertilisers and purchased protein concentrates.

If R&D organisations wish to see the technologies developed from their research programs delivering benefits to farmers, they will need to take extension work more seriously. They will need to be prepared for long-term involvement, and to build partnerships with other organisations with complementary expertise and interest but similar goals. Increased investment will be needed to support R&D programs, including greater support for long- and short-term training and education programs to overcome declining availability of forage legume expertise and lack of awareness and opportunity for use of tropical forage legumes. Such investment will ensure adoption of tropical forage legume technology, and will increase the economic, environmental and social well-being of rural communities.

Acknowledgement

We acknowledge with thanks the editorial inputs and creative suggestions of Dr Bob Clements and Dr Scott Dalzell.

References

Andrade de, R.P., Karia, C.T. and Braga Ramos, A.K. (2004) *Stylosanthes* as a forage legume at its centre of diversity. In: Chakraborty, S. (ed.) *High-yielding anthracnose-resistant* Stylosanthes *for agricultural systems. ACIAR Monograph,* **115**, 39–50.

Anon. (2004) Producer R&D awareness and adoption research — northern beef report. *Report prepared for Meat and Livestock Australia by Solutions Marketing and Research.* 21pp.

Barco, F., Franco, M.A., Franco, L.H., Hincapié, B., Lascano, C.E., Ramirez, G. and Peters, M. (2002) *Base de datos de Recursos Genéticos Multipropósito*. Version 1.0. Centro Internacional de Agricultura Tropical (CIAT) Serie CD-ROM.

Boonman, J.G. (1993) *East Africa's grasses and fodders: their ecology and husbandry*. (Kluwer Academic Publishers: Dordrecht). 343p.

Braun, A.R. and Hocdé, H. (2000) Farmer participatory research in South America: four cases. In: Stür, W.W., Horne, P.M., Hacker, J.B. and Kerridge, P.C. (eds) *Working with farmers: the key to adoption of forage technologies. ACIAR Proceedings* No. **95**, 32–53.

Cameron, A.G. (2005) *Centrosema pascuorum* in Australia's Northern Territory: a tropical forage legume success story. *Proceedings of the XX International Grassland Congress: Offered papers, Dublin*, *2005*. p. 326.

Coleman, R.L. and Leslie, J.K. (1966) The 9th International Grassland Congress and tropical grasslands. *Journal of the Australian Institute of Agricultural Science*, **32**, 261–270.

Conway, M.J. (2005) Butterfly pea in Queensland: a tropical forage legume success story. *Proceedings of the XX International Grassland Congress: Offered papers, Dublin, 2005*. p. 331.

Cramb, R.A. (2000) Processes influencing the successful adoption of new technologies by smallholders. In: Stür, W.W., Horne, P.M., Hacker, J.B. and Kerridge, P.C. (eds) *Working with farmers: the key to adoption of forage technologies. ACIAR Proceedings* No. **95,** 11–22.

Delgado, C., Rosegrant, M., Steinfeld, H., Ehui, S. and Courbois, C. (1999) Livestock to 2020: the Next Food Revolution. *Food, Agriculture and the Environment Discussion Paper* No. **28**. *International Food Policy Research Institute, Washington, D.C.* 72pp.

Domingo, S.N. (2004) Simulation modelling gaining support in Casren countries. *Casren Newsletter Special Edition, April 2004, ILRI, Nairobi, Kenya.* 8pp.

Douthwaite, B., Manyong, V.M., Keatinge, J.D.H. and Chianu, J. (2002) The adoption of alley farming and *Mucuna*: lessons for research, development and extension. *Agroforestry Systems*, **56**, 193–202.

Elbasha, E., Thornton, P.K. and Tarawali, G. (1999) An *ex post* economic impact assessment of planted forages in West Africa. *ILRI Impact Assessment Series 2, ILRI, Nairobi, Kenya.* 68pp.

Fernandes, C.D., Grof, B., Chakraborty, S. and Verzignassi, J.R. (2005) Estilosantes Campo Grande in Brazil: a tropical forage legume success story. *Proceedings of the XX International Grassland Congress: Offered papers, Dublin*, *2005*. p. 330.

Fliert, van de E., Asmunati, R. and Tantowijoyo, W. (2000) Participatory approaches and scaling-up. In: Stür, W.W., Horne, P.M., Hacker, J.B. and Kerridge, P.C. (eds) *Working with farmers: the key to adoption of forage technologies. ACIAR Proceedings* No. **95**, 83–90.

Franzel, S., Wambugu, C., Tuwei, P. and Karanja, G. (2003) The adoption and scaling up of the use of fodder shrubs in central Kenya. *Tropical Grasslands*, **37**, 239–250.

Franzel, S., Wambugu, C., Stewart, J., Cordero, J. and Sande, B.D. (2005) Fodder shrubs for improving incomes of dairy farmers in the east African highlands. *Proceedings of the XX International Grassland Congress: Offered papers, Dublin*, *2005*. p. 319.

Fujisaka, S., Rika, I.K., Ibrahim, T. and An, L.V. (2000) Forage tree adoption and use in Asia. In: Stür, W.W., Horne, P.M., Hacker, J.B. and Kerridge, P.C. (eds) *Working with farmers: the key to adoption of forage technologies. ACIAR Proceedings* No**. 95**, 243–253.

Guodao, L. and Chakraborty, S. (2005) Stylo in China: a tropical forage legume success story. *Proceedings of the XX International Grassland Congress: Offered papers, Dublin, 2005*. p. 322.

Hasniati, D. and Shelton, M. (2005) *Sesbania grandiflora*: a successful tree legume in Lombok, Indonesia. *Proceedings of the XX International Grassland Congress: Offered papers, Dublin, 2005*. p. 324.

Horne, P.M. and Stür, W.W. (1999) Developing forage technologies with smallholder farmers — how to select the best varieties to offer farmers. *ACIAR Monograph* No. **62.** 80pp.

Horne, P.M., Magboo, E., Kerridge, P.C., Tuhulele, M., Phimphachanhvongsod, V., Gabunada, F. Jr, Binh, L.H. and Stür, W.W. (2000) Participatory approaches to forage technology development with smallholders in Southeast Asia. In: Stür, W.W., Horne, P.M., Hacker, J.B. and Kerridge, P.C. (eds) *Working with farmers: the key to adoption of forage technologies. ACIAR Proceedings* No. **95**, 23–31.

Kristjanson, P.M., Okike, I., Tarawali, S. and Singh, B.B. (2004) Adoption and impact of improved dual-purpose cowpea on food, feed and livelihoods in the West African dry savanna zone. *Agricultural Economics*, **32**, 195–210.

Lascano Carlos, E., Peters, M. and Holmann, F. (2005) *Arachis pintoi* in the humid tropics of Colombia: a forage legume success story. *Proceedings of the XX International Grassland Congress: Offered papers, Dublin, 2005.* p. 327.

Maasdorp, B.V., Jiri, O. and Temba, E. (2004) Contrasting adoption, management, productivity and utilisation of mucuna in two different smallholder farming systems in Zimbabwe. In: Whitbread, A.M. and Pengelly, B.C. (eds) *Tropical legumes for sustainable farming systems in Southern Africa. ACIAR Proceedings* No. **115**, 154–163.

Maass, B.L. and Pengelly, B.C. (2001) Tropical forage genetic resources — will any be left for future generations? *Proceedings of the XIX International Grassland Congress*, *Sao Paulo, Brazil.* pp. 541–542.

Miles, J.W. (2001) Achievements and perspectives in the breeding of tropical grasses and legumes. *Proceedings of the XIX International Grassland Congress*, *Sao Paulo, Brazil.* pp. 509–515.

Miles, J.W. and Lascano, C.E. (1997) Status of *Stylosanthes* development in other countries. 1. *Stylosanthes* development and utilisation in South America. *Tropical Grasslands*, **31**, 454–459.

Mullen, B.F., Shelton, H.M. and Dalzell, S.A. (2005) Leucaena in northern Australia: a forage tree legume success story. *Proceedings of the XX International Grassland Congress: Offered papers*, *Dublin, 2005*. p. 333.

Ndove, T.S., Whitbread, A.M., Clark, R.A. and Pengelly, B.C. (2004) Identifying the factors that contribute to the successful adoption of improved farming practices in the smallholder sector of Limpopo Province, South Africa. In: Whitbread, A.M. and Pengelly, B.C. (eds) *Tropical legumes for sustainable farming systems in Southern Africa. ACIAR Proceedings* No. **115**, 146–154.

Neill, S.P. and Lee, D.R. (2001) Explaining the adoption and disadoption of sustainable agriculture: the case of cover crops in northern Honduras. *Economic Development and Cultural Change*, **49**, 793–820.

Omore, A., Muriuki, H., Kenyanjui, M., Owango, M. and Staal, S. (1999) The Kenyan dairy sub-sector: a rapid appraisal. *Ministry of Agriculture/Kenya Agricultural Research Institute/International Livestock Research Institute Smallholder Dairy Project Report, ILRI, Nairobi, Kenya.* 37pp.

Pengelly, B.C., Whitbread, A., Mazaiwana, P.R. and Mukombe, N. (2003) Tropical forage research for the future — better use of research resources to deliver adoption and benefits to farmers. *Tropical Grasslands*, **37**, 207–216.

Pengelly, B.C., Whitbread, A., Mazaiwana, P.R. and Mukombe, N. (2004) Tropical forage research for the future — better use of research resources to deliver adoption and benefits to farmers. In: Whitbread, A.M. and Pengelly, B.C. (eds) *Tropical legumes for sustainable farming systems in southern Africa. ACIAR Proceedings* No. **115**, 28–37.

Pengelly, B.C., Cook, B.G., Partridge, I.J., Eagles, D.A., Peters, M., Hanson, J., Brown, S.D., Donnelly, J.L., Mullen, B.F., Schultze-Kraft, R., Franco, A. and O'Brien, R. (2005) Selection of Forages for the Tropics (SoFT) — a database and selection tool for identifying forages adapted to local conditions in the tropics and sub-tropics. *Proceedings of the XX International Grassland Congress: Offered papers*, *Dublin, 2005.* p. 348.

Peters, M., Argel, P., Burgos, C., Hyman, G.G., Cruz, H., Klass, J., Braun, A., Franco, A. and Posas, M.I. (2000) Selection and targeting of forages in Central America linking participatory approaches and geographic information systems — concept and preliminary results. In: Stür, W.W., Horne, P.M., Hacker, J.B. and Kerridge, P.C. (eds) *Working with farmers: the key to adoption of forage technologies. ACIAR Proceedings* No. **95**, 63–66.

Peters, M., Horne, P., Schmidt, A., Holman, F., Kerridge, P.C., Tarawali, S.A., Schultz-Kraft, R., Lascano, C.E., Argel, P., Stür, W.W., Fujisaka, S., Müeller-Sämann, K. and Wortman, C. (2001) The role of forages in reducing poverty and degradation of natural resources in tropical production systems. In: *Agricultural Research and Extension Network Paper* No. **117**, *ODI, London.* 12 pp. <http://www.odi.org.uk/agren/papers/agrenpaper_117.pdf>

Peters, M. and Lascano, C.E. (2003) Forage technology adoption: linking on-station research with participatory methods. *Tropical Grasslands*, **37**, 197–203.

Phaikaew, C., Ramesh, C.R., Yi Kexian and Stür, W. (2004) Utilisation of *Stylosanthes* as a forage crop in Asia. In: Chakraborty, S. (ed.) *High-yielding anthracnose-resistant* Stylosanthes *for agricultural systems. ACIAR Monograph* No. **111**, 65–76.

Phaikaew, C. and Hare, M.D. (2005) Stylo adoption in Thailand: three decades of progress. *Proceedings of the XX International Grassland Congress: Offered papers, Dublin, 2005.* p. 323.

Piggin, C. (2003) The role of *Leucaena* in swidden cropping and livestock production in Nusa Tenggara Timur province, Indonesia. In: da Costa, H., Piggin, C., da Cruz, C.J. and Fox, J.J. (eds) *Agriculture: new directions for a new nation. ACIAR Proceedings* No. **113**, 115–129.

Rains, J.P. (2005) Stylos: the broad acre legumes of N Australian grazing systems. *Proceedings of the XX International Grassland Congress: Offered papers, Dublin, 2005.* p. 332.

Ramesh, C.R., Chakraborty, S., Pathak, P.S., Biradar, N. and Bhat, P. (2005) Stylo in India — much more than a plant for the revegetation of wasteland. *Proceedings of the XX International Grassland Congress: Offered papers, Dublin, 2005*. p. 320.

Robertson, A.D. (2005) Forage *Arachis* in Nepal: a simple success. *Proceedings of the XX International Grassland Congress: Offered papers, Dublin, 2005*. p. 321.

Roothaert, R. and Franzel, S. (2001) Farmers' preferences and use of local fodder trees and shrubs in Kenya. *Agroforestry Systems,* **52** (3), 239–252.

Russell, D. and Franzel, S. (2004) Trees of prosperity: agroforestry, markets, and the African smallholder. *Agroforestry Systems,* **61–62** (1–3), 345–355.

Shelton, H.M. (2004a) Importance of tree resources for dry season feeding and the impact on productivity of livestock farms. In: Mannetje, L.'t, Ramiriz, L., Ibrahim, M., Sandoval, C., Ojeda, N. and Ku, J. (eds) *The importance of sylvopastoral system in rural livelihoods to provide ecosystem services. 2nd International Symposium on Silvopastoral Systems, Merida, Mexico.* pp. 158–174.

Shelton, H.M. (2004b) Perspectives on forage tree legumes. In: Reynolds, S.G. and Frame, J. (eds) *Grasslands: developments opportunities perspectives*. pp. 87–118. (FAO and Science Pub. Inc.).

Shelton, H.M., Piggin, C.M., Acasio, R., Castillo, A., Mullen, B.F., Rika, I.K., Nulik, J. and Gutteridge, R.C. (2000) Case studies of locally-successful forage tree systems. In: Stür, W.W., Horne, P.M., Hacker, J.B. and Kerridge, P.C. (eds) *Working with farmers: the key to adoption of forage technologies. ACIAR Proceedings* No. **95**, 120–131.

Sollenberger, L.E. and Kalmbacher, R.S. (2005) Aeschynomene and carpon desmodium: legumes for bahiagrass pasture in Florida. *Proceedings of the XX International Grassland Congress: Offered papers, Dublin, 2005*. p. 334.

Sumberg, J. (2002) The logic of fodder legumes in Africa. *Food Policy*, **27**, 285–300.

Tarawali, S., Thornton, P. and de Haan, N. (2005a) Planted forage legumes in west Africa. *Proceedings of the XX International Grassland Congress: Offered papers, Dublin, 2005*. p. 318.

Tarawali, S., Okike, I., Kristjanson, P.K., Singh, B.B. and Thornton, P. (2005b) Dual-purpose cowpea for west Africa. *Proceedings of the XX International Grassland Congress: Offered papers, Dublin, 2005*. p. 317.

Thomas, D. and Sumberg, J. (1995) A review of the evaluation and use of tropical forage legumes in sub-Saharan Africa. *Agriculture, Ecosystems and the Environment*, **54**, 151–163.

Tuhulele, M., An, L.V., Phengsavanh, P., Ibrahim, Nacalaban, W., Yen Hai, V.T., Tan Khanh, T., Tugiman, Heriyanto, P., Asis, P., Hutasoit, R., Phimmasan, H., Sukan, Ibrahim, T., An, B.T., Magboo, E. and Horne, P.M. (2000) Working with farmers to develop forage technologies — field experiences from the FSP. In: Stür, W.W., Horne, P.M., Hacker, J.B. and Kerridge, P.C. (eds) *Working with farmers: the key to adoption of forage technologies. ACIAR Proceedings* No. **95**, 54–62.

Valentim, J.F. and Andrade, C.M.S. (2005a) Tropical kudzu (*Pueraria phaseoloides*): successful adoption in sustainable cattle production systems in the western Brazilian Amazon. *Proceedings of the XX International Grassland Congress: Offered papers, Dublin, 2005*. p. 328.

Valentim, J.F. and Andrade, C.M.S. (2005b) Forage peanut (*Arachis pintoi*): a high yielding and high quality tropical legume for sustainable cattle production systems in the western Brazilian Amazon. *Proceedings of the XX International Grassland Congress: Offered papers, Dublin, 2005*. p. 329.

Wickham, B., Shelton, H.M., Hare, M.D. and de Boer, A.J. (1977) Townsville stylo seed production in northeast Thailand. *Tropical Grasslands*, **11**, 177-187.

Williams, M.J., Quesenberry, K.H., Prine, G.M. and Olson, C.B. (2005) Rhizoma peanut — more than a 'lucerne' for subtropical USA. *Proceedings of the XX International Grassland Congress: Offered papers, Dublin, 2005*. p. 335.

Wortman, C. and Kirungu, B. (2000) Adoption of legumes for soil improvement and forage by smallholders in Africa. In: Stür, W.W., Horne, P.M., Hacker, J.B. and Kerridge, P.C. (eds) *Working with farmers: the key to adoption of forage technologies. ACIAR Proceedings* No. **95**, 140–148.