Forages for the Red Soils Area of China

Proceedings of an International Workshop, Jianyang, Fujian Province, P. R. China, 6–9 October 1997

Editors: J.M. Scott, D.A. MacLeod, Minggang Xu and A.J. Casanova

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MULTI-DIMENSIONAL AGRICULTURE — A PROMISING SUSTAINABLE AGRICULTURAL MODEL FOR SLOPING LAND

Liu Chungchu[1], Weng Boqi[1] and Liu Xiashi[2]

[1] Fujian Academy of Agricultural Science, 247 Wuxi Road, Fuzhou, Fujian 350003, P. R. China
[2] National Azolla Research Center, Fuzhou, Fujian, P. R. China

Abstract

This paper describes a sustainable agricultural model for hilly red soil regions. The model, called 'multi-dimensional agriculture for sloping land', incorporates fruit and tea orchards interplanted with forages to preserve water and soil, and to be utilised for animal husbandry. Animal residues are utilised to culture edible fungi and develop biogas, and finally biogas liquid is applied as manure/ fertiliser to trees, thus improving the quality of the fruit. A favourable nutrient cycle is established that leads to better economic and ecological results.

INTRODUCTION

In mountainous areas of southern China, the two principal causes of serious soil erosion are the over-exploitation of forests and the planting of fruit orchards and tea tree plantations on a large scale. In recent years the problem of over-exploitation of forests has been largely overcome by the government paying attention to re-afforestation. This paper concentrates on the problem of soil erosion in orchards. In Fujian province, for instance, orchard areas occupy more than 10% of the total land area, and are increasing at the rate of 5000 km^2/year. It is important to know how to control soil erosion in the orchard areas, especially when they are located on sloping land.

The construction of a multi-dimensional layer cropping model

A comprehensive scheme has been developed to control soil erosion in combination with the productive development of hilly areas. It has been designated as a 'multi-dimensional agricultural model for sloping land', and is based on techniques which permit high fruit yields, the interplanting of high-quality fodder in the orchard areas and developing a functional nutrient recycling system (Table 1).

DESCRIPTION

Selection of grass species

Planting grass is a key feature for controlling soil erosion as well as for developing more productive systems. With cooperation from Australia (ACIAR and the University of New England), more than 100 forage legumes and grasses from other countries were evaluated. After screening, the most suitable species found to grow in Fujian were Wynn cassia (*Chameacrista rotundifolia*), grazing peanut (*Arachis pintoi*), Premier finger grass (*Digitaria eriantha*), Bahia grass (*Paspalum notatum*), white clover (*Trifolium repens*), cocksfoot (*Dactylis glomeratum*) and hybrid *Pennisetum* spp. These were interplanted in orchard areas and harvested to assess yield potential (Table 2).

The orchard terraces, banks and walls were planted with different forages. Generally, on the level terraces, legumes such as Wynn cassia, white clover and *Arachis pintoi* were planted, to provide a continuous supply of quality forage. Bahia grass was planted around the edges of the paths in the orchards. The terrace walls were planted with broad-leaf paspalum, Bahia grass, or elephant grass. In some cases, a mixture of white clover, white radish and ryegrass was sown in the winter season. Within 1 m of orchard tree trunks, only dry mulch was used.

Combining forages with livestock husbandry

The raising of geese requires approximately 30 m^2 of forage production area for each mature goose.

Forages fed to pigs or fish can be either green or dried.

Approximately 0.8–1 ha of forage is required to support each cow.

Table 1. The structure of a multi-dimensional agricultural model for hilly land in southern China.

Aims: to prevent soil erosion and to improve ecosystem functions			
Structure (within one watershed)		**Function and efficiency**	
Top of hilly land	Mixed plantings of trees for timber and bamboo; fast-growing trees; shrub plants	To control soil erosion at the source and to conserve water	Selectively cut timber and bamboo; fast-growing trees increase profits both in the short- and long-term
Middle part of the hill	Plant fruit orchards and tea plantations, using contoured terraces with water-draining ditches; plant leguminous fodder on terraced surfaces; grow grasses and leguminous plants on terrace wall to limit erosion	Effectively control soil erosion in orchard; prevention of drought and improvement in ecological functions	Increased fruit quality; improved farmers' income and cost savings
Foot of the hill	Agriculture and animal husbandry; mushroom production; rice–azolla–fish system; biogas	Comprehensive development involving • feeding animals with forages; • growth of mushrooms in media supplemented with forages; • develop biogas; • biogas liquid for growing grass and biogas residual for fertilising fruit trees	• Forages in feed for pigs may save 10–30% concentrated feed. • Development of forage feeding of animals, such as cattle, sheep, geese etc. • Provide feed to fish in paddy field • Decrease of 15–20% in chemical fertiliser; farmers increase their income by up to 8000 yuan/ha

Table 2. The yield and nutrient value of interplanted forages grown on sloping orchard land.

Species	Fresh yield (kg/ha)	Nutrient content			Harvest date
		Crude protein	Fibre	N-free extraction	
Wynn cassia	29,010	16.40	28.41	42.71	20 October 1992
Pennisetum spp.	86,370	7.75	31.61	34.23	29 February 1992
White clover	14,010	24.70	25.38	36.75	27 April 1992

Combining forages with mushroom production

Dried and powdered forages, such as broad-leaf paspalum, Premier finger grass, Wynn cassia, Bahia grass and *Pennisetum* spp., can be mixed and used as a component of the media used for growing wood-ear mushrooms, straw mushrooms and golden-needle mushrooms, thus leading to savings of 15–45% of the fine medium typically used.

Biogas production

The grasses growing on terrace walls in the orchard area are cut and mixed with dung of cows, sheep, ducks and geese to produce biogas. It has provided the energy source for farmers' lighting and fuel. After biogas production has finished, the residual biogas liquid is applied to orchards as an organic manure to enhance fruit tree growth.

The benefits of using this technique

Yield and quality

Interplanting fodder grasses in orchard areas decreases soil erosion and improves soil fertility, and the fermentation residues of biogas serve as organic manure for fruit trees. This practice not only increases fruit yield but also improves quality. The amount of fruit of larger size is increased, so the benefit also increases.

Table 3 shows that yields of Nai-apple in erosion-controlled areas were 39% and 28% higher than the control areas in 1994 and 1995 respectively. The resulting production benefit is reflected in higher profits per tree and an improved output:input ratio (Table 4).

Table 3. The effect of controlling soil erosion on the yield of Nai-apple. Data presented are the average values obtained from 30 trees of each treatment.

Treatment	1994		1995	
	Average yield (kg/plant)	Proportion of large size fruit (%)	Average yield (kg/plant)	Proportion of large size fruit (%)
Control	11.3	46.3	14.1	39.0
Interplanted with forages	15.7	57.7	18.1	50.5

Table 4. Comparison of economic benefits of controlling soil erosion with interplanted forages on Nai-apple orchard land.

Treatment	Investment costs (yuan/plant)				Price (output)		
	Labour	Fertiliser	Pesticide	Management fee	Total costs	Value of production (yuan/plant)	Value: input cost ratio
Control	2.3	1.6	2.2	0.4	6.5	23.4	3.6
Interplanted with forages	3.0	1.2	1.8	0.7	6.7	33.5	5.0

Table 5. Soil fertility changes in a Nai-apple orchard at Jiang Kou, Fujian.

	Before underplanting (1991)	After underplanting (1994)	Increase/decrease (%)
pH (H_2O)	4.8	5.2	+8
Organic matter (%)	1.0	1.3	+15
Available N (ppm)	47.6	58.5	+23
Available P (ppm)	2.3	3.5	+53
Available K (ppm)	30.4	38.9	+28
Bulk density	1.13	0.95	–16

Livestock production

The forage growth in orchards is sufficient to support approximately 1 cow/ha, resulting in an annual cost saving of feed of about 755 yuan. The use of forage powder can substitute for 12.8% and 15% of the concentrated feed for pigs and egg-laying ducks respectively without any production penalty. Such substitution resulted in the egg-laying rate of ducks being increased by 8.7%, while the costs fell 17.4%. The use of mixed forage powder to substitute for 15–45% of the growing medium and adding 5–10% biogas residue has resulted in increased yields of wood-ear mushroom and rice straw mushroom of 13.6% and 16.7%, respectively, compared with the control. The five types of amino acids in mushroom were also present in higher amounts than those in the control group.

The application of this ‘multi-dimensional agricultural model’ was also found to improve soil fertility on sloping orchard land. After being planted to forages continuously for three years, the organic matter in red soil increased while the bulk density decreased (Table 5). Soil erosion also decreased. At the same time, there was an increase in income of approximately 8000 yuan/ha. For these reasons, this integrated development model for sloping orchard land, stressing the prevention of soil erosion, has been welcomed by local farmers.

CONCLUSIONS

Although farmers’ incomes have improved in recent years, the need for improvements in agricultural technology continues. Agricultural technology should first be easy to implement; second, beneficial to agricultural production; and third, should result in economic benefits. If these criteria are not met, it will not be adopted by farmers. If technology is concerned only with controlling soil erosion, farmers will be unwilling to accept it. If forages planted are used only for animals, the farmers’ benefit will not be sufficient to encourage adoption. The development of animal husbandry greatly depends on the availability of markets as well as quality products. The ‘multi-dimensional agricultural model’ of comprehensive development takes forage culture and soil and water preservation as its core, and then builds in animal husbandry, the culture of edible fungi, the production of biogas, the application of biogas liquid to fruit trees, and the production of improvements in fruit size and quality. With this model, farmers can achieve comprehensive benefits and thus readily adopt the technology. This is one of the best characteristics of the model — that it combines agricultural and ecological benefits with economic benefits to the farmers. Under these conditions, forage systems can be developed more quickly.

RED SOILS II AREA DEVELOPMENT PROJECT — A FARMING SYSTEMS APPROACH TO RED SOIL DEVELOPMENT

Richard H. Chisholm[1] and John L. Stemp[2]

[1] Natural Resources and Environmental Management Consultant, Canberra, Australia
[2] Agronomist and Task Manager, Red Soils II project, World Bank, Washington D.C. USA

Abstract

World Bank assistance for the development of under-utilised, degraded red soils in southern China has comprised two projects. The first Red Soils Area Development Project (RSI) was a pilot which developed relatively favourable sites covering 27,000 ha in Jiangxi and Fujian and was completed in 1991. The second project (RSII), which started in 1993, is located in Guangxi, Hunan, Jiangxi, Fujian and Zhejiang provinces and has a project area of about 53,000 ha. It is based on a small watershed approach to development which encompasses a broader range of site conditions than RSI. The project, which is due to be completed in June 2000, includes 217 small watersheds of about 60–750 ha and aims to develop replicable, sustainable models for further development of the red soils of southern China.

The opportunities for expansion of arable land in China are limited and the red soils areas, covering 20 million sq km south of the Yangtze, are a major under-developed resource. The main focus of RSII is on development of degraded upland areas for agriculture, horticulture, forestry and animal production. Severe degradation of large areas of red soils means that several years of improvement by adding organic matter has to be undertaken. Because of concern over loan repayments there has previously been an emphasis on activities (e.g. citrus production) which give the fastest returns on investment but may threaten the sustainability of development. The model adopted was designed for both sustainability and acceptable income generation. Several problems emerged in RSI: lack of crop diversification, marketing concerns due to over-planting of citrus in South China, and sustainability of technologies adopted (e.g. reliance on imported potassium fertiliser). To address these problems a livestock component integrated into orchards' was adopted, to provide cash income and manure for land improvement.

Land development was based on small watersheds with areas above 25° slope planned for forestry, mid-slopes between 5° and 25° for orchards and annual cropping, and areas below 5° for paddy cultivation. Terraces and vegetative hedges were constructed on mid-slopes, with grassland and forestry on steeper slopes. Planning has been based on individual household units combining orchards, animal production, intercropping of annual crops and lowland paddy production in over 217 watersheds. The major difficulties encountered so far include: faulty terrace construction works, lack of familiarity with upland irrigation design, and slow adoption of agroprocessing. Despite these difficulties the project's approach to development has been enthusiastically accepted by farmers and net per capita incomes in 1996 were 978 RMB compared with 816 RMB in non-project areas. Reasons for this success include integration of animal production with orchards, with farmers currently earning net margins of 100 RMB per pig fattened; income from annual intercropping peanuts, brassicas and maize; and improved orchard management.

The World Bank continues to support red soil development and is following with interest the work of ACIAR in its development of low cost approaches to the problem. The Bank has adopted many of the findings of this research in its own recommendations, particularly those on fertiliser requirements. Experience gained under the second Bank-funded project is also providing useful lessons in refining red soil area development models that may be more cost effective and affordable for wider adoption in future.

INTRODUCTION

WORLD BANK assistance for the development of under-utilised, degraded red soils in southern China has comprised two projects. The first Red Soils Area Development Project (RSI) was a pilot which developed relatively favourable sites covering 27,000 ha in Jiangxi and Fujian and was completed

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BACKGROUND

China's agriculture must support a population of over 1.2 billion people, although China's agricultural land base is exceptionally small relative to its large population and geographic area. The opportunities for expansion of arable area are limited and the red soils areas, covering 20 million sq km south of the Yangtze River (with 8 million ha in Hunan alone), are a major under-developed resource.

As incomes rise, an increasing share of the gross value of agricultural output is being taken by fruit, vegetables and animal products. Moreover, local governments have placed a high priority on developing uplands, natural pasture and water resources for expanding productivity and production of non-staple and commercial crops as a means of increasing farm income. As a result, the focus of RSII is on upland development. Although rehabilitation of irrigated valley bottoms is being undertaken through drainage and irrigation improvement as part of the watershed approach, the main emphasis is on development of degraded upland areas for agriculture, horticulture, forestry and animal production.

The areas to be developed under the project in Guangxi, Hunan and Jiangxi are located in broad, open valleys with slopes of 5–15°. In Fujian and Zhejiang, the sites are typically located in narrow, steep-sided valleys. Elevation varies from 50–1000 metres above sea level across the project sites and the difference in relief within a watershed is typically about 100 metres.

INTENSIVE VERSUS EXTENSIVE HOUSEHOLD MODELS

The severely degraded nature of large areas of red soils in the project area means that several years of improvement by organic matter addition (to counteract the dual effects of acidity and iron and aluminium toxicity) be undertaken before rehabilitation is fully effective. This is sometimes difficult for local authorities to accept because of their concerns over loan repayments. There is therefore a tendency to favour activities (e.g. citrus production) and methods of development (e.g. dense planting) that offer the fastest returns on the investment, but may threaten the sustainability of the development. The model adopted for the project was designed for both sustainability and acceptable income generation. However, there are several critical constraints to overcome:

- The resident population is poor, with some 25% of the households in the project area below the absolute poverty threshold income. As a result, farm sizes must be within the means of poor families to develop, yet produce adequate income at full development to support 4–5 people. Existing households commonly operate 0.35 ha arable irrigated (paddy) land and 0.29 ha of dryland, producing maize, sweet potato, brassicas, peanuts and fruit on scattered dryland orchards.
- The climate can be extreme with winter minimum temperatures of minus 12°C and summer maxima in excess of 35°C. A two to three months summer drought occurs over most of the project area.
- The soils are predominantly high in exchangeable aluminium, have a low pH (4.5–5.5) and are limited by deficiencies of phosphorus, nitrogen, potassium, magnesium and calcium, as well as the micronutrients boron, zinc and molybdenum.
- Soil erosion is serious (Lu and Shi, 1991), covering 21% of land area in Jiangxi, and occurs at rates of 5–10,000 tons/sq km on Quaternary red clay soils in project areas.
- Despite the excellent work being done in south China on forages for red soils (Horne et al., 1991 eds.), the Bank and Chinese preparation teams could not identify any particular strategies for forage development or native pasture improvement based on extensive methods which would be sufficiently attractive financially to the borrower, whose key concern was ability to repay a loan. The experience is that forage development shows promise in favourable higher altitude areas of Fujian, parts of Hubei, Guizhou and possibly in Guangxi using tropical species. However, summer drought and winter cold still limit yields of grasses and survival of the legume component in areas such as Hunan and Jiangxi. Similarly, China had already developed large areas with low input plantations of tung oil producing trees and tea oil shrubs, but the plantations were languishing for lack of markets.

For these reasons, an intensive model for household development was seen as necessary to support household development. The key determinants identified were:

- An approach based on development of small watersheds encompassing forestry on hilly areas, sloping land development for high value crops and improvement of lowland irrigated areas.

- Irrigation improvement and drainage to stabilise food crop output in the lowlands and ensure stable yields in the upland areas.
- Orchard development to provide stable incomes from small areas at full development.

NEW INITIATIVES

The approach outlined above, however, had already been tried in RSI, albeit on the most favourable available sites that avoided the steeper and less fertile areas. While they resulted in a project with good returns on the investment, several problems emerged. Firstly RSI had not taken particular note of sustainability or environmental protection concerns. *Crop diversification* was seen as a critical omission in RSI. In December 1991, an extreme cold front destroyed or damaged large areas of citrus and tea plantations in the RSI areas. Subsequent analysis of meteorological data demonstrated a recurring pattern of low minimum winter temperatures at about 7 yearly intervals. Clearly, deciduous fruits, citrus, tea, medicinal crops such as gingko and nut crops such as chestnut, offer a more stable farming system at household level. Reliance on one crop, such as ramie, as a sole source of household income also proved unsound when the market collapsed for the product in 1988 as this resulted in even greater poverty for some participating households.

Indeed *marketing* was a major concern for project designers, given past and continuing concern at the extent of overplanting of citrus in south China, and the need to produce products which could be differentiated by their quality, which in turn requires superior production and processing techniques.

Sustainability of the technologies employed was also a concern. Very large inputs of fertilisers had been used on RSI but with little attention to environmental sustainability or household financial viability. Almost all of China's potassium fertiliser is imported and although nitrogen fertiliser is available it is often of low quality. A technology based on soil improvement through the use of locally produced organic amendments was clearly needed. To make developments financially sustainable for the beneficiaries in the years before orchards reached bearing, *a livestock component, integrated into the orchards*, rather than developed as a separate agroenterprise as in RSI, was adopted to provide cash income and manure for land improvement. Agroprocessing enterprises were incorporated as vertically integrated components to provide added value and employment opportunities.

Integrating the initiatives into a watershed design

Land use planning

The first step in designing the small watersheds was to divide the areas using accepted local methods into land uses according to slope. Areas above 25° were planned for forestry, mid-slope areas between 5 and 25° were allocated to orchard development and annual cropping. Areas below 5° were almost always existing paddy cultivation. Conservation measures consisted of terraces on lands from 8–25° slope, with forestry and grasslands on steeper slopes. Lower slope areas were to be developed for orchards or annual crops using vegetative hedges of Vetiver (*Vetiver zizanoides*), Premier finger grass (*Digitaria smutsii*) and paspalum (*Paspalum wettsteinii*). Counterpart staff prepared soils and land use maps on this basis, after selecting watersheds with the basic resources of wasteland, access to irrigation water and available labour.

The household model

Within the mid-slope areas, the next step was to decide the design of an individual household unit. With the change from communal to household responsibility in the project areas, the project was designed to be implemented primarily using the labour requirements of an individual household. Labour balances for all development and operating activities that would comprise an annual cycle of activity (trenching, terracing, tree maintenance, animal production, crop harvest, etc) were constructed assuming an available labour of 2.4 persons per family, with 25% under-employed labour and thus 1.8 labour units per farm or about 600 labour days per year. This volume of labour was calculated as adequate for development of a farm model based on about 0.4 ha of orchard, 0.13 ha of paddy and 0.06 ha of vegetables and forage, or approximately 0.6 ha in total. Labour requirements could be met from household labour until year 10 and even then the excess was within the 25% allowance for existing under-employed labour. On this basis, development proceeded assuming an orchard area of about 0.3–0.7 ha within a total farm area of between 0.5 and 1.5 ha. On the smaller farms, higher value fruits such as grapes, kiwi, longan and lychee were to be substituted for deciduous fruit and citrus. In all cases a mix of orchard trees rather than a single crop was planned to provide a buffer against climatic and market variability.

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To supply a contribution to their own organic fertiliser requirement, the household units were designed around an organic matter balance assuming inputs as paddy straw, residues from annual crop and intercrop areas and from pig manure. Outputs were the pig manure, green manure and rice straw requirements for initial incorporation into contour trenches under the trees, and the straw and fodder requirements for livestock production and fuel.

Most project areas had already achieved the national goal of 1 pig per mu of irrigated area. The organic matter balance showed that about 3 pigs per mu of orchard would be needed for orchard establishment and maintenance. The basic household model therefore incorporated between 20 and 60 pigs for fattening annually in two cycles. Some households were based on pig breeding using 7–8 sows, or 250 ducks and fish ponds of about 0.5 ha . Others used poultry (100/mu), geese (25/mu), ducks (50/mu) and, occasionally, cattle (0.5/mu) in addition to paddy and orchard areas. Some specialised dairy households were based on 1 ha of forage and purchased concentrates, with 4 heifers breeding ultimately to 8 milking cows. This specialization was to be implemented in Jiangxi and Zhejiang.

Project feasibility studies included plans to maximise early returns by use of high density plantings in orchards. However, the nature of the soils involved demanded ongoing inputs of organic matter, for which intercropping of annual crops (to achieve early cash flow before bearing) and legumes (to supply nitrogen and high quality crop residues for animal feed and soil maintenance) would be later needed. Project standards were therefore set to limit orchard density and regulate tree spacing to achieve intercropping over a sustained period. Lower densities were also seen as a means of assisting production of larger, higher quality fruit, which is in demand in the market. Similarly, upper slope and agroforestry planting densities were reduced to a maximum of 1650 trees/ha of any species to provide for higher quality timbers.

A total of 35 ‘technical standards’ including upland development, roads, forestry, irrigation design, rural energy from biogas digesters, infrastructure, water requirements for humans and animals, and staff training were ultimately included in the Staff Appraisal Report (Anon. 1994) as minimum standards, which project implementers were to meet during construction.

IMPLEMENTATION EXPERIENCE

Given the extent of the project — with over 217 watersheds and the relative complexity of individual household units combining orchards, animal production, intercropping of annual crops and lowland paddy production — problems with the implementation of the project at farm level were to be expected. The major difficulties experienced so far have included:

- Farmers and project staff at county level have been slow to recognize that *level* terraces constructed on the contour were necessary for orchards. Initially, many developments were constructed off contour, without vegetative protection and without necessary arrangements for drainage. Concentration of flow would have ultimately destroyed many of these terraces and they had to be reconstructed to project standards. Demonstration areas of 20 ha per watershed were used for initial practical training of farmers. For many years, bulldozers were used for terrace construction by experienced operators at Lingling demonstration farm, Hunan. However, in the hands of inexperienced operators, they proved unsuitable elsewhere in the project and were withdrawn in favour of hand labour.
- Irrigation development using pipe systems to supply water from hilltop reservoirs to hand held sprinklers has not proven easy. Despite previous experience in Hunan at the Lingling demonstration farm, most staff of the county level Bureaus of Water Resources were not familiar with upland irrigation designs. Assistance from provincial staff and study tours have been necessary for design staff.
- In a rapidly expanding economy, the availability of counterpart funds for construction of roads, buildings, pumping stations and power facilities has been restricted. This has slowed the pace of implementation and sometimes contributed to sub-standard developments.
- Implementation of agroprocessing, initially thought to be a very attractive part of the project, financially has been rather disappointing. Insufficient attention was paid to marketing aspects, and management of financial and physical resources relied on inexperienced staff. Inefficient designs for processing resulted from a reluctance to use foreign technical assistance and the modern design principles which such expertise might have been able to apply.
- It proved difficult to convince some local governments that the project objective was to develop practical working models for red soil development, not showcases.

Despite these difficulties, the major success of the project's high input style of development has been its enthusiastic acceptance by farmers in all areas. Despite the costs which project farmers have had to bear, and the lack of income from orchards to date, net per capita incomes across 41 watersheds in 1996 were 978 RMB compared with 816 RMB in non-project areas. Watershed development is about 80% complete, with most areas expected to exceed initial targets for land development and crop establishment. The reasons for this include:

- Despite early reluctance by planners, integration of animal production with orchards has been a major factor in boosting household incomes. Farmers currently earn net margins of about 100 RMB per pig fattened, partly because they are not totally reliant on purchased feeds as a result of early planning for annual crop intercropping. Farmers utilise pig manure enthusiastically as a substitute for inorganic fertilisers on trees and crops, reducing their costs and increasing project sustainability. Where fertiliser has been purchased, it has been predominantly local calcium magnesium superphosphate — a cheap and effective fertiliser as proven by ACIAR project 8725 in Hunan.
- Annual crop incomes from intercropping peanuts, brassicas and maize also contribute directly to improved living standards. Improved drainage in the lowlands, a practice already well known to farmers, has boosted paddy yields in areas with iron and manganese toxicity problems.
- Most orchards are not at bearing stage but will reach bearing within 1–2 years and should produce considerable increases in income. Tree growth is vigorous as a result of care in trenching, organic matter incorporation and the placement of topsoil around the roots of seedlings. The use of only first class virus free seedlings also has contributed to vigorous early growth.

As a result of these practical benefits, farmers' contributions to project funds have universally exceeded initial estimates and previously pessimistic local governments have at least seen some success in improving wasteland resources.

THE FUTURE

Experience to date suggests that the present model will require modification to reduce investment costs to more affordable levels for wider adoption on a large scale. There has been a tendency to spare no expense in development in order to meet targets. Project staff admit that costs for development might be reduced by 30–40% from current levels of 7500–9000 RMB/ha for land development and 20–25,000 RMB/ha for crop establishment. Such inputs place a severe strain on the resources of local government. However, what is not yet clearly understood is the financial impact of orchard harvests on incomes and tax revenues. Much will depend on whether the promising early growth of orchards is matched by good yields in years 5–10.

The mid-term review recommended that ways to reduce the cost of development be sought across the project in the remaining period of project life. Some examples might include:

- Developing contiguous watersheds so as to gain economies of scale from infrastructure and management investments. In the ongoing project, demonstration of value across a range of watersheds was sought. However, for practical implementation, a tighter grouping of developments could well be more cost effective.
- Revised standards for terracing. Areas below 8° have often been terraced when this was never required. It has been difficult to persuade farmers and project staff not to adopt some form of terracing. However, research under the project in Fujian has shown that contour planting and ground covers of *Arachis pintoi* can be equally effective in reducing erosion.
- More critical appraisal of agroprocessing investments. In many cases, earlier investments by companies based in Guangdong have achieved dominance in the market, particularly for fruit juices, and the project investments have been at too small a scale to be competitive.
- More selectivity in choosing areas to develop. While the greatest poverty commonly occurs in isolated mountainous areas, the most cost effective development might be possible in areas of broad open valleys, with minimum differences in relief for irrigation pumping and low slopes to minimise terracing.
- More cost effective irrigation design, with minimum use of sprinklers as a solution to irrigation of steep slopes. Hand held hoses and simple hilltop reservoirs can be effective if well designed.

CONCLUSION

The World Bank continues to support red soil development and is following the work of ACIAR in its development of low cost approaches to the problem with interest. The Bank has adopted many of the findings of this research in its own recommendations, particularly those on fertiliser requirements. Experience gained under the second Bank-funded

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project is also providing useful lessons in refining red soil area development models, which may be more cost effective and affordable for wider adoption in future.

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A STRATEGY FOR THE DEVELOPMENT OF THE RED SOIL AREAS OF SOUTHERN CHINA

D.L. Michalk

NSW Agriculture, Pasture Development Group, Orange Agricultural Institute Forest Road, Orange, NSW, Australia 2800

Abstract

Soils in the red soil region of south China have impoverished nutrient status and high levels of exchangeable aluminium. To achieve sustained production on these acid infertile soils, improvement programs must be undertaken to raise fertility sufficiently to enable plants to take full advantage of the favourable climatic conditions of the region. Attempts to quickly increase available nutrients by large fertiliser inputs are of limited value in these low cation exchange, kaolonitic soils that render nutrients unavailable through fixation processes or through leaching of them beyond the root zone. Rather, the development of low-input systems, in which the selection of appropriate pasture species and fertiliser inputs are focused initially on improving soil conditions primarily through an increase in the organic matter pool, is seen as a more feasible and sustained means of improving the productivity of red soil in south China. This review provides an example of a low-input soil management strategy, developed at Lechang Model Cattle Farm in north Guangdong Province, for well-drained, acid, inherently infertile Hapludult soils. Three stages of development are described through which individual paddocks may advance before high and sustained livestock or crop production can be achieved. In this program, a molasses grass/roundleaf cassia pasture that is very productive with low P and K inputs is recommended for Stage 1 because the >11 t DM/ha of top and root growth provides a significant boost to soil organic matter. With moderate P and K inputs and some soil improvement in Stage 1, better quality species such as setaria combined with lotononis, forage peanut or fine stem stylo showed promise for summer grazing by cattle in Stage 2. Lime application further increased the range of summer grasses and temperate species in Stage 2 development. Only after several years of rebuilding soil fertility and nutrient recycling under grazing can production of high-producing Stage 3 subtropical and temperate species be sustained without high annual fertiliser and lime inputs. Cash crops and forages can be integrated at strategic points in the soil improvement program to diversify income, provide more cattle feed at critical periods, stop weed invasion and break insect and disease cycles. Desirable and undesirable change in pasture composition provide a useful guide to changes in soil fertility and the appropriateness of management practices. While further research is required to refine some of the components of low-input soil improvement strategies for other locations in south China, such as the selection of the most suitable species and fertiliser combinations, this approach will result in sustained pasture and crop production on the red soils region, especially if supported by changes in social perceptions on livestock production and appropriate economic reforms.

INTRODUCTION

THE ability of countries within the tropical and subtropical zone to produce the food needed for expanding populations depends largely on more effective use of the resources available (Baird 1978). Concentrating on the weakest links in the current production process produces the best return for the physical effort and capital invested in developing agriculture and animal husbandry (Whiteman 1980). In China, the red soil region which extends from the Chang-jiang River in the north to the South China Sea in the south offers tremendous potential to relieve the food pressures resulting from China's increasing population (Cao 1991), provided some fundamental constraints to crop and livestock production can be overcome.

Soil acidity is the major problem that limits the development of the wasteland areas in tropical and subtropical regions, including south China. Although acid soils are found in temperate regions, they are more common in the tropics and subtropics where the combination of high rainfall and high temperature promotes rapid weathering of soil minerals and the loss of nutrients through leaching and erosion. These soils are important because of the magnitude of the land area affected. In tropical Asia, for example, more than 38% of the total land area (or 330 million ha) is classified as infertile acid soils (Sanchez and Salinas 1981). Within south China more than 70% of the 2 million km^2 of red soils (Flex-Henningsen et al. 1989) are strongly acid (Zhao and Shi 1986). This accounts for about 14% of the total land area of the

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nation, and includes more than 40 million ha of grassland (Hong 1985).

The soils in China's red soil region show marked horizontal and vertical changes brought about by the influences of bioclimatic and topographic conditions (Figure 1). For example, from south to north the soil distribution occurs as Oxisols, Ultisols and Inceptisols; from sea level upwards as Oxisols (50–300 m), Ultisols (300–800 m), Inceptisols (800–1000 m); and from east to west as Ultisols, Mollisols, Inceptisols and Entisols (Zhao and Shi 1986). The Chinese equivalents of these *Soil Taxonomy* orders and the areas of each compared to tropical Asia and world totals are shown in Table 1.

Acidity develops in soils as a result of leaching of base cations and their replacement with hydrogen and aluminium. In the well-drained acid soils in south China, aluminium rather than hydrogen is the cation mainly responsible for the exchangeable acidity which affects plant growth, particularly at pH <5. In turn, aluminium toxicity and acute deficiencies of phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) pose the major constraints to all but the most tolerant crops and pastures. While these nutrient deficiencies are common to most soils in tropical regions, there are continental differences in the impact of aluminium on plant growth with aluminium toxicity widespread throughout Latin America (Sanchez and Salinas 1981) and tropical Asia including China (Wen and Lin 1986), but infrequent in soils in northern Australia (Sanchez and Isbell 1979). The similarity between soils in China and South America suggest that tropical America may be a better source of species for China's rangeland improvement programs than Australia. This has already been demonstrated with the registration of 'Pi Hua Dou 184', a CIAT *S. guianensis* ecotype, as the first Chinese stylo cultivar (CIAT 1988) and more extensive testing program of CIAT lines is currently underway in Hainan Province (Clements et al. 1997).

In addition to aluminium toxicity and the impoverished nutrient status of red soils, analyses of the climatic regimes experienced in the southern provinces of Guangdong (Michalk et al. 1988; Michalk and Huang 1994), Hunan and Fujian (Horne 1991) have identified other fundamental constraints to agricultural development including periods of severe moisture deficit, low temperatures and frosting. North of the Nanling Range (25°N), which marks the boundary between subtropical and tropical zones (Chu and Yuan 1963), frequent drought in July/August severely affects pasture production (Horne 1991), whereas south of the Nanling Range in north Guangdong Province drought has a minimal effect on production (Michalk et al. 1994).

Despite these constraints, agricultural planners are keen to develop the large areas of barren red soil lands in south China for integrated crop and livestock

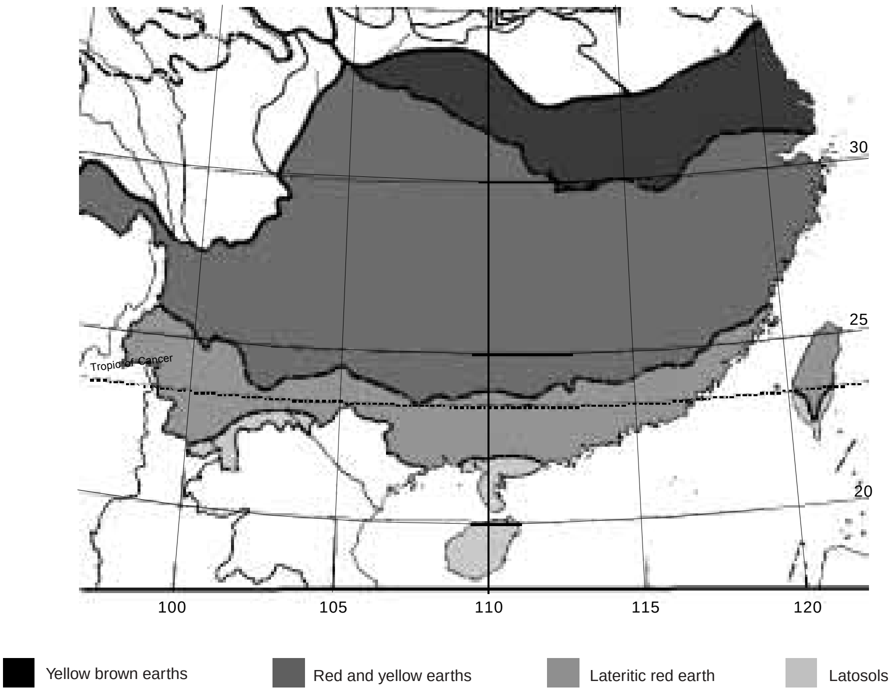

Figure 1. Soil map of south China (after Xi et al. 1990).

Table 1. Generalised distribution of soils in the tropics.

Soil association dominated by:	World total[1] (× 10^6 ha)	Tropical Asia[1] (× 10^6 ha)	South China[2] (× 10^6 ha)
Oxisols (Latosols, dry red earths)[3]	833 (23)[4]	15 (2)	6 (4)
Ultisols (Red earths)	749 (20)	286 (36)	83 (50)
Entisols (Purple soils)	574 (16)	75 (9)	10 (6)
Alfisols	559 (15)	123 (15)	?
Inceptisols (Yellow earths)	532 (14)	169 (21)	28 (17)
Vertisols	163 (5)	66 (8)	?
Aridisols	87 (2)	23 (3)	?
Mollisols (Limestone soils)	74 (2)	9 (1)	13 (8)
Andisols	43 (1)	11 (1)	?
Histisols (Paddy soils)	36 (1)	27 (3)	25 (15)
Spodosols	20 (<1)	6 (<1)	?
Total	3670	810	165

[1] Based on data from Sanchez and Salinas (1981) which includes temperate portions of India, Bangladesh and Indochina plus Papua New Guinea.
[2] Calculated from data and maps reported by Zhao and Shi (1986).
[3] Chinese equivalents to Soil Taxonomy groups.
[4] Area given first followed by percentage of total in brackets.

production as part of the national program to rapidly increase red meat and crop production from wastelands to feed China's expanding population (Xie et al. 1991). However, improvement of infertile, acidic red soils is a formidable task that will not be successful unless we follow the advice of Rao et al. (1993) and "collect sufficient data and facts upon which we can honestly base our recommendations which guarantee a decent living from agricultural enterprises". For south China, this means that we must find feasible ways to effectively alleviate the soil and water constraints of the region at minimal cost.

STRATEGIES TO IMPROVE ACID SOILS

There are two complementary approaches to improve plant growth on acid soils: (1) amend the soil conditions by applying lime and essential nutrients to suit the range of crops and pastures suited to the climatic conditions; (2) select species or cultivars that will tolerate the soil constraints with only minimal fertiliser inputs.

The elimination of soil constraints by applications of the necessary amounts of fertiliser and amendments can be considered as *high-input soil management technology*. While this approach is largely responsible for world food production keeping pace with population increase, its applicability diminishes in marginal lands where soil and water constraints are not easily overcome at low cost (Sanchez and Salinas 1981). In degraded environments such as the red soils region of China, where more than 35% of the area is affected by soil erosion to varying degrees (Shi 1986), research efforts are now directed towards developing *low-input soil management technology*. This approach does not attempt to eliminate the use of fertilisers or amendments but rather attempts to maximise the efficiency of purchased inputs by not necessarily aiming for maximum pasture production (Sanchez and Salinas 1981).

Low-input technology aims to rebuild soil fertility through planned manipulation of pasture species and fertiliser inputs to raise soil organic nitrogen and carbon levels (Sanchez 1976). This is a slow but sustainable process. In contrast, attempts to quickly build a bank of readily available nutrients are rarely successful in well-structured kaolonitic soils like those that predominate in south China. This is because the low cation exchange capacity cannot hold the applied nutrients (e.g. potassium, calcium and magnesium) in the root zone and they are either lost through leaching or rendered unavailable through fixation processes (e.g. fixing of phosphatic fertiliser by aluminium and iron oxide). Understanding the effects and interactions between fertiliser, amendments and the prevailing soil characteristics is central to the sustainable management of infertile, acid red soils.

The purpose of this review is to provide an example of a low-input soil management strategy developed at Lechang Model Cattle Farm in north Guangdong Province for well-drained, acid, inherently infertile soils. These red Hapludult soils, which belong to the Chinese groups 4-1-5 and 4-1-7 and are described as "red earths" (Anon. 1985), are a significant soil type occupying about 22% of the total area of Shaoguan Prefecture (Anon. 1986). Similar Hapludult soils account for 84% of the soils in south China identified as Ultisols by Zhao and Shi (1986).

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LOW-INPUT TECHNOLOGY: THE BASIS FOR SUSTAINED SOIL IMPROVEMENT ON ACID RED SOILS

Sanchez and Salinas (1981) outline three basic principles which underpin low-input soil management technology: (1) adaptation of plants to soil constraints rather than elimination of constraints to meet the plant's requirement; (2) maximisation of the output per unit of added fertiliser input; and (3) making advantageous use of favourable attributes of acid, infertile soils. A fourth principle that should be added to this list is management to increase soil organic matter. These four aspects were examined at Lechang Model Cattle Farm in a number of small plot experiments and field demonstrations. This information was then used to develop a soil improvement strategy for improvement of acid red soil.

Use of adapted pasture species

More than 400 species of economic importance contain ecotypes tolerant to acid soils (Duke 1978). These plants all have their centre of origin in regions dominated by acid soils where they have evolved physiological mechanisms to tolerate high aluminium levels and low phosphorus stress (Sanchez and Salinas 1981). Extensive screening of tropical pasture species for acid soil tolerance has been conducted in Australia (Burt et al. 1983), South America (Spain 1975; Schultze-Kraft and Giacometti 1979; CIAT 1981) and south-east Asia (Shelton and Humphreys 1975; Tudsi et al. 1989).

Although pasture species were introduced to China in the 1920s (Anon. 1924), little progress was made identifying species adapted to the red soil region until the 1980s when pasture testing programs were initiated at model farms in Hunan (Nan Shan Farm), Guizhou (New Zealand project, farm site unknown), Guangxi (Qian Jian Farm), Guangdong (Lechang Farm) and Hainan (Gaopoling Farm). Due to the inherently low soil N levels and the high cost of N fertiliser relative to the price of livestock products, these demonstration programs have all focused on developing grass-legume mixtures rather than fertilised grass swards. The role of legumes in mixtures is to provide symbiotically fixed N to the grass (via the animal and deposition in urine) and thereby to improve the nutritional content of pasture, particularly protein, P and Ca. The grasses are expected to provide the bulk of the energy to ruminant livestock because of their higher dry matter production (Sanchez 1976).

Studies conducted at Lechang Farm by Michalk and Huang (1994a, 1994b) provide an indication of the relative tolerance of pasture grasses and legumes to the acid conditions that exist on the red soils in subtropical China (Table 2). In these studies, species which responded to low rates of P (<18 kg P/ha/3 yr) and K (0–50 kg K/ha) on unlimed soil were classified as "tolerant", whereas "susceptible" species required lime application to lower aluminium saturation as well as higher P and K inputs to produce acceptable yield (Michalk et al. 1994).

Legumes

Since legumes are generally more susceptible to low soil pH than grasses, because of requirements for nodulation, the selection of adapted legumes is the most difficult part of low-cost pasture development on acid soils. However, since N deficiency affects almost all of the red soils region in China (Li 1986) as is the case in other tropical and subtropical regions (Sanchez and Salinas 1981), the use of legume-Rhizobium symbiosis to meet the N demands of plants in crop and pasture systems is the best known low-input soil management technology. Of the 88 legume accessions and cultivars tested on unamended soil at Lechang Farm only 7 yielded more than 1 t DM/ha (Table 2) with Wynn cassia (*Chamaecrista rotundifolia*), Miles lotononis (*Lotononis bainesii*) and Oxley fine-stem stylo (*Stylosanthes guianensis* var. *intermedia*) being the most consistent producing perennial legumes (Michalk and Huang 1994a). Forage peanut (*Arachis pintoi*), jointvetch (*Aeschynomene falcata*) and Maku lotus (*Lotus pedunculatus*) were slower to establish and did not reach peak production until three years after sowing. Wynn cassia and Maku lotus also proved to be useful legumes in Hunan (Zhang et al. 1991a). Once established, forage peanut is persistent in mixtures with a range of grasses, even when mis-managed (Lascano 1994), and further testing of the *Arachis* genus is warranted in south China.

Serradella (*Ornithopus compressus*), a legume that is widespread on acid and/or infertile light soils in Europe and sown to improve similar soils in southern Australia (Michalk and Revell 1994), was the only temperate legume to produce more than 1 t/ha on unamended red soil in the north Guangdong evaluation (Michalk and Huang 1994a). White clover (*Trifolium repens*) and subclover (*T. subterraneum*) survived on unlimed soils but yields were low (<0.75 t/ha) and deficiencies of essential plant nutrients were detected in plant top growth (Michalk and Huang 1992; 1993a). Zhang (1991b) also reported low yield and nutrient deficiencies in temperate species when grown on unamended red soil at Mengongshan, Hunan Province.

Table 2. Adaptability to soil conditions of grasses and legumes recommended for grassland improvement in north Guangdong Province (Michalk et al. 1994).

Botanical name	Common name	Expected yield[1] (t DM/ha)	Tolerance[2] to:					
			High Al	High Mn	Low Ca+Mg	Low P	Low K	Fire
GRASSES								
Brachiaria decumbens	Signal grass	2.58	M[3]	?	?	M	S	T
Cenchrus ciliaris	Buffel grass	0.32	S	S	S	S	S	T
Chloris gayana	Rhodes grass	1.46	S	?	?	S	?	T
Melinis minutiflora	Molasses grass	4.80	T	T	T	T	M	S
Panicum maximum	Guinea grass	1.67	T	T	?	S	S	T
Paspalum dilatatum	Common paspalum	0.90	T	T	T	S	S	T
P. plicatulum	Brownseed grass	2.72	T	T	T	T	?	T
P. notatum	Bahia grass	0.68	T	T	T	T	T	?
Pennisetum clandestinum	Kikuyu	0.34	?	?	?	S	?	?
Setaria sphacelata	Setaria (bristle grass)	2.71	T	?	T	T	S	?
LEGUMES								
Aeschynomene falcata	Jointvetch	2.12	T	?	?	T	T	?
Arachis pintoi	Forage peanut	1.08	T	?	T	M	M	?
Chamaecrista rotundifolia	Round-leaf cassia	2.24	T	?	T	T	S	?
Lotononis bainesii	Lotononis	1.05	T	T	T	T	S	?
Lotus pedunculatus	Lotus trefoil	1.96	T	?	T	M	?	?
Macroptilium atropurpureum	Siratro	0.31	T	S	S	T	T	M
M. lathyroides	Phasey bean	0.54	T	M	S	S	T	?
Ornithopus compressus	Yellow serradella	0.84	T	T	?	T	?	?
Stylosanthes guianensis	Common stylo	1.12	T	T	T	T	T	S
S. guianensis var. *intermedia*	Fine-stemmed stylo	1.62	T	T	T	T	T	T
Trifolium repens	White clover	0.42	S	S	S	S	S	?
T. subterraneum	Subclover	0.62	S	S	S	S	S	?

[1] Mean of evaluations conducted at Lechang Farm with variable fertiliser regimes and with or without companion legumes (or grasses) on unamended Hapludult soil (Michalk and Huang 1994a, 1994b).
[2] Based on Andrew and Robins 1969, 1971; Andrew and Hegarty 1969; Andrew et al. 1973; Andrew and Vanden Berg 1973; Spain. 1975; Sanchez 1976; Michalk and Huang 1992, 1993a and b, 1994a, 1994b; and personal observations.
[3] T = tolerant, S = susceptible, M = moderately tolerant, and ? = tolerance unknown.

Grasses

In general, pasture grasses are more tolerant of acid soil conditions than legumes. This explains why a number of indigenous grasses such as *Miscanthus floridulus*, *Digitaria sanguinales*, *Sorghum porpinquum*, *Hemarthia compressa* and *Pennisetum polystachyon* have been cultivated and utilised for many years in south China (Hong 1985; Hwang et al. 1986), whereas there is a dearth of legumes in native rangelands throughout the region. Of the 34 tropical/subtropical grasses tested at Lechang Farm, molasses grass (*Melinis minutiflora*), signal grass (*Brachiaria decumbens*), brownseed grass (*Paspalum plicatulum*), guinea grass (*Panicum maximum*) and setaria (*Setaria sphacelata*) produced between 4.5 and 7.5 t DM/ha when sown with moderate P and K inputs on unlimed soil (Michalk and Huang 1994b). Native grasses responded to PK fertiliser with yield exceeding 2.5 t DM/ha in plots where production of sown species was poor. However, where sown grass yield exceeded 4 t DM/ha, production of volunteer species was low (<0.5 t DM/ha). Molasses and brownseed were the only grasses to produce a satisfactory yield (>2 DM/ha) when only P was applied at sowing and no maintenance fertiliser applied (Michalk and Huang 1994b).

Ryegrass (*Lolium perenne*) and cocksfoot (*Dactylis glomerata*) were the only temperate grasses to establish on unlimed soil (Michalk and Huang 1994b), but even these showed severe yellowing caused by a combination of moisture stress, N deficiency and aluminium toxicity. Oats (*Avena sativa*), a winter forage cereal, performed better on unlimed soils than temperate grasses producing a 2 t DM/ha forage yield. Triticale, a wheat/rye hybrid, failed to produce useable forage due to acute deficiencies in the emerging seedlings. The low magnesium levels rather than the high aluminium saturation may be implicated in this poor performance of triticale in north Guangdong Province.

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Maximisation of output per unit of fertiliser input by combining appropriate fertilisers with agronomic practices

Nutrient deficiencies

Nutrient deficiencies are the main cause of the low productivity of red soils in China (He et al. 1990). Missing element experiments and tissue analyses undertaken at Lechang Farm highlighted the severity of nutrient deficiencies on plant productivity (Tables 3 and 4) with N (for grasses only), P, K, Ca, Mg and B limiting plant growth and reproduction. In commercial pastures, many species showed yellowing and/or reddening of the older leaves which suggests low levels of P, B and/or Mg. These deficiencies are commonly found on Oxisol and Ultisol soils in tropical areas. In South America, for example, Sanchez and Salinas (1981) report that P, K, S, Ca, Mg and S deficiencies affect more than 70% of the 1043 million ha of acid infertile soil. Similar deficiencies occur throughout south China, although the severity of these deficiencies varies with soil type (Anon. 1990).

Of this range of nutrients, P and K deficiencies are of major concern in south China (Lu and Jiang 1990; Xie and Li 1990), and need to be applied to ensure high production from even the most acid soil tolerant species. For example, fertiliser studies at Lechang Farm showed that there is a significant P × K interaction for setaria-based pastures grown on unlimed soils (Figure 2). Economic analyses of this data suggested that application of 37 kg P/ha and 133 kg K/ha at sowing, which produced a cumulative yield of 17 t DM/ha of top growth over three years, was the most profitable option when calculated using the traditional economic concepts of investing to the

Table 3. Growth response of white clover to twelve elements grown on Ultisol soil in north Guangdong Province (Michalk et al. 1988).

Treatment	Relative forage yield[1]	Significance
Check (no fertiliser)	7	**
Complete (P+K+Ca+Mg+S+Cu+Zn+Mo+Mn+B+Co+Fe)	100	
Complete minus P	7	**
Complete minus Ca	67	**
Complete minus K	43	**
Complete minus S	104	
Complete minus Mg	81	*
Complete minus Cu	96	
Complete minus Zn	110	
Complete minus Mo	104	
Complete minus Co	104	
Complete minus Fe	114	
Complete minus Mn and B	53	**

[1] Forage yield is expressed as a percentage in relation to complete treatment.
* and ** indicate values are significantly different ($P < 0.05$ and $P < 0.01$) from the complete treatment.

Table 4. Plant tissue analyses of grasses and legumes grown on unlimed soil in north Guangdong Province.

Nutrient	Legumes				Grasses			
	Subclover	Siratro	Stylo	Vetch	Ryegrass	Oats	Setaria	Guinea grass
N (%)	3.0 D	NA	NA	NA	1.3 D	2.8 D	2.4 D	1.9 D
P (%)	0.16 D	0.13 D	0.12 D	NA	0.14 D	0.19 D	0.11 D	0.14 D
K (%)	1.2 D	0.9 D	0.5 D	NA	1.6 D	3.6	1.5 D	1.1 D
Ca (%)	1.6	1.8	1.6	1.8	0.75	0.44	0.79	0.71
Mg (%)	0.08 D	0.38	0.27	0.22	0.16 D	0.06 D	0.12 D	0.19 D
Mn (mg/kg)	190	205	160	150	270	290	370	319
Cu (mg/kg)	12	6	9	7	8	8	6	3
Zn (mg/kg)	75	23	33	66	44	27	20	17
B (mg/kg)	20	13 D	25	5 D	5 D	13 D	3 D	4 D

D indicates nutrient deficiency for species according to Reuter and Robinson (1986).
NA indicates that no analysis was undertaken.

point where marginal cost in fertiliser equates with the marginal return in product. As a general rule, however, only rates that return 150% or more on fertiliser investment are recommended for use in low input systems (Sanchez 1976). Based on this principle, only 7 kg P/ha and 50 kg K/ha were recommended for low input setaria-based pastures in north Guangdong Province. This combination produced 75% of maximum pasture yield, returned 290% on fertiliser investment (Michalk et al. 1994), and maximised output per unit of fertiliser input over a three year period (47 kg DM/ha/yr/kg K; 36 kg DM/ha/yr/kg P).

Agronomic practices — placement methods and application strategies

In addition to determining fertiliser recommendations, there are a number of agronomic practices that also increase the efficiency of fertiliser use, such as better fertiliser sources, application strategy, and placement methods (Sanchez and Salinas 1981). In south China, for example, the majority of the P-deficient red soils are suitable for application of rock phosphate (RP) as an alternative to superphosphate (Jiang et al. 1986). In contrast to the P in superphosphate, which is fixed by Al and Fe within a short time after application, Zhu et al. (1981) reported that it took more than 6 months for half the P of powdered RP (2% citric soluble phosphate) to be released into the soil solution. The first direct application of RP in China was carried out in 1949, and although Lu and Jiang (1990) recommended that sparingly soluble RPs be used in south China, there is little information available on the response of forage grasses or green manure crops to RP or on strategies for using these fertilisers in pasture systems. Studies such as those reported by Hammond et al. (1986) that showed a similar yield response between P applied as a 50:50 ratio of water-soluble:citric soluble P forms and P applied as superphosphate need to be undertaken for a range of crops and pastures in south China.

Little is also known about the effect of placement and timing on the efficiency of fertiliser use. For example, should P fertiliser be incorporated in bands for pasture establishment or be surface broadcast, especially when native grassland is augmented with an introduced legume such as Wynn cassia using minimal soil disturbance? While it is important to ensure that an adequate supply of P is provided to seedlings, as is the case with banding fertiliser, surface application may significantly reduce P fixation by minimising contact with the ferric oxide (often exceeding 15% in Chinese Ultisols) in high P-fixing soils (Sanchez and Salinas 1981). These questions relating to fertiliser practice remain unanswered for a significant proportion of the red soil region of China.

Using the correct timing strategy can also have a significant effect on fertiliser response. Should large rates of fertiliser be applied at one point in time to saturate the fixation capacity of the soil at once and then count on an adequate release over time to provide nutrient to pasture, or alternatively should only small amounts be applied at frequent intervals? Figure 2, for example, demonstrates the poor residual value of P and K fertilisers applied to the Lechang Hapludult soils. This response is most likely to be the case throughout much of south China. Since response to superphosphate did not extend beyond the first cut, it was assumed that most of the applied P (37 kg/ha) was rendered unavailable to plants by the end of the first summer, through transformation of monocalcium phosphate to less soluble Al and Fe forms or by precipitation reaction with exchangeable Al (Michalk

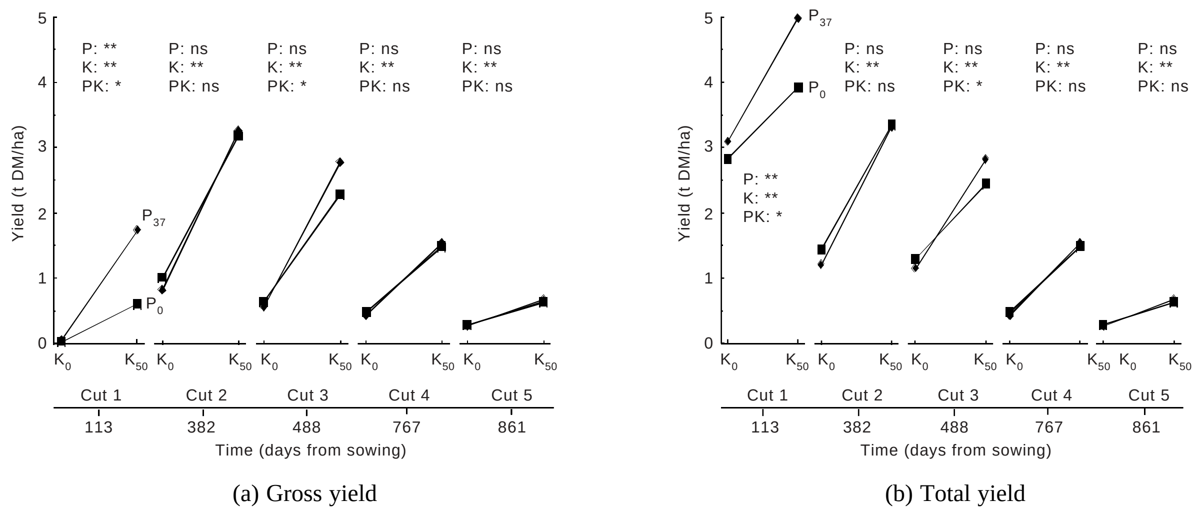

Figure 2. Effect over time of P and K fertilisers on total and grass yield applied to setaria-based pasture grown on Ultisol soil in north Guangdong Province (Michalk and Huang 1993b).

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and Huang 1993b). The return of the available P in soil to the pre-treatment level within 18 months after application and the small amount of P removed in plant top growth (<12 kg P/ha over three years) support this conclusion. These results suggest that for low-input systems small, frequent P applications are the strategy most appropriate for Chinese red soils.

Although setaria response to applied K was more sustained than for P, the residual effect was minimal after three years (Figure 2) and it was predicted to disappear after five years (Michalk and Huang 1993b). However, this higher residual effect may have been influenced by the ability of setaria to access the slowly available soil K fraction since the estimated K removal in pasture top growth (170 kg K/ha over three years) significantly exceeded the total available K supplied by the exchangeable K (0.06 meq/100 g soil in the 0–20 layer) and the 50 kg K/ha of fertiliser applied. This means that relying on the K-cycle to supply a substantial amount of the K extracted by the pasture (Figure 3) will undoubtedly exhaust both the exchangeable and non-exchangeable K because of the low content (<4%) of K-bearing minerals in Chinese Ultisols (Xie et al. 1981).

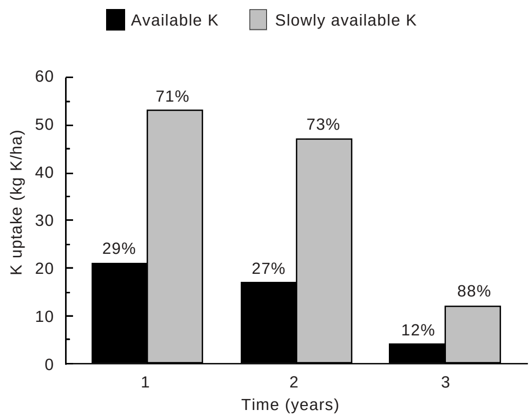

Figure 3. Potassium uptake by setaria from low K-potential soils over time in north Guangdong Province.

Not all pasture species can efficiently access slowly available soil K. In the Lechang experiment (Michalk and Huang (1993b), the leaf K level of Siratro (*M. atropurpureum*) sown as the companion legume to setaria in the pasture mix was low (0.6%) compared with the K content of setaria leaf (1.3%). Since K deficiency may be more serious for legumes than grasses these results suggest that more frequent, small applications may be needed to maintain palatable legumes in tropical grass based pastures. However, the success of other more acid-tolerant legumes, such as Wynn cassia, to perform well on Chinese red soils may be related as much to their ability to access K as it is to their P efficiency. For example, in another study at Lechang Farm, Michalk and Huang (1995) showed that a single application of 50 kg K/ha at sowing was sufficient to maintain cassia in native grass pasture for at least three years without maintenance inputs. The overall increase of 55% in total yield due to applied K was of the same order as that measured by He et al. (1990) for a range of crops. More importantly for soil improvement and livestock production, K fertiliser doubled the legume content of the pasture. Together, these results highlight the importance of understanding the response of adapted pasture species to different fertiliser strategies. The adoption of a single fertiliser strategy for all pastures will be beneficial to some species but will limit the efficiency of fertiliser usage by others. More studies are needed to formulate appropriate fertiliser strategies for a wider range of crops and pastures in the red soils region of China.

Making use of favourable soil attributes

Despite their acidity and low nutrient status, many Oxisols and Ultisols have positive agronomic features that can be used advantageously (Sanchez and Salinas 1981). For example, by keeping the soil acid, the solubility of RP fertiliser is considerably higher than if soil is limed, and weed growth may be decreased significantly compared with a limed and well fertiliser soil. Physical attributes can also increase the effectiveness of soil improvement activities. In general, a large proportion of the red soils of China possess good structure resulting from the primary soil particles being aggregated into very stable sand-sized granules (>80% of aggregates >1 mm), especially in cultivated soils (Yao 1986). This structural stability enables these soils (particularly those with a clay texture) to bear considerable rainfall intensity and allows rapid downward water movement to recharge subsoil moisture.

Improving the root environment

Water movement is also the cause of the poor fertility status of these soils through heavy leaching of base cations. Like most Oxisols and Ultisols, the subsoils of Chinese lateritic and red earths are highly acidic (pH <4.3) and can present a chemical barrier to root development either because of Al toxicity, extreme Ca and Mg deficiencies, or both. It is common to observe roots confined to the top 10 cm of soil and for plants to suffer water stress even though there appears to be ample water in the lower horizons. Moisture stress is also exacerbated by a narrower range of water available to plants than expected in proportion to their clay and water content, particularly in the surface layer where the inter-aggregate pores drain quickly and the within aggregate water is strongly absorbed on clay surfaces and unavailable to plants (Xu and Yao 1991).

The potential effect of limited rooting depth on pasture productivity was examined at Lechang Farm (Michalk et al. 1994) using moisture and growth indices (Fitzpatrick and Nix 1970). Over a 6-year period, the soil moisture budget based on the whole profile (70 cm) indicated that moisture would limit pasture growth for <5% of the time. However, when the model was run using a restricted root depth of 10 cm, plants were stressed for >30% of the time. This stress effectively reduced potential growth by about 44% (Figure 4).

The need to extend the rooting depth of plants growing in acid soils to secure subsoil water and nutrient supplies is a major objective of low-input technology (Sanchez and Salinas 1981). The combination of rapid downward water movement and the inherent low CEC that restrict plant growth can also assist in solving the problem by assisting the downward movement of surface applied Ca and Mg to the subsoil of Oxisols and Ultisols, accompanied by anions such as sulfates and nitrates. Studies at Lechang Farm showed that fourteen months after liming with 4 t/ha, Ca and Mg were detected down to 40 cm. The reason for the rapid movement of cations is related to low permanent charge (<1 meq/100 g clay) of the kaolonitic clays that dominate these soils (Yu and Zhang 1986). Once the permanent charge sites are saturated, exchangeable Ca and Mg held on the pH-dependent charge sites are likely to move down the profile fairly easily (Sanchez 1976). This effectively reduced Al saturation to about 50% at 30 cm, which is below the critical level for a large range of tropical legumes and grasses.

Liming to increase CEC and fertiliser efficiency

In addition to increasing the amount of subsoil moisture available to plants, lime application at the appropriate rate is an effective means of increasing the CEC and fertiliser efficiency of soils with low CEC due mainly to variable charge (Gillman 1984). This is possible and desirable since deprotonation of hydroxy groups generates the additional negative charge needed for retention of nutrient cations (i.e. Ca, Mg, K and NH_4). Figure 5 illustrates this effect for soils in Lechang County where increasing pH in the top soil (0–10 cm) from 4.1 to 5.3 increases the CEC from 3.5 meq/100 g soil (4 meq is the minimum needed to retain most cations against leaching — Sanchez 1976) to 6.7. This pH change also reduced Al saturation to <5% (Figure 5).

The effect of lime application on the efficiency of fertiliser response through cation retention was demonstrated for K fertiliser at Lechang Farm. Figure 6 shows the increase in K response of greenleaf desmodium (*Desmodium intortum*) when the

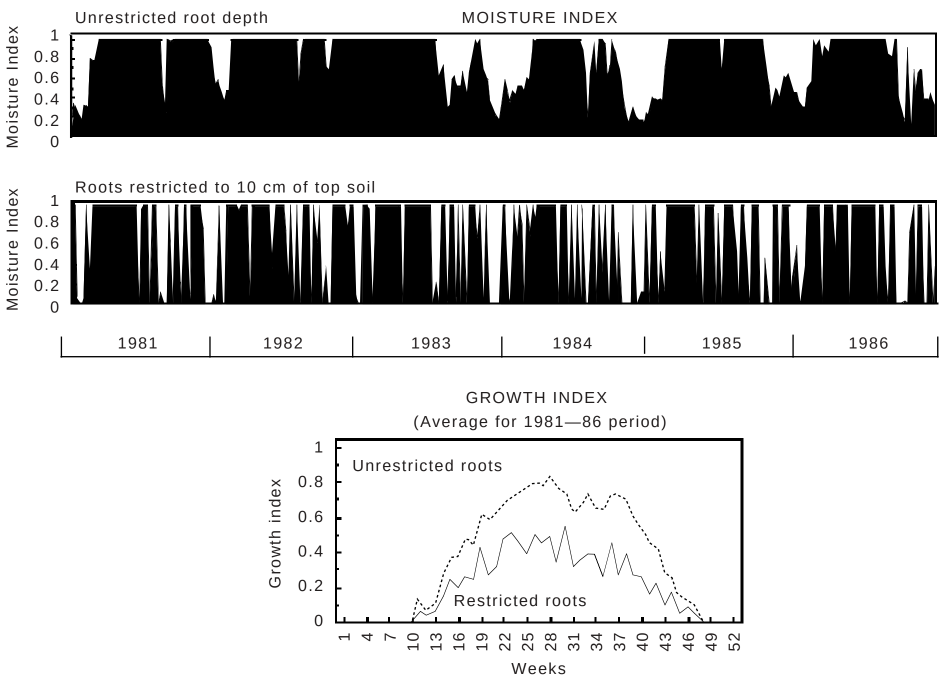

Figure 4. Effect of plant rooting depth on moisture and growth indices for tropical legume-based pastures at Lechang Farm (Michalk et al. 1994).

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Hapludult soil was limed to pH 5.5. In this case, only 50 kg K/ha was needed on limed soil to produce yield response similar to that obtained with 150 kg K/ha on unlimed soil. This improved retention of K as a result of lime application represents a significant benefit that should be seriously considered in relation to initial and maintenance K fertiliser strategies. However, further research is needed in the red soil area to identify the minimum lime input required to produce an economic K response.

Another important reason for applying lime is to increase P availability of soils with high P-fixing capacity by blocking some of the fixation sites (Sanchez and Uehara 1980). Figure 7 shows the decrease in P fixation (as measured by available soil P at equivalent P input) when an Hapludult soil from Lechang County was limed to pH 5.5. The results indicate that less than half the P application rate was needed for limed soil to produce the maximum white clover yield on unlimed soil. Studies on acid soils in South America show similar decreases in P fixation when exchangeable Al was neutralised with lime (e.g. Mendez and Kamprath 1978).

Organic matter — the key to sustained soil improvement

Together with clay, organic matter is the seat of all soil reactions. In variable charged soils such as those dominated by kaolinite and iron oxides (which are common features of the Chinese red and yellow earths), organic matter in an important source of cation retention, nutrient cycling, water holding capacity and physical structure (Jenny 1980). This means that management to preserve and increase soil organic matter is critical to improve the growth environment for plants, to promote more efficient

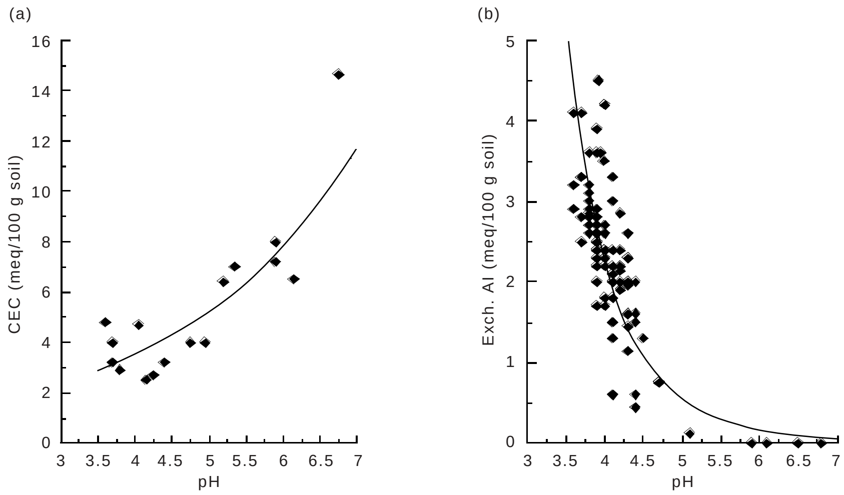

Figure 5. Relationships between (a) cation exchange capacity and soil pH and (b) exchangeable aluminium at different pH levels for Lechang soils.

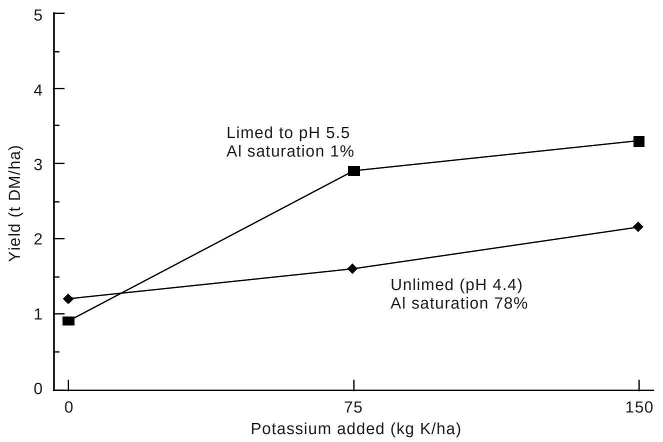

Figure 6. Effect of lime application on K response of greenleaf desmodium grown on Hapludult soil at Lechang Farm.

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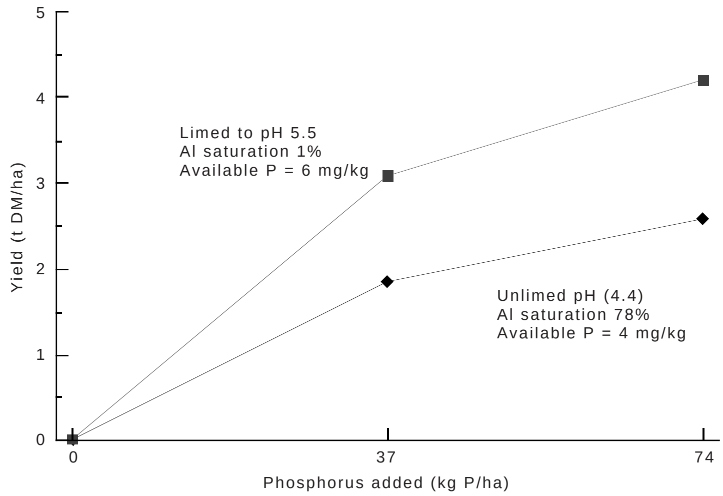

Figure 7. Effect of lime application on phosphorus response of white clover grown on Ultisol soil at Lechang Farm.

utilisation of fertilisers, and to increase soil fertility (Adiningsih et al. 1991), especially if the organic matter level is below 1% as is often the case in eroded red soil (Zhao et al. 1990). An additional advantage of increasing the soil organic matter level is to reduce the "greenhouse effect" by storing atmospheric organic carbon in soil organic matter (Hu et al. 1997).

Contrary to commonly held views, organic matter contents in tropical soils are not very different from those in temperate regions (Sanchez 1976). A reason for this is that while the high temperatures and abundant precipitation promote high decomposition rates in tropical/subtropical areas, these conditions also produce high plant growth rates, which result in higher biomass accumulation than is possible in temperate regions. However, climate, soil type and soil management can impact significantly on soil organic matter.

In south China, for example, Wen and Lin (1986) reported that under well grown natural vegetation, the organic matter content in the 0–20 cm horizon of yellow earths (Dystrochepts) is higher than that of red earths (Hapludults) by an average of 2% in non-eroded soils. Felix-Henningsen et al. (1990) reported that decreasing temperature and increasing precipitation reduced mineralisation and favoured the formation of more stable humates thereby increasing the rate of organic matter accumulation in the yellow earths. This means that, under proper management, soil organic matter levels are likely to increase at a faster rate in soils located to the north and west of the Nanling Range.

Modes of utilisation (i.e. crop or pasture cultivars sown, crop rotations used, and frequency and method of cultivation) interact with climatic variability to further modify the organic matter content of similar soils. For example, a soil survey undertaken in 1985 indicated that the 2.5 million hectares of red Ultisol soil in the 12 counties in Shaoguan Prefecture, north Guangdong Province, had an average organic matter content of 3.4% (Anon. 1985). However, the 30% of this area occupied by the soils coded in the Chinese classification as groups 4-1-5 and 4-1-7 averaged less than 3.0% with a range of 0.8 to 4.0% in the top 25 cm. This variability reflected differences in land use with the lower values found in continuous cropping areas and the higher values in more isolated grassland and shrubland.

For sustainable soil improvement, strategies must be developed to increase soil organic matter from the present low levels, particularly on soils that have been in continuous crop production. The original and most abundant source of organic matter is plant tissue, and grazing systems are the agricultural activity most likely to promote rapid increases in the organic matter and nutrient conditions of tropical soils (Williams and Chartres 1991). In grazing systems, roots, animal excrement and up to 80% of the above ground biomass is left in the soil, which is in marked contrast to cropping systems where only about 30% of biomass is retained in the soil (Brady 1984). In south China, however, soil improvement is not evident under current land use practices, even in the low output traditional grazing systems.

There are two possible reasons for this observation. First, much of the dry matter produced on grassland areas is harvested and used as an organic input to crop land; and second, the unimproved grasslands are not very productive and the annual biomass input is small. For rapid soil improvement, large annual inputs of plant biomass are required. However, to gain the full benefit of organic matter inputs, management

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practices must be developed to reduce the rate of residue decomposition because in tropical soils a large proportion of organic C is in a fairly labile form with a residence time of 10 years or less. This compares with the high proportion of highly recalcitrant organic C in temperate soils, which may have a turnover time of a thousand years (Trumbore 1993). Residue management practices such as surface placement (Holland and Coleman 1987) and minimum tillage cultivation (Hu et al. 1997) are needed to effectively reduce microbial access and thereby retain soil organic C in low clay red soils.

Other chemical characteristics of the red soils will complement these management practices in reducing the rate of organic matter breakdown. For example, Sanchez (1976) reported that the rate of organic matter decomposition in tropical soils is reduced as the clay content and the proportion of oxides and allophanes increase. In a study of Thai soils, Virakornphanich et al. (1988) showed that the rate of decomposition was determined by the amount of Al and Fe supplied by clays which, in turn, complexes with and stabilised humus against microbial decomposition. These soil characteristics occur in the majority of the soils in south China.

To incorporate appropriate organic matter management practices into grazing systems may require considerable extension effort and demonstration. Appropriate management to maximise surface residue may require acceptance of short-term losses in livestock production through reduced or zero grazing levels to guarantee long-term soil improvement. However, Figure 8 shows the significant effect that an increase in soil organic matter has on cation retention with CEC increasing by 50% when organic matter was increased from 2 to 5% on an Hapludult soil at Lechang Farm. An increase in organic matter of this magnitude would also significantly increase the water stable aggregate index and make the soil more resistant to erosion (Shi 1986). Better farming practices (e.g. higher fertiliser inputs, minimum tillage and chemical fallowing, retaining crop stover *in situ*) are also required to better manage organic matter resources in cropping soils to reduce the necessity to import supplementary organic matter from surrounding grasslands, which is related in part to the degradation of upland soils.

PUTTING TOGETHER A SOIL IMPROVEMENT SYSTEM

Various attempts have been made to improve the sustainability of grazing and cropping systems on the acid red soils throughout the Asian region. Many programs have correctly identified the chemical and physical constraints to production, but have failed to develop systems which combine the technological capabilities with the economic resources of the target producers. Too often integrated packages endeavour to change the whole system at once, rather than adopting a step-wise program. For sustained improvement of red soils, there are several stages through which individual paddocks must advance before satisfactory livestock production can be realised, or before alternative cropping enterprises can be considered. To achieve lasting results, sufficient time must be allowed for the full impact of the low-input technologies to take effect.

A strategy for improvement of Hapludult soils in north Guangdong Province was developed by combining the principles of low-input technology detailed above and research data collected at Lechang Farm between 1986 and 1989. Details of the objectives and methods used

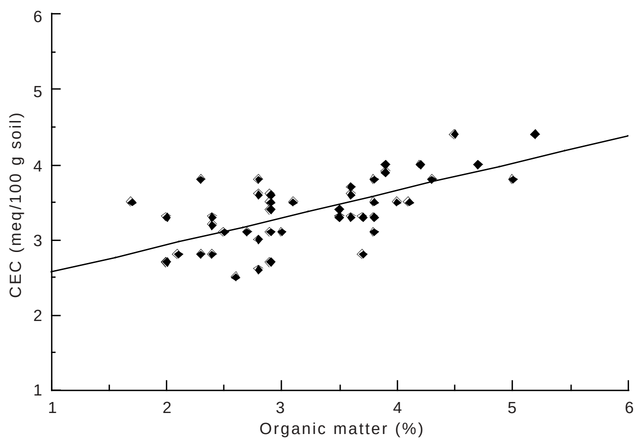

Figure 8. Effect of soil organic matter level on cation exchange capacity of Ultisol soils at Lechang Farm (Michalk et al. 1994).

in each stage of the improvement strategy described by Michalk et al. (1994) are provided in the following sections. Similar strategies developed for other parts of Asia are also detailed where appropriate. While the species used in this improvement strategy may not suit the climatic conditions that prevail north of the Nanling Range, the principles are applicable to the entire red soil region.

Stage 1: Initial improvement with pioneer pasture species

Most native grasslands in south China are low in available N, and there are few indigenous legumes present. Even when P and K fertilisers are applied the response in terms of dry matter per hectare is small. This means that either oversowing legumes into existing grassland or establishing introduced legume-grass combinations is required for initial improvement. To rehabilitate land dominated by alang-alang (*Imperata cylindrica*), Blair et al. (1978) oversowed centro (*Centrosema pubescens*) with fertiliser to smother the grass. This principle of legume augmentation in combination with rock phosphate (RP) has been used to develop a rehabilitation strategy for alang-alang land. *Mucuna* sp., a legume often used as a green manure crop, is planted as the first phase with a high application of RP to suppress alang-alang, to protect the soil from erosion by promoting vigorous legume growth, to fix N, and to transform some of the applied P into organic P. When combined with proper organic matter management, this system has significantly increased productivity of land previously dominated by alang-alang (Adiningsih et al. 1991). A strategy of oversowing native grassland with Wynn cassia and RP fertiliser is a strategy that should be investigated throughout south China.

No oversowing strategies were investigated at Lechang Farm due to the low productivity of the unimproved grasslands. The grass-legume combination recommended for Stage 1 improvement was molasses grass-Wynn cassia. Molasses grass has also been used successfully as a pioneer species in combination with common stylo (*Stylosanthes guianensis*) for Stage 1 development of pastures on acid infertile Oxisols in South America (Spain 1975).

Pioneer species must be well-adapted to low fertility acid soils. Michalk et al. (1994) recommended cassia as a suitable pioneer legume for rehabilitation of red soils in subtropical China for the following reasons: (1) high dry matter production with minimal fertiliser inputs; (2) ease of establishment; (3) quick ground cover to prevent soil loss; (4) good regeneration from seed; (5) high survival of established plants over winter (south of Nanling Range); (6) high seed production; (7) seed pods readily harvested by hand; and (8) no observed insect or disease damage. Similarly, molasses grass also rapidly forms a dense sward in the establishment year with minimal fertiliser. An added advantage of molasses grass is that it is susceptible to fire and can be removed by strategic burning (Sanchez 1976) to make way for more palatable species as soil conditions improve. Brownseed grass also performed well with minimal fertiliser inputs but is more persistent in the frost-free zone of south China which makes it more difficult to remove for Stage 2 improvement.

With minimal fertiliser inputs, the molasses grass-cassia combination is capable of supplying 10 t DM/ha in root and top growth. Most of this production (about 75%) can be returned to the soil as both species are not very palatable to livestock (Clements et al. 1996; Sanchez and Salinas 1981). The effect of the residual dry matter of a dense molasses grass-cassia pasture on the rate of accumulation of organic matter is yet to be determined. However, the potential impact of this strategy on the organic carbon content of soil can be calculated using equations which combine annual additions with decomposition rates expected in subtropical pastures (Sanchez 1976). Assuming an annual addition of 7.5 t/ha of organic matter, a decomposition rate of organic matter into organic carbon of 50%, a soil organic C decomposition rate of 2.5%, and soil bulk density 1.5 g/cm^3 (Sanchez 1976; Yao 1990), soil organic carbon should increase by 0.24% in the top soil (0–10 cm) each year under pioneer pasture. This would effectively double the level of organic C (and organic matter) in the top soil after 4 years.

This is consistent with the organic C increments reported by Deng et al. (1981) when rice straw and green manure were incorporated with fertiliser into crop land. Other studies also report significant increases in the organic matter level of Chinese soils. In experiments conducted in Jiangxi Province, He et al. (1990) measured an annual increase in organic matter of 0.2% where six consecutive green manure crops were grown on a red earth. Pei et al. (1957) also reported a 0.07% annual increase in organic matter within the first 3–5 years of growing green manure crops like *Raphanus sativus* in combination with fertiliser application. Together, these results highlight the potential improvement of red soils that can be gained by using pioneer and green manure crops. In these studies, base saturation, available nutrient levels and soil moisture characteristics were also significantly improved along with the organic matter content.

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Stage 2: Replacement of pioneers with better species

In general, pioneer species that are tolerant of soil acidity and low levels of P and K also have low nutritional value, which may affect palatability to livestock. For example, graziers report that Wynn cassia has low acceptability to cattle (Clements et al. 1996). While this may have a positive impact during Stage 1 improvement by ensuring a high legume component and aiding persistence (Jones et al. 1993), it is not desirable during Stage 2 improvement where the emphasis is shifted from soil improvement towards cattle production. Since pasture production has no direct value until converted into a saleable product (e.g. meat, milk, fibre), it is necessary to replace pioneer species with more nutritious grasses and legumes as soon as sufficient improvement in soil properties has occurred. Michalk et al. (1994) outlined two options available to achieve this transition.

Option 1: Better species still with minimal inputs

As soil organic matter increases with minimal fertiliser, pioneer species can be replaced with species that are still acid-tolerant but require higher fertiliser inputs. However, these species are better suited for cattle production. At Lechang Farm, setaria combined with lotononis or Oxley stylo showed promise for summer grazing on unlimed soil when adequately fertilised with P and K. Since it was first introduced in the early 1980s, setaria has proved to be a valuable species for cattle production in south China. In addition to the studies in north Guangdong Province, setaria has performed well in Fujian Province where yields have exceeded 90 t FW/ha when cut 4 to 7 times per year (Hong 1985; Wu et al. 1986). Setaria is now recommended for pasture improvement of all red soil upland areas below 1000 m in Fujian (Wu et al. 1986), Guangxi (Michalk 1988), Yunnan (Bruce-Smith et al. 1989), Guangdong (Michalk and Huang 1994b) and Hainan Provinces (Michalk et al. 1993). Cultivar selection is important for production and persistence with Narok and Solander (var. *splendida*) performing better than Kazungula in subtropical China because of their superior winter yield and frost tolerance. Tolerance to both drought and severe frosts are features which also make Premier digit grass (*Digitaria smutsii*) a species suitable for Stage 2 development in the red soil region north of the Nanling Range.

In general, suitable Stage 2 pasture species require higher soil fertility to establish and persist. Additional fertiliser inputs do not always result in greater dry matter yield, but they do ensure that forage quality is suitable for livestock production. The nutritive value of highly acid tolerant pioneer species can also be improved by applying higher fertiliser rates, especially P and S (McLean et al. 1981; Lascano and Salinas 1982), but this does not always guarantee acceptability to livestock, as is the case with Wynn cassia (Clements et al. 1996). This low acceptability of cassia suggests that alternative legumes such as lotononis and forage peanuts are needed for Stage 2 improvement. However, these alternatives also have their strengths and weaknesses. For example, lotononis seedlings are small and slow to establish, while forage peanut establishment from seed can be hampered by theft of seed by rodents. Both species, however, produce palatable, high protein forage. Further, lotononis tolerates shading better than cassia and is known to utilise RP fertiliser better than most other tropical legumes (Bryan and Andrew 1971).

Option 2: Application of lime to increase species range

Further flexibility in species selection may be possible in Stage 2 development if lime is used to reduce the Al-saturation to a level that will enable selected species to grow to potential. For some pasture plants, such as many of the temperate grasses and forages needed to overcome winter feed shortages in the red soil region, this will mean applying lime to effectively reduce Al saturation to near zero (i.e. increase soil pH to >5.5). This means that about 3.6 t of good quality lime is required to neutralise the 2.2 meq of exchangeable Al found in Lechang soils using the simple formula of Cochrane et al. (1980) of applying lime at a rate equivalent to 1.8 times the exchangeable Al level when expressed in meq/100 g soil. However, many species will respond significantly to more modest lime inputs. For example, while plants endemic to calcareous soils (e.g. *Glycine wightii*, *Medicago sativa*, a range of annual medics, *Trifolium repens*, *Lolium perenne* and *Phalaris aquatica*) are susceptible to Al saturation levels around 15%, pasture species originating on acid soils only require Al levels to be reduced to about 40% for maximum yield. At Lechang Farm, these conditions were achieved with as little as 1.5 t lime/ha.

Lime application increased production of a number of grasses and legumes at Lechang Farm (Michalk and Huang 1994a, 1994b). However, of the range of grasses that included Rhodes grass, signal grass, buffel grass, guinea grass and green panic, only green panic has sufficient cold tolerance and superior quality to setaria to be potentially useful for Stage 2 improvement in North Guangdong. Lime application had a beneficial effect on legume production, especially the twining tropical types and white clover. However, based on legume response and the cost of lime, soil amendment with lime may only be economic when used on small areas of special-purpose pasture to fill gaps in the forage supply for cattle rather than for use over large areas. Lime application can also have a negative effect on pasture production. Studies at Lechang Farm showed that yield of molasses grass (Michalk and Huang 1994b) and Wynn cassia (Michalk and Huang 1995) was reduced significantly by lime application.

In addition to increasing the range of species available for pasture production, lime application also provides an opportunity for cash crops to be grown prior to establishment of Stage 2 pastures. Cash crops not only generate cash flow to support the soil improvement/ pasture development program, but also provide a break in the pasture sequence to assist with control of weeds, pests and diseases, as well as allowing time for lime to ameliorate soil to a greater depth. Research in Jiangxi province has identified some peanut cultivars, mung beans, radish, rye, buckwheat and vetch as crops suitable for growing on red soils with Stage 2 inputs (He et al. 1990). However, more attention needs to be focused on developing systems that integrate appropriate crop and pastures for the red soil region of south China.

In addition to reducing the impacts of Al on plant growth through changes to soil pH, lime also alleviates Ca and Mg deficiencies which are known to limit plant growth in south China. Mg is particularly important in north Guangdong with lotononis, white clover and subclover all showing symptoms of Mg deficiencies when grown on unlimed soil. However, these symptoms disappeared and production increased when Mg fertiliser was applied (Michalk and Huang 1992, 1993a). It is also suspected that triticale may require Mg inputs when grown on Chinese Hapludult soils. Since local lime contains <0.3% Mg (Michalk and Huang 1993a), there is a need to procure more concentrated Mg fertilisers or good quality dolomitic limestone to sustain production on special-purpose pastures that contain species sensitive to low Mg. Boron (B) fertiliser should also be included in all liming programs as lime application greatly increases the adsorption of B by clays in red acidic soils, thereby reducing its availability to plants. B deficiency caused sterility in forage oats in north Guangdong Province and severe B deficiency was observed in white clover growing in limed soil (Michalk and Huang 1992).

These examples highlight the need for careful fertiliser and amendment strategies to avoid detrimental effects on plants caused by too great a change to the pH of these poorly buffered red soils. Further, the results suggest that while Option 1 will provide pastures for large area sowings, Option 2 is more suited for development of smaller areas where special-purpose pastures are required to fill gaps in the feed supply for livestock.

Stage 3: High production pastures

Only after several years of rebuilding soil fertility through careful management of fertiliser inputs and organic matter under grazed permanent pastures is the establishment of higher quality species a feasible option. The importance of improving soil conditions prior to Stage 3 was demonstrated at Lechang Farm by the failure of many species to reach their expected potential even when high fertiliser inputs were applied. For example, species such as kikuyu and paspalum that have the capacity to grow under the climatic conditions at Lechang Farm either failed to establish or yielded poorly (Michalk and Huang 1994b). Similarly, a temperate pasture mix failed to grow as expected even when fertilised with 600 kg/ha superphosphate, 300 kg/ha potash and 4 t/ha lime. These examples highlight the inability of inorganic fertilisers alone to solve the fertility problems of these soils, and re-emphasise the importance of organic matter in the process of retaining and recycling plant nutrients in pasture systems.

Like high producing pastures, crops require an adequate supply of nutrients throughout their growth cycle to produce maximum yield. The combination of decomposition of plant residues and good fertiliser management may also improve soil sufficiently over time to enable a wider range of more profitable crops to be integrated with pastures in ley systems. Sugar cane, ginger and a range of vegetables are often grown on the more fertile soils in Guangdong Province. The range of suitable high value crops should be determined for red soils located in the more subtropical regions of China north of the Nanling Range.

Capitalising on succession in soil improvement

The strategy for soil improvement formulated at Lechang Farm outlined in Table 5 is presented as distinct stages. In practice, however, changes from one stage to another may be achieved by manipulating soil fertility, plant introduction and grazing management to form a continuum, especially from Stage 1 to Stage 2 (Option 1). Changes that occur by manipulating these factors in a management system are an effective example of man-assisted succession in which one group of species is replaced by another when the environment (e.g. soil) or management is changed. Changes in pasture composition provide the guidelines to assist producers recognise the signs of deterioration

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or improvement in pastoral systems and define the boundaries of good management within stable states. For example, changes from legume to grass dominance under a fertiliser and grazing management strategy known to maintain legumes signals an increase in soil N resulting from legume N fixation and N release from accumulated organic matter.

Table 5. Proposed strategy for soil improvement and pasture development for red soil areas in north Guangdong Province (Michalk et al. 1994).

Stage	Time (years)	Pasture-crop program
Stage 1	1–3	Sow cassia-molasses grass-setaria mixture
Stage 2		Option 1
	4–8	Oversown with Oxley stylo
		Option 2
	4	Lime:plough, sow winter forage.
	5–9	Then: (1) Re-sow lotononis-setaria in spring
	5	or (2a) Spring cash crop of beans or peanuts
	5	(2b) Forage (oats-vetch) in winter;
	6–10	(2c) Sow to lotononis-setaria in following spring (Note: Oxley stylo can be sown with or as an alternative to lotononis)
	9–13	Paddocks treated as Option 1 must be treated as Option 2 before proceeding to Stage 3
Stage 3	11–?	Soil fertility improved enough to grow more productive and better quality tropical legumes, tropical grasses and temperate species.

This program is based on limited observations over 3 years at Lechang Farm, and experience of pasture development in tropical-subtropical areas elsewhere.
To achieve the anticipated soil improvement, it is assumed that all pastures and crops are adequately supplied with initial and maintenance fertiliser using low-input technology criteria.

Changes in species dominance were observed in Stage 1 pastures at Lechang Farm over a three-year period with molasses grass being replaced by Wynn cassia in Year 2, and setaria (sown at a low rate in Year 1) becoming a co-dominant in Year 3 (Michalk et al. 1994). The inability of cassia to compete effectively with setaria may be due to several factors including shading by the taller perennial grass and the superior K absorbing ability of setaria due to the higher density of grass roots compared with the legume. These observed changes suggest that, with the correct management, it may be possible to develop a continuum between Stage 1 and Stage 2 pastures. Such management may include a combination of grazing pressure and strategic rest (Michalk and Kemp 1994). The effectiveness of strategic rest has proved to be a valuable tool for manipulating tropical pastures. For example, Jones (1992) showed that for a Siratro (*Macroptilium atropurpureum*)-setaria (*Setaria sphacelata*) pasture in sub-tropical Queensland, rest was an effective means of changing pasture composition. The effectiveness of grazing tactics on pasture succession in south China still needs to be assessed.

Degradation is the reverse process in which less desirable weedy species invade pastures as soil fertility changes or where inappropriate grazing management or fertiliser tactics are applied. An example of degradation was reported by Michalk et al. (1994) for temperate pasture where slow regrowth of perennial ryegrass enabled native grasses and weeds to invade and utilise the N fixed by companion white clover. Monitoring such changes provides the focus for the identification of practical thresholds in terms of movement towards or away from a desirable composition for the particular stage of soil improvement and pasture development. Movement towards a less desirable pasture composition may indicate that inappropriate grazing management, fertiliser practices or soil improvement strategies have been used. Management envelopes and matrices such as those developed for temperate pastures by Kemp et al. (1996, 1997) should be developed to aid management of subtropical and temperate pastures in south China.

CONCLUSION

It was once thought that acid infertile red soils like those found in south China could not support productive and sustainable agricultural activities in tropical and subtropical regions. However, there is now abundant evidence to indicate that acid infertile red soils are useful for crop and pasture production provided the general principles of low-input management are applied (Sanchez and Salinas 1981). Research undertaken at Lechang Farm and in other parts of south China provides a positive pattern on which to build a program to improve soil through conservation of organic matter, nutrient recycling, species selection and fertiliser application at minimal cost and risk.

While the general approach is most likely to lead to sustained production on red soils throughout south China, further research is required to refine some of the components of the soil improvement strategy for use in the more subtropical region north of the Nanling Range. Some of the species selected for the system developed at Lechang Farm may perform as well in these more northern locations, but it is likely that further testing is needed to identify the best species and fertiliser inputs for these areas with colder and wetter climates. However, in addition to formulating appropriate strategies to successfully restore the productivity of red soils, lasting solutions will also depend on implementing change in social perceptions and encouraging economic reforms. As Brown et al. (1991) rightly point out, until governments and support agencies provide farmers with the incentives they need to invest in land productivity, little progress will be made in large-scale improvement of degraded soils, including the infertile red soils of south China.

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SOIL EROSION AND ITS EFFECTS IN FUJIAN

Yang Xuezhen[1], Hong Shuangjin[1] and Huang Yanhe Lu Chenglong[2]

[1] Fujian Soil Conservation and Rural Development Office, 115 Guysing Road, Fuzhou, Fujian, 350003. P. R. China

[2] Soil and Environmental Science Department, Fujian Agricultural University, Fuzhou, Nantai Island. P. R. China

Abstract

Soil erosion has affected 21,130 km^2 of Fujian province — 17% of the total soil area. Erosion gradually decreases as one moves from the southeast to the northwest, and from the coastal areas to the inland. Quanzhou City has the highest proportion of its area eroded at about 34%. The area with a potential for erosion in Fujian province is approximately 21,500 km^2 or 18% of the total area. Potential erosion in the southeast prefectures near the coast is much higher than in the inland mountain areas. Flood and drought disasters are closely linked to soil erosion and, in recent decades, along with the extension of the soil erosion areas, the frequency and intensity of floods have increased.

INTRODUCTION

FUJIAN province lies between 23°33′–28°19′ N and 115°50′–120°43′ E, crossing the middle and southern subtropical zone and has a typical subtropical monsoon climate. The annual average temperature is 15–21°C; the accumulated temperature greater than 10°C is 4500–7500°C; and the annual rainfall is 1000–2000 mm. The distribution of rainfall is not regular, with the period March to June receiving 50–60% of annual rainfall. The period from October to February is the dry season, when rainfall is only 15–20% of the annual total. The terrain descends in stepwise fashion from northwest to southeast, successively comprising mountains, hills, mesas and plains. The area of the mountains and hills is 88% of the total. The southern subtropical monsoon rainforests and the middle subtropical hardwood forests contain the dominant tree species native to Fujian province. However, due to man's influence, the natural vegetation has largely been destroyed and replaced by second-growth forest. The soils are mostly red and yellow, derived from granite and basalt rocks, with those derived from metamorphic and sedimentary rocks accounting for about one-third of the soils. The natural environmental conditions such as high rainfall, combined with the mountainous terrain and the influence of human activity have brought about severe soil erosion in the province.

SOIL EROSION STATISTICS FOR FUJIAN PROVINCE

From general investigations by the Water Conservancy Ministry in 1987 using remote sensing technology, the total area of soil erosion in the whole province was found to be 21,130 km^2. Of this area 4867 km^2 was affected by medium erosion, 13,049 km^2 by serious erosion and 186 km^2 by extreme erosion. There are two causes of soil erosion in Fujian province: water and wind. Water erosion is the major cause, resulting in 99% of the erosion, whereas wind erosion is responsible for just 1% of the total.

It has been found that the distribution of soil erosion in the nine prefectures in Fujian province gradually reduces from the southeast to the northwest, and from the coastal areas to the inland areas (Table 1).

The proportion of land affected by erosion in coastal prefectures such as Quanzhou, Xiamen, Fuzhou, Zhangzhou, Putian and Ningde is higher than the average level for the whole province, and much greater than for inland areas such as Longyan, Sanming and Nanping. Quanzhou has the largest proportion (34% of the total land area), followed by Xiamen (32%), whereas Nanping has the smallest proportion (9%). The 186 km^2 of extreme erosion within Fujian Province are found in the Guanqiao township, the Anxi county of Quanzhou, and the Hetian township in the Changting county of Longyan. The former is the result of the collapse of granite slopes in southern Fujian while the latter is the outcome of a lack of vegetation cover.

After some improvements in management over the past decade, the areas affected by erosion have been reduced to about 16,000 km^2 or 13% of the total land area.

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Table 1. Soil erosion areas (km^2) in the prefectures of Fujian province.

Prefecture (City)	Total area of land	Light erosion	Medium erosion	Serious erosion	Extreme erosion	Total erosion area	Percentage of land area affected by erosion
Fuzhou	11,551	1,871	900	629		3,301	29
Xiaman	1,555	276	171	53		499	32
Putian	3,839	499	183	148		840	23
Sanming	22,974	1,327	509	339		2,174	9
Nanping	26,303	1,542	695	25		2,262	9
Ningde	12,996	1,628	680	196		2,503	19
Quanzhou	10,984	1,979	732	920	95	3,727	34
Zhangzhou	12,562	2,262	539	534		3,326	27
Longyan	19,028	1,675	448	283	90	2,498	13
Total	121,793	13,049	4868	3027	186	21,130	17

Table 2. Areas (km^2) subject to soil erosion areas in the prefectures of Fujian Province, classified by degree of danger.

Prefecture or City	Danger class			Total	Percentage of land affected by erosion
	Slight	Moderate	Completely eroded		
Fuzhou	2,719	682	80	3,481	30
Xiaman	446	53		499	32
Putian	677	163	53	893	23
Sanming	1,731	344		2,074	9
Nanping	2,157	105		2,262	8
Ningde	2,398	196	13	2,606	20
Quanzhou	3,163	564	53	3,780	34
Zhangzhou	2,879	446	40	3,366	27
Longyan	1,675	823		2,498	13
Total	17,845	3376	239	21,459	18

THE POTENTIAL DANGER OF SOIL EROSION IN FUJIAN PROVINCE

Estimates have been made of the severity of erosion potential based on the time that it will take for soil to be eroded to a depth of 80 cm. For example, the Water Conservancy Ministry has classified erosion into five classes: zero; slight; moderate; extreme; and complete removal of soil that has already occurred. In some cases it may take less than 160 years for the soil to be completely removed. The total area of soil with potential for erosion (including that which has been destroyed) is 21,459 km^2 or 18% of the total area.

In general, the greatest potential for erosion is in the southeast coastal areas of the province (Table 2).

The potential erosion hazard is greatest for Quanzhou (34% of its land). Xiamen, Fuzhou and Zhangzhou also have large areas of potentially dangerous erosion: 32%, 30% and 27%, respectively. Inland prefectures have lower percentages, with Nanping, Sanming and Longyan having 9%, 9% and 13%, respectively. Again, the areas classified as having potentially dangerous erosion decline as one moves from southeast to northwest. In the southeast, the soil remaining is generally less than 80 cm, but in the northwest it is comparatively thick, being mostly between 80 cm and 150 cm.

THE EFFECTS OF SOIL EROSION

The harmful effects of soil erosion vary, and include depletion of the soil, reduction of its productivity, siltation of rivers and reservoirs, and degradation of the environment. There is also a relationship between soil erosion and flooding in Fujian.

Soil erosion has become particularly serious in Fujian only in the past one hundred or so years. According to

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statistics gathered in 1958, the area with soil erosion was only 4500 km^2; in 1966 it was 6557 km^2; in 1976, 9318 km^2; and in 1987, 21,130 km^2. Following the rapid increase in the erosion areas, sediment load increased, and the level of water in reservoirs has fallen. Floods have become more frequent. Huang Wen (1993) reported that, whereas there were 166 years which incurred a medium flood in the 522 years from 1490 to 1991 (an average of one flood in 3.14 years), in the 53 years from 1939 to 1993, the average has risen to one flood in 2.79 years. Also the frequency of 'heavy' floods has increased over recent years occurring in nine of the last 53 years, or once every sixth year. Thus, since 1939, the frequency and intensity of floods appear to be increasing. This trend is consistent with the trend for increasing soil erosion. In order to reduce the frequency and intensity of floods, more attention must be paid to soil and water conservation.

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SOIL CONSERVATION PRACTICES FOR SUSTAINABLE AGRICULTURE ON SLOPING LANDS IN SOUTHERN CHINA

Adisak Sajjapongs and Yin Dixin[1]

[1] IBSRAM, Bangkok, Thailand

Abstract

On sloping lands in southern China, farmers generally plant their crops up-and-down the slope and cultivate the soil with minimal concern for soil erosion. This causes the loss of not only the topsoil but also plant nutrients. In addition, siltation of valleys and dams occurs and threatens the environment. In the case of serious soil erosion, the soil can quickly lose its productivity to the point where it cannot sustain crop growth.

Since sloping lands cover vast areas in southern China and are being encroached on for cultivation every year, it is imperative that efforts should be made to identify appropriate technology for managing these lands so that threats to the immediate surrounding areas can be arrested and more sustainable agriculture achieved. Various soil conservation technologies, including hillside ditches, alley cropping and farmers' practices, were evaluated at a site in Xinlong village, Guizhou Province, to identify technologies that could render a more sustainable form of agriculture on sloping lands.

The results showed that soil losses, run-off and nutrient losses were reduced remarkably by alley cropping and hillside ditches, when compared with farmers' current practices. As a result of the filtering out and accumulation of sediment by hedgerows, mini-terraces were formed above the hedgerows in the alley-cropping treatment. Alley cropping gave yields as high as those from farmers' practices. On the other hand, yields under the hillside ditch treatment were lower than those of the farmers' practices. The annual net returns from alley cropping were less than those from the farmers' practices for the first two years of the trial. In later years, the economic returns of alley cropping were as high as those of the farmers' practices. The economic returns under the hillside ditches were not as high as those of alley cropping and the farmers' practices, except in the years when additional revenue could be obtained from bananas.

INTRODUCTION

THE south China subtropical red and yellow soil regions occupy an area of 218 million ha, 90% of which are in mountainous or hilly areas. The regions possess a long plant growth season and are rich in water resources and sunlight. These regions, therefore, have great potential in the overall pattern of agricultural development. In some parts of these subtropical regions, however, the population is increasing rapidly; the forest is slashed extensively and cleared for farming. Land utilisation and cropping are not organised properly. These circumstances have caused severe soil erosion, a loss of soil fertility, and soil degradation, resulting in a low level of crop production and detrimental effects on the rural economy. Statistics indicate that soil erosion in these regions covers 615,800 km^2, which accounts for 30% of the total area of the subtropical regions. As severe soil erosion deteriorates soil resources and silts up rivers, hillside pools, and reservoirs, natural disasters (flooding and drought) occur frequently, the ecological balance is disturbed, and agricultural development declines (Chen et al. 1995).

Guizhou Province is in the centre of southwestern China, where karst landforms are common. It is located between 24°30′–29°13′N and 103°36′–109°30′E, and is a plateau with a subtropical climate. The province has a total area of 17.6×10^4 km^2, of which 12.96×10^4 km^2 are karst. Guizhou has a population of 33.1 million, and a residential density of 188 persons/km^2. Within the territory, the landform is complex and the earth surface is sharply dissected. Mountains and hills constitute 92% of the total area, and the rest is lowland and valley plains. The shortage of soil resources constrains the development of agricultural production in Guizhou. Soil formation is extremely slow, so it is very difficult to replenish the soil once erosion occurs. Because of the lack of arable land and the rapid increase in population, the steep sloping lands are beginning to be reclaimed on a large

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scale. At present, the cultivated land area amounts to 0.8 million ha for paddy and 1.1 million ha for uplands. Sloping land constitutes most of the upland area, and uplands with gradients of more than 45% are not equipped with the necessary technologies for soil and water conservation. Sloping uplands occupy about 15% of the total cultivated land area and are consequently the major zones for soil erosion (Zhu 1994).

With the support of the International Board for Soil Research and Management (IBSRAM) and the Swiss Agency for Development and Cooperation (SDC), a project has been developed over approximately five years to prevent the deterioration and erosion of sloping lands in southern China.

Its objectives are to:

- validate the effectiveness of different technologies in reducing soil loss and run-off;
- determine changes in crop yield and soil properties as affected by soil erosion; and
- identify options that are cost-effective and acceptable to farmers.

LOCATION AND CHARACTERISTICS OF THE EXPERIMENTAL SITE

In early 1992 an experimental site was established in Xinlong village, Luodian county, Guizhou Province. This site is on an eastern slope of 40% on the western side of Shancha stream, with an elevation of about 630 m asl. The soils are Hapludult and Hapludalf; the soil profile descriptions are given in Table 1.

The average annual precipitation for the site is 1177 mm, of which 90% (1054 mm) falls in the rainy season from April to October. Furthermore, in the four-month period between May and August, storms occur frequently, and 68% of the total annual precipitation is received. However, there are substantial fluctuations between years.

EXPERIMENTAL DESIGN

The experiment was carried out on an area with slope of about 40%, using a non-replicated trial. Individual plots were 16 m wide and 25 m long and were equipped with a soil-erosion collection system. The treatments evaluated were as follows:

T1: hillside ditches with banana and *Amomum xanthioides* grown on the bund;

T2: farmers' practice (no soil conservation measures and up-and-down planting of crops);

T3: alley cropping using *Tephrosia candida* as hedgerows (crops planted along contours in alleys);

T4: bare plot.

The cropping system employed was maize during the rainy season and vetch (*Vicia sativa*) during the dry season. Fertiliser application for maize was: 227.5 kg/ha urea, 450 kg/ha calcium–magnesium phosphate, and 15 t/ha compost for alley cropping; 227.5 kg/ha urea, 450 kg/ha calcium–magnesium phosphate, and 15 t/ha compost for the farmers' practice; and 227.5 kg/ha urea, 450 kg/ha calcium–magnesium phosphate, and 15 t/ha compost for hillside ditches. No fertiliser was applied for vetch, since it was grown as a green manure crop.

Table 1. Soil type and profile description of the experimental site in Guizhou Province.

Slope position	Soil type	Depth (cm)	Profile description
Upslope	Hapludult	0–21 (A)	Dull yellow orange, silty clay, 10 YR7/4[a], granular structure, slightly sticky, many fine roots
		21–61 (B)	Orange, silty clay, 7.5 YR7/6, blocky structure, slightly hard and compact, fewer roots
Midslope	Hapludalf	0–21 (A)	Dull yellow orange, silty clay loam, 10 YR6/3, granular structure, friable, many fine roots, few animal channels
		21–33 (BC)	Dull yellow orange, silty clay, 10 YR6/4, blocky structure, slightly hard and compact, few roots
Downslope	Hapludalf	0–30 (A)	Light brownish grey, silty clay loam, 7.5 YR7/2, some angular gravel, friable, many fine roots
		30–45 (BC)	Dull yellow orange, silty clay loam, 10 YR6/4, blocky structure, slightly compact, fewer roots

[a] Y = yellow; R = red.

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RESULTS

Soil loss and run-off

Soil loss at the site was significantly affected by the various treatments (Table 2). Over four years, soil loss ranged from 0.3 to 342.1 t/ha. Bare plots had the highest soil loss in all years, followed by the farmers' practice. Alley cropping and hillside ditches were equally effective in reducing soil loss, which was much lower than the farmers' practice and bare plot. Run-off showed similar trends to soil loss (Table 3). Run-off ranged from 12 mm to 645 mm over the trial period and was closely related to the amount of rainfall.

Table 2. Soil loss as affected by different soil conservation practices during 1992–95.

Treatment	Soil loss (t/ha)			
	1992	1993	1994	1995
Alley cropping	0.9	54.4	0.0	0.3
Hillside ditch	1.8	62.1	1.1	5.0
Farmers' practice	4.0	112.2	1.4	4.2
Bare plot	80.5	342.1	107.9	97.6
Rainfall (mm)	772.7	1179.7	684.6	1066.7

Table 3. Run-off under different soil conservation practices during 1992–95.

Treatment	Run-off (mm/year)			
	1992	1993	1994	1995
Alley cropping	22.7	201.6	172.0	205.6
Hillside ditch	11.9	77.6	91.6	164.7
Farmers' practice	89.6	324.3	141.8	206.2
Bare plot	217.3	645.2	306.8	456.1
Rainfall (mm)	772.7	1179.7	684.6	1066.7

Of all the treatments, the bare plot had the heaviest soil loss and run-off; many rills and shallow gullies were formed. The formation of terraces, as a result of filtering and accumulation of run-off sediment by hedgerows under alley cropping, was obvious. After the formation, soil loss and run-off were minimal under alley cropping. Hillside ditches trapped water and soil; this is significant for soil and water conservation.

CONSERVATION OF SOIL NUTRIENTS

Loss of surface soil also means the loss of essential plant growth nutrients such as N, P and K, i.e. the higher the soil loss, the higher the loss of plant nutrients. The cumulative loss of N, P_2O_5 and K_2O from 1992 to 1994 under the different treatments is presented in Table 4. Because of heavy soil erosion, severe losses of P_2O_5 and K_2O occurred on bare plots and those subject to farmers' practice.

Table 4. Cumulative nutrient losses under different treatments, 1992 to 1994.

Treatment	Nutrient loss (kg/ha)		
	N	P_2O_5	K_2O
Hillside ditch	173	47	673
Farmers' practice	355	99	1314
Alley cropping	127	40	444
Bare land	1016	361	4667

Nutrient losses under the alley-cropping treatment, in terms of N, P_2O_5 and K_2O, were only 36%, 41%, and 34%, respectively, of the farmers' practice.

Table 5 shows the changes in soil nutrients between 1992 and 1995. Under all treatments, pH tended to rise, whereas organic matter and available potassium decreased. Total nitrogen did not change, and available phosphorus also increased. The increase in available phosphorus is most likely the result of substantial fertiliser applications. Because of the soil erosion and zero fertiliser application, the nutrient content of bare land decreased rapidly. In other treatments, changes in nutrient status reflect the balance between the opposing effects of fertilizer application and soil loss.

ANALYSIS OF CROP YIELD

Table 6 shows maize yields over five years from 1992 to 1996 as affected by various treatments. The results showed that hillside ditch gave the lowest yield, because of a smaller cropping area. On the other hand, although the cropping area was smaller, the yield under the alley cropping was as high as the farmers' practice, a beneficial effect of biomass trimmed from the hedgerows.

ECONOMIC ANALYSIS

An analysis of the economic returns under different treatments from 1994 to 1996 is presented in Table 7. On average, similar benefit:cost (B:C) ratios were obtained in all three treatments. Similar B:C ratios of the farmers' practice and the alley-cropping treatment reflected the same magnitude of yields obtained under these treatments. The high B:C ratio under the hillside ditches was the result of additional income from banana and Amomum xanthioides. It should be borne in mind, however, that in this analysis no account has been taken of the economic benefit of reducing soil loss.

Table 5. Changes in topsoil nutrient contents under different treatments in 1992 and 1995.

Treatment	Year	pH	N (%)	Organic matter (%)	P (mg/kg)	K (mg/kg)
Hillside ditch	1992	4.90	0.13	2.21	7.50	100.5
	1995	5.37	0.13	1.50	11.30	47.6
Bare land	1992	5.10	0.14	2.34	0.90	121.0
	1995	5.76	0.13	1.32	1.65	71.3
Farmers' practice	1992	6.70	0.14	2.25	3.80	126.3
	1995	7.12	0.14	1.51	18.70	122.4
Alley cropping	1992	7.20	0.16	—	5.80	121.5
	1995	7.76	0.17	1.90	29.10	109.9

Table 6. Maize yields over time under different treatments during 1992–96.

Year	Yield (t/ha)		
	Alley cropping	Farmers' practice	Hillside ditch
1992	1.73	1.33	1.33
1993	2.84	3.05	2.02
1994	3.86	4.02	2.53
1995	3.50	2.88	1.53
1996	4.00	4.05	2.43
Average	3.10	3.06	1.97

Table 7. Economic returns under different treatments during 1994–96.

Items		Economic analysis (US$/ha)		
		Farmers' practice	Alley cropping	Hillside ditch
1994	Input	302.6	299.8	304.1
	Output	472.8	453.6	479.7
	B:C ratio[a]	1.6	1.5	1.6
1995	Input	452.6	452.6	428.6
	Output	703.0	856.7	373.2
	B:C ratio	1.55	1.87	0.87
1996	Input	405.9	440.3	339.9
	Output	761.8	774.0	588.1
	B:C ratio	1.88	1.76	1.73
Average	B:C ratio	1.68	1.71	1.67*

* In hillside ditches the B:C ratio in 1995 was low because the income from banana and Amomum xanthioides seeds was not included. The average is of two years, i.e. 1994 and 1996.
[a] B:C ratio = benefit:cost ratio.

CONCLUSIONS

The results of this study clearly showed that the alley-cropping technology not only reduced soil erosion and water loss but also promoted soil fertility. Economically, alley cropping gave net returns as high as those of the current farmers' practice. To be more beneficial and to generate more returns, the technology should be combined with perennials, especially fruit trees.

Currently, the project is carrying out on-farm research that is being implemented by farmers. Alley cropping is the technology chosen by the farmers to be validated against their common practice. Instead of employing only a legume shrub to establish hedgerows, a mixture of the legume shrub with fruit trees is being used. The results of this on-farm trial are quite encouraging; farmers are positive about the technology. The project plans to introduce this technology to more farmers in Sichuan and Yunnan provinces.

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FORAGES FOR EROSION CONTROL ON THE RED SOILS OF SOUTH CENTRAL CHINA

Shilin Wen[1], D.A. MacLeod[2], A.J. Casanova[2], J.M. Scott[2], P. Horne[2], Liangshang Xie[1] and Zhang Jiuquan[1]

[1] Red Soils Experiment Station, CAAS, Qiyang, Hunan, P. R. China
[2] University of New England, Armidale, Australia

Abstract

Twelve run-off plots were constructed in 1991 to evaluate the impacts of incorporation of forage with upland cropping systems and engineering measures on erosion control. The results over three years showed that forages and terraces had significant effects on controlling run-off and soil loss. The annual soil loss was 0.8 t/ha in treatments with forage and/or crop and/or terraces, compared with 40 t/ha in the control treatment. The soil loss mainly resulted from heavy storms which occurred frequently in April, May and June. Forages grow well in this period, hence forage can reduce the effect of storms on erosion. Inter-cropping forage can reduce soil and water loss before crop sowing and post-harvest. Forage also benefits by intercepting nutrients lost from crop strips.

INTRODUCTION

SOIL erosion is a serious problem due largely to deforestation since the 1950s on the red soils of southern Hunan, P. R. China. The area of Lingling Prefecture recorded as forest decreased from 54% to 12% between 1950 and 1985. Most of the soil nutrient reserves have been lost with the eroded topsoil resulting in exposed landscapes, which native vegetation is unable to recolonize. Such land degradation has resulted in 12.5% of the total land area being classified as wasteland in this region (Gou 1985). Widespread plantings of forests and citrus orchards have met with some success and have increased the productivity of Lingling Prefecture. For example, 49% of the total land area has now been classified as reforested. However, in many cases, without adequate inputs of fertilizers, growth of forests has been poor and the soils remain exposed to continuing erosion.

Forage plants provide the quickest, cheapest and most effective method of controlling soil erosion (Zhang and Zhang 1991). In addition they have the potential to provide forage for livestock in the region where forage quality year-round is poor and forage availability in the winter months is low. An experiment was established in 1991 to evaluate the impacts of incorporating forages with upland cropping systems on erosion control.

MATERIALS AND METHODS

The experimental site

The experimental site was a wasteland located on the eastern upper slopes of a hill at Mengongshan (26.7°N, 111.6°E), Lingling Prefecture, Hunan Province, where severe gully erosion was occurring and where native vegetation was almost totally absent. The altitude is about 130 m. The soil had not been cultivated, at least not in recent decades.

Climate

The climate of Lingling is classified as mid-subtropical with four distinct seasons and a predominance of spring-summer rainfall (65% of the 1412 mm annual total) (Leng et al. 1992). Yearly average temperature is 17.8°C with the lowest temperature on record of –7.0°C in January and the highest 40°C in July.

Soil

The soil studied was a deep red clay soil that is acid and nutrient poor but well structured and free draining. It is physically suited to cultivation and forage development.

Experimental procedures

The experiment site was levelled using a tractor to remove gullies. Twelve run-off plots were constructed in April 1991. The slope of the site was 6.5°. The individual plots were each 3 m wide × 22 m long (aligned down the slope). Brick walls were constructed around each plot while at the bottom of each plot, three concrete-lined brick tanks were constructed to collect run-off water and eroded soil. The sizes of the tanks were 0.43, 0.68, 0.87 m^3, respectively and water and sediment flowed from the

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smallest to the largest to allow accurate measurements to be made of run-off events of different size. After measurements were taken following a run-off event, the water and sediment were removed and the tanks cleaned ready to capture the next run-off event.

Twelve treatments were imposed as follows:

1. Control (bare plot). The plot was left untreated. Any plants that grew in the plot were removed and thus this treatment represents the worst erosion potential.
2. Natural vegetation. The plot was left untreated, but differed from Treatment 1 in that any volunteer colonising plants were allowed to grow.
3. Forages (100%). The plots were planted to forages (white and red clovers, phalaris and cocksfoot).
4. Crop (50%) and forages (50%). Forages and crops were planted in alternate 2 metre-wide strips along the length of the plot.
5. Crop (75%) and forages (25%). Forages and crops were planted in alternate strips (3 m — crops; 1 m — forages) along the length of the plot.

The above treatments represent the ‘standard’ treatments. Treatments 6 to 8 were designed to evaluate the effects of incorporating crops and forages together with engineering measures for controlling run-off and erosion.

6. Terraces + Crop (100%). This is similar to the typical treatment used on the purple soil hills in southern Hunan. There were 6 terraces per plot; 4 terraces in the middle of the plot were 4 m wide whereas the terraces at the top and bottom of the plot were each 2 m wide.
7. Terraces + Crop + Forage. As for Treatment 6 but with a 0.5 m wide strip of forages on the front edge of each terrace.
8. Terraces + Crop + Forage + pits. As for treatment 7 but with 2 water-collecting pits at the foot of each terrace. The size of pits was 0.3 m wide, 0.5 m long and 0.4 m deep.

Additional treatments:

9. Forages (100%) with Consol lovegrass strips. As for treatment 3 but with 0.3 m wide strips of Consol lovegrass planted at 4 m intervals.
10. Crop (50%) and forages (50%) with Consol lovegrass strips. As for treatment 4 but with 0.3 m wide strips of Consol lovegrass planted at the lower edge of each forage strip.
11. Crop (75%) and forages (25%) with Consol lovegrass strips. As for treatment 5 but with 0.3 m wide strips of Consol lovegrass planted at the lower edge of each forage strip.
12. Crop (75%) and forages (25%) with tree lucerne strips. As for treatment 5 but with 0.3 m wide strips of tree lucerne planted at the lower edge of each forage strip.

All plots, except terraces, were kept at the same slope of 6.5°.

Consol lovegrass failed to establish and the tree lucerne died in the first winter. Thus, the latter four treatments (9–12) could be treated as the replicates of corresponding treatments of 3, 4 or 5.

At the beginning of the experiment, the soil was limed to bring the top 10 cm of soil up to pH 5.6. A basal application of fertilizer was applied at rates of 80 kg/ha P and 50 kg/ha K. Additional N at 160 kg/ha N and 30 tons/ha of pig dung were added to the crop strips. For the forages, 25 kg N/ha was applied in spring, 1992, and 20 kg P/ha and 20 kg K/ha were applied in the spring of both 1993 and 1994.

Four forage species (Haifa white clover, red clover, phalaris and Porto cocksfoot) were sown on December 1, 1991. Wynn cassia seed was over-sown in spring, 1993.

Crops were sown as follows:

- Rape on 1 December, 1991;
- Peanut on 8 April, 1992;
- Rape on 25 November, 1992;
- Sweet potato on 3 June, 1993;
- Peanut on 10 April, 1994.

The crops and forages were harvested at maturity.

The quantities of run-off and sediment were measured after each rainfall event during 1992–1994. The yields of forage and crop were recorded. Rainfall amount and intensity were measured by a ‘tipping bucket’ rain gauge fitted with an electronic data logger. Additional rainfall data was obtained from the Qiyang Meteorological Station.

RESULTS

Precipitation characteristics

Annual rainfall ranged from 1370 to 1918 mm during 1992–1994, which is considerably more than the

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annual mean of 1283 mm recorded over the past 35 years by the Qiyang Meteorological Station (27 km from the experimental site). The precipitation was concentrated mainly in April, May and June, and occurred mostly in heavy storms (Figure 1). The annual number of rainy days in 1992, 1993 and 1994 were 135, 177 and 194 days, respectively. In most cases the daily rainfall was less than 10 mm. The number of days in which rainfall exceeded 30 mm was 10, 11 and 15, in 1992, 1993 and 1994 respectively. However, the total amount of rain falling on those days was 33.6%, 31.4% and 42% of the annual totals respectively (Table 1).

Run-off

In the early stages of the experiment (December 1991 to April 1992), there were few differences in run-off among treatments, except for the terrace treatments, before the forages became established and the initial crop (rape) grew. From May 1992, after the forages had become established and the crop strips were planted to peanuts, run-off from treatments with crops and forage was much less than for the control. This was because cultivation of the crop strips left the surface rough and the soil loose, thus decreasing the speed of overland flow and increasing water infiltration.

Three years of experimental results showed that the effects of treatments 4 and 5 on reducing run-off were similar. The 100% forage treatments had no effect on controlling run-off in 1992, as the forages had just established and the summer and autumn was extremely dry in this year (Figure 1) so that the forage grew poorly. When the forages had become established and were growing well, the effects of treatments containing forages on reducing run-off became more significant. The run-off from treatments 3, 4, and 5 were 55%, 29% and 27% in 1993, and 30%, 17% and 16% of the control in 1994, respectively (Figure 2).

Terrace treatments had significant effects on reducing run-off, being less than 20% of the control. There were no significantly differences among terraces treatments. The natural vegetation treatment (2) had some effect, compared to the control, and the effect became greater with time as colonisation of the plot by volunteer native plants increased.

Soil loss

Eroded soil was measured as suspended material in the run-off water, and as sediment at the bottom of the collection tanks. The effects of treatments on soil loss followed the same pattern as run-off, but the differences were much larger. This was particularly

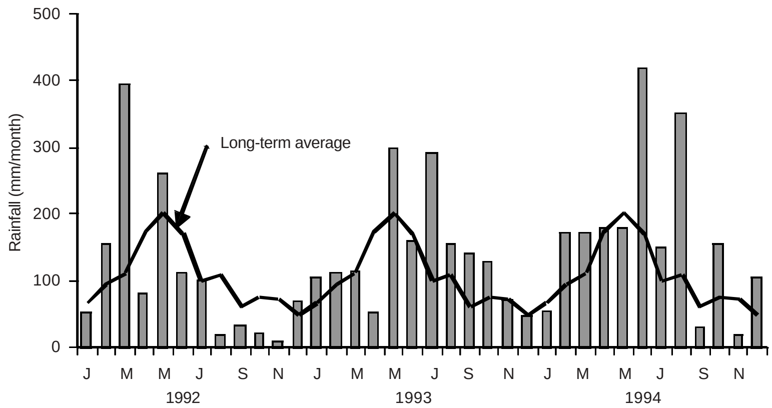

Figure 1. The monthly rainfall during the experimental period.

Table 1. Summary of the size of rainfall events and the number of rain days during the experimental period.

Rainfall range (mm)	1992		1993		1994	
	Rainfall	Days	Rainfall	Days	Rainfall	Days
0–10	263	91	377	123	404	139
10–30	647	34	758	43	709	40
30–50	267	7	252	7	311	9
>50	194	3	268	4	494	6
Total	1370	135	1654	177	1918	194
Rainfall less run-off	1213		928		1382	

the case for the 100% forage treatment, which had similar run-off to the control in 1992 but the soil loss was much less than the control (Figure 3). Forages and crops had significant effects on controlling soil loss. In 1994, the soil loss from all treatments, except natural vegetation (2), was less than 2% that of the control. For the 100% forage treatment, soil loss was just 1.8% that of the control (Figure 3).

The effects of rainfall intensity on soil and water loss

The experimental results showed that run-off occurred only when rainfall was greater than 10 mm. Soil and water loss were due mainly to storm events, which occurred frequently in April, May and June, especially for treatments with forages and crops (Figure 3). For example, on May 2, 1992, an 80 mm storm caused 56% of the annual soil loss in the control.

Relationships between run-off, soil loss and rainfall

Run-off and soil loss have been related to rainfall using different measures of that rainfall. In general, the longer the time period, the stronger the relationship. This is likely to be due to longer time periods having an averaging effect on other factors influencing erosion such as soil moisture and vegetation. Regression analyses (not shown) between run-off and monthly rainfall showed correlation coefficients (r) above 0.7 with some as high as 0.9. There was an exponential relationship between monthly run-off and monthly rainfall.

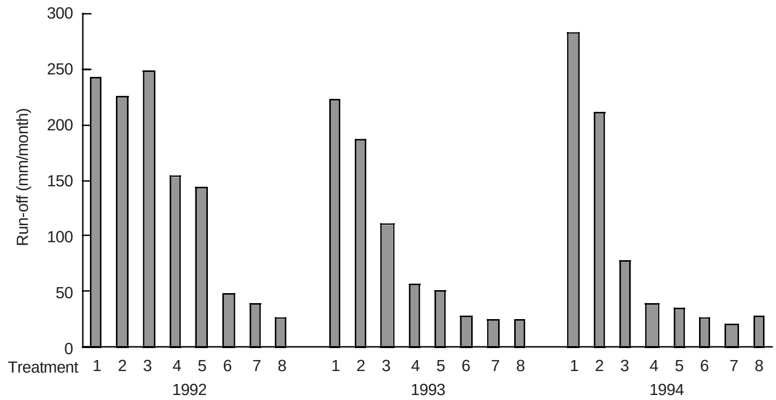

Figure 2. Annual run-off measured on eight treatments over three years.

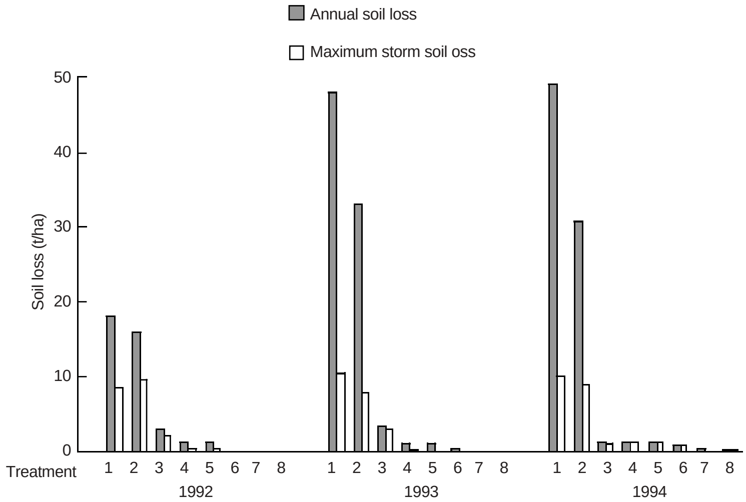

Figure 3. The effects of treatments on annual soil loss and that occurring during the maximum storm within each year.

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Table 2. Forage yields during the experimental period.

Forage treatment	1992	1993			1994		
	Grass	Grass	Legume	Total	Grass	Legume	Total
	(t DM/ha)						
3: 100% forage	1.1	2.5	1.3	3.8	1.7	3.4	5.1
4: 50% forage; 50% crop	1.0	4.8	1.3	6.1	3.7	3.4	7.2
5: 25% forage; 75% crop	1.4	11.3	2.3	13.6	8.3	4.4	12.8
7: Terrace + crop + 10% forage	1.0	14.0	0.0	14.0	8.4	0.2	8.6
8: Terrace + crop + 10% forage + pits	1.0	12.0	0.3	12.3	8.8	0.3	9.1

Table 3. Crop yields during experimental period.

Crop treatment	1992	1993		1994
	Peanut	Rape	Sweet Potato	Peanut
	(t/ha)			
4: 50% forage; 50% crop	1.3	0.8	14.3	2.1
5: 25% forage; 75% crop	1.2	0.7	14.0	1.6
6: Terrace + crop	1.4	0.6	13.6	1.4
7: Terrace + crop + 10% forage	1.4	0.5	12.2	1.3
8: Terrace + crop + 10% forage + pits	1.0	0.5	8.9	1.1

Forage yield

Only Porto cocksfoot and Haifa white clover germinated and established. After the dry summer of 1992, only Porto cocksfoot survived. All species were re-sown in autumn, 1992. The growth of the forages was still poor in 1992 but greatly improved in 1993 and 1994 (Table 2). For the forage plus crop treatments, yields have been expressed as dry matter per hectare of forage area within these plots. It is noticeable that yield increases with the proportion of crop area within plots. Thus, in 1993, the yield for Treatment 5 with 75% crop was more than twice that of Treatment 4 with 50% crop, which in turn is 1.6 times that of Treatment 3 with 100% forages.

The marked differences are due to the forage strips intercepting nutrients lost from crop strips by run-off and erosion. The forage strips thus benefit from the large amounts of N added to the crops, whereas the 100% forage treatment received only 25 kg N/ha in spring 1992. The extra N had the greatest effect on the grass component of the forage strips. Once the legume component had become fully established in 1994, the extra N had only a small effect on legume production whereas grass yield of the 75% crop treatment was almost 5 times that of the 100% forage treatment.

Crop yields

In the most cases, the yields of crops in terraced treatments were less than for the unterraced sloping treatments (Table 3). One of the reasons for this was that terrace construction reduces the area of plots that could be planted to crops. The crop yields were always the lowest in treatment 8 which, in addition to terraces, contained pits for trapping run-off. Pits further reduced the area for cropping and less run-off flowed into the strips for crop use.

DISCUSSION AND CONCLUSIONS

Many factors influence soil and water loss, including a soil’s erosive factor, rainfall characteristics, slope length, vegetation, slope, and soil cultivation and management. Terracing is one of the most effective conservation measures. Terraces can reduce the velocity of water flow significantly, increase infiltration and thus decrease run-off and soil loss. In this experiment, run-off from terrace treatments was less than 20% that of the control, and the soil loss was less than 1%.

Forages had a highly significant effect on soil and water loss. They are effective in controlling soil and water loss for the following reasons:

1. They intercept rain drops and reduce splash erosion at the soil surface caused by rain drop impact.
2. They produce numerous tillers, which can decrease flow velocity and intercept eroded soil.
3. They have strong root systems, which can hold soil mechanically and increase resistance against erosion.
4. Litter and roots of forages increase soil organic matter, which promotes the stability of soil structure, which in turn increases infiltration.

Large amounts of plant nutrients are lost by the erosion of topsoil. The nutrient content of eroded soil is higher than that of the remaining soil (Bai et al. 1991; Costin 1980). The eroded soil silts up rivers, ponds and reservoirs. Planting forages can therefore effectively reduce soil nutrient loss and eutrophication of waterways.

Storm events causing most erosion occur from April to July. This is the most important period for soil and water conservation. Temperate forage species grow well in this period, but grow poorly from mid-summer to autumn. A mixture of temperate and tropical species can effectively prevent soil and water loss throughout the year.

Locally, peanuts and sweet potatoes are the main economic crops in upland production. These are grown in summer and autumn so the soil can be bare during this period which can receive intense rainfall. Planting crops and forages in alternate strips can solve this problem of excessive soil loss (Robinson 1996; Leihner et al. 1996). Forages intercept nutrients lost from crop strips and thus forage yield is significantly increased and pollution of water resources decreased.

Pits to intercept run-off at the base of terraces adversely affected crop yield due to a reduction of the area able to be cropped as well as the available water. The practice has little to recommend it.

Colonisation of the bare plot, mainly by *Imperata cylindrica*, reduced run-off and soil loss. However, *Imperata* is a weed and better results can be achieved by planting forages which can be utilised by growing livestock.

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MANAGING FERTILITY OF THE RED SOILS FOR FORAGE PRODUCTION

Donald A. MacLeod

Agronomy and Soil Science, University of New England, Armidale, NSW 2351, Australia

Abstract

The degraded red soils are acid and deficient in several plant nutrients, particularly N, P, K and Mg. Nutrients continue to be lost through soil erosion and removal of forages by cut-and-carry without return of animal manures. Due to the low organic matter status of the soils, N is a major limitation to forage production. Forage legumes with a good tolerance of soil acidity have been shown to add substantial amounts of N to the soil through symbiotic N_2 fixation. Successful use of these legumes depends on adding a small amount of N fertiliser at sowing (in addition to overcoming other nutrient limitations) to promote seedling growth and inoculating seed with the appropriate type of rhizobia.

The acid, highly weathered red soils adsorb P strongly, but P adsorption isotherms give a misleading impression of the amount of P fertiliser to be applied. To reduce adsorption, P fertiliser should not be incorporated into the soil. Higher forage yields were obtained by broadcasting P fertiliser compared with banding. Once N and P deficiencies had been reduced, symptoms of Mg deficiency appeared on both grasses and legumes, indicating the limited ability of the acid soils to retain cation nutrients, such as Mg and K. Since pH is usually in the range of 4.5 to 5.2, lime is needed to raise the pH to 5.6 to remove Al toxicity. The most successful grasses and legumes have a good tolerance of acidity and little is to be gained by liming to neutrality.

A key strategy for forage production on the red soils is increasing soil organic matter. The benefits of organic matter include reducing P adsorption, increasing effective CEC to retain K, Mg and Ca, and complexing Al. On wasteland, pioneer species tolerant of acidity and low nutrient status should be used. Grasses on their own, however, will achieve little without complementary legumes to add N. Increasing soil fertility should be set in the context of an integrated soil-plant-animal system. For sustainable animal production forages should provide good quality feed year-round and adequate protection against erosion.

INTRODUCTION

THE red soils of southern China are acid and poor in nutrients. The analytical data for the Mengongshan soil shown in Table 1 illustrate the soil fertility problems that have to be addressed in developing forages on the red soils. The soil has a pH_{water} of 4.3, and is low in the nutrients N, P, Ca, Mg and K. Organic carbon is low and so is the effective cation exchange capacity (ECEC), which is an indication of the soil's capacity to retain nutrient cations. Associated with the acid pH is the large amount of adsorbed Al, which dominates the exchange complex.

The low availability of nutrients in the soil results in nutrient concentrations in forages being deficient. Table 2 shows that Premier finger grass (*Digitaria eriantha* cv. Premier) grown on an infertile soil at Guanshanping, Hunan was deficient in N, P, S and K with Ca and Mg being marginal.

Table 1. Analyses of 0–10 cm samples of red soils from Hunan Province.

	Parent Material	
	Mengongshan Quaternary clay	**Huilongxhu Limestone**
Organic C (%)	1.20	1.00
pH (1:5 water)	4.3	5.9
Nitrate N (mg/kg)	1.2	1.7
P (bicarbonate) (mg/kg)	3	6
Exch Ca (c mol_c/kg)	0.65(15[1])	5.14(85)
Exch Mg (c mol_c/kg)	0.16(4)	0.75(12)
Exch K (c mol_c/kg)	0.11(3)	0.14(2)
Exch Na (c mol_c/kg)	O.04(1)	0.02(1)
Effective CEC (c mol_c/kg)	4.29	6.05
Base Saturation (%)	23	100
Aluminium Saturation (%)	77	—
Mg/K	1.45	5.4

[1] % of Effective CEC.

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Table 2. Nutrient concentrations in Premier finger grass from low input[1] experiment, Guanshanping, Hunan.

Nutrient	Concentration	Optimal/Normal[2]
N%	1.01	2.0–3.0
S%	0.15	0.23–0.40
P%	0.10	0.2–0.35
K%	1.51	2–2.5
Ca%	0.31	0.25–0.55
Mg%	0.28	0.25–0.60

[1] P applied at 10 kg/ha. Grass grown in combination with *Chamaecrista rotundifolia* cv. Wynn.

[2] Based on values for kikuyu grass, a C4 tropical.

The degraded state of the red soils has arisen mainly from the deterioration and often the destruction of the protective vegetative cover, leading to widespread soil erosion. Topsoil has been lost, leaving behind acidic nutrient-poor soil. Even where erosion has not been serious, current practices of forage management are depleting the nutrient store. In the cut-and-carry system of feeding housed animals, nutrients are removed in harvested forages but are not returned because animal manures are applied to rice paddy. Forage litter and roots are also harvested for domestic fuel. Generally no fertilisers are applied to forages to counterbalance the loss of nutrients caused by these practices.

The red soils are generally infertile but considerable variation occurs within this extensive soil group. Obviously, the greater the loss of topsoil by erosion, the lower is the fertility. Yang et al. (2002) have grouped the red soils of Fujian according to the depth of topsoil removed by erosion. These groups provide a preliminary indication of their potential for forage production. Variation in fertility also arises from natural causes, particularly soil parent material. Thus the red soil from Huilongxhu developed on limestone (Table 1) is much less acid and contains no exchangeable Al compared with the soil developed on Quaternary clay at Mengongshan. Planning forage development on the red soil has to take into account variation in soil fertility. Soil maps at the prefecture and county levels were produced in China in the early 1980s as part of a national soil survey (D. Michalk, pers. comm.). These maps should form the basis for rational land use planning for forage development and its integration with other forms of agricultural production.

This paper is concerned with the management of fertility of the red soils for forage production. Aspects of N, P, K and Mg fertility and liming are considered. The material presented is mainly based on research conducted in Fujian and Hunan Provinces under ACIAR Projects 8925 and 9303.

NITROGEN

N supply is the major limitation for pasture production on the red soils. The N concentration of Premier finger grass grown on a degraded red soil from Hunan was found to be less than half the optimal concentration (Table 2). N is released for uptake by plants through the mineralisation of soil organic matter. The problem is that organic matter levels in the red soils are low due to loss of topsoil by erosion (Table 3). Furthermore, vegetative growth on degraded soil is poor, so that inadequate plant debris is returned to the soil to build up its organic matter content.

The limitation imposed by N shortage is illustrated by the response of forage growth to the application of fertiliser (Table 4). Applying 50 kg N/ha increased finger grass yield by 2.5 times. However, this approach is not recommended for forage production on the red soils due to the high cost of N fertiliser. Moreover, the benefit of applying N was lost within two to three years due to leaching of nitrate from the highly permeable soil.

Table 3. Carbon and nitrogen levels in red soils.

Sample depth	Location	Forages	Date of sampling	Total C%	Total N%
Eroded land	Fujian		7/10/93	0.82	0.127
	Hunan		2/4/94	0.55	0.091
After forage establishment					
0–10 cm	Hunan	Premier	7/5/94	1.24 (100)[1]	0.111 (100)
			2/5/96	1.58 (127)	0.117 (105)
0–20 cm	Fujian	Premier+Wynn	10/5/94	1.33 (100)	0.099 (100)[2]
			16/4/96	1.63 (123)	0.116 (117)

[1] Figures in brackets denote changes over time expressed as a % of the value at the first time of sampling.

[2] At the same location ^{15}N measurements indicated that 87% of the increased N was derived from N_2 fixation by Wynn cassia.

Table 4. Effect of application of N fertiliser on dry matter production of Premier finger grass at Jiangkou, Fujian.

N application (kg/ha)	DM[1] (kg/ha)	Increase
0	1326[a]	
50	3335[b]	× 2.52
100	3479[b]	× 2.62

[1]Values followed by the same letter are not significantly different at P = O.05.

The N status of the red soils is best improved by growing forage legumes that fix atmospheric N_2. Table 3 shows the ability of the tropical legume *Chamaecrista rotundifolia* cv. Wynn (formerly known as Wynn cassia) to add N to the soil. Over a period of two years Wynn grown in combination with Premier finger grass increased the N content of the Fujian soil by 17%. ^{15}N measurements indicated that 87% of the increased N was derived from N_2 fixed by Wynn. Grasses grown on their own mainly recycle existing N. Thus, at a similar site in Hunan over a similar period of time, Premier finger grass growing on its own increased soil organic C by 27%, comparable to that for the Fujian soil, but N was only increased by 5% (Table 3).

Fortunately, a range exists of tropical forage legumes adapted to the conditions found in acid soils. These legumes can withstand acidity, high levels of Al and low levels of available P (Sanchez and Salinas 1981). Many of these legumes originate from South America but are unable to withstand the cold winters experienced in Fujian and Hunan. For example, *Stylosanthes guianensis*, which has a critical level of Bray II available P of only 2.5 µg/g (Sanchez and Salinas 1981), failed to survive the first winter after sowing. The most suitable forages found in our evaluation trials were *Chamaecrista rotundifolia* cv. Wynn, *Arachis pintoi* cv Amarillo and *Lotononis bainesii*. The last two species have the advantage of a prostrate creeping growth habit which makes them well suited for planting beneath trees in orchards for erosion control. Of the temperate legumes Haifa white clover (*Trifolium repens* cv. Haifa) initially grew well but died out after two or three years due to the heat and moisture stresses suffered in late summer and autumn.

Recommendation for managing forage legumes to increase soil N

1. In addition to applying other limiting nutrients, a small amount of N fertiliser should be applied at the time of planting to ensure that young seedlings have an adequate supply of N until rhizobia are established on the forage roots (Tisdale and Nelson 1975). This is especially important where rhizobial activity is restricted by cold wet conditions in spring.

2. Legumes should be inoculated with the correct strain of rhizobium to obtain satisfactory nodulation and thereby N_2 fixation. Just as plants, rhizobial strains vary in their tolerance of acid soil conditions (Sanchez and Salinas 1981). It is therefore essential to match the nutritional requirements and tolerances of both legume and rhizobia. An adequate supply of suitable rhizobia should be built up throughout the red soil region if forage development is to be successful.

3. Ideally grasses and legumes should be grown together with the legumes fixing N_2 to increase grass production and its protein content and ultimately lead to a build-up of soil organic matter. The most productive grass and legume species found in our experiments were Premier finger grass and Wynn cassia. When grown in combination, however, Wynn was suppressed by the grass (Ying et al. 2002). Wynn relied on seed produced during the previous year for establishment. This, together with the much higher yield when grown alone, suggests that it should be grown as an annual forage crop. Grasses should still be grown, preferably in rotation in order to prevent excessive loss of N by nitrate leaching. The red soils are prone to leaching on account of their stable micro-aggregates. Thus, although the red soils are usually rich in clay, hydrologically they behave as sandy soils. Leaching is most serious in spring, when 40% of the annual precipitation falls. Deep rooting grasses have the ability to capture nutrients leached into the soil and promote recycling. In addition to the loss of valuable N, nitrate leaching causes soil acidification, as has happened in areas of south-eastern Australia where pasture legumes are grown in rotation with cereal cropping.

Although temperate legumes such as white clover failed to persist, they still have a role to play in forage management on the red soils. In addition to providing feed in late winter and early spring before tropical forages have fully recovered from winter, temperate legumes can add N to the soil to benefit subsequent grass production. Ying et al. (2002) found that, although it had died out, white clover increased subsequent grass yields by up to 480 kg DM/ha.
In view of their inability to survive the stresses of summer and autumn, temperate legumes should be regarded as a short-term component within rotations.

In summary, N is a major limitation for forage production on the red soils. Grasses on their own only recycle N and the plant system will remain degraded without N being increased. The most efficient way of doing this is by growing forage legumes adapted to the soil and climatic conditions of the red soil region.

PHOSPHORUS

N deficiency is best approached by growing forage legumes capable of fixing atmospheric N_2. However, the major limitation for legume growth on the red soils is P deficiency. Once the supply of P is increased so that legumes add N to the soil, the increased N increases top and root growth. The increased root mass then increases P uptake (Tisdale and Nelson 1975). Thus P indirectly determines N supply.

P has long been recognised as a major deficiency of the red soils. Available P levels are low (Table 1) and the soils have a strong P sorption capacity (Figure 1). A number of factors contribute to this strong P sorption: low pH, high content of Al and Fe in adsorbed and hydrous oxide forms, high clay content and thus surface area, and dominance of kaolinite in the clay fraction.

The problem of P sorption is illustrated by data from a low input trial at Guanshanping, Hunan. After receiving 10 kg P/ha, the available P (Colwell) had dropped from 19 to 5.6 µg/g eleven months later.

Table 5 shows the amounts of P sorbed at P solution concentrations of 0.2 µg/ml for topsoils from experimental sites in Fujian and Hunan. The higher values for the Fujian soils are attributed to the greater degree of weathering, and hence great Fe and Al contents, under the higher rainfall experienced at the Fujian site. The soils also differ considerably in the response of P sorption to liming.

Table 5. Mean values of P sorption for topsoils in low input experiments in Hunan and Fujian and for comparable Australian soils. Data for Australian soil published by Probert (1983).

Location		P sorption[1] (kg/ha/10cm)	Cost of required P fertiliser to obtain 0.2 µg/ml in soil solution[2] (Yuan/ha)
China Red Soils			
Hunan	unlimed	273	3910
	limed	243	3480
Fujian	unlimed	412	6180
	limed	299	4300
Comparable Australian Soils			
Topsoil:	Oxisols	205	
	Ultisols	104	
Subsoil:	Oxisols	654	
	Ultisols	319	

[1] Calculated as the amount of P sorbed at P in solution = 0.2 µg/ml. Soil bulk density taken as 1330 kg/m^3.
[2] Using Chinese superphosphate containing 8% P, costing 0.574 Yuan/kg.

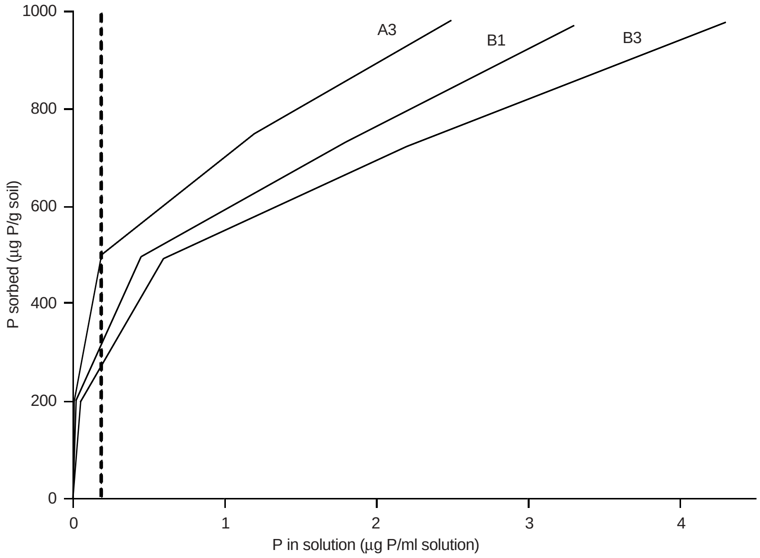

Figure 1. P sorption isotherms for three soils from Jiangkou, Fujian. The vertical dotted line is used to calculate the amount of P sorbed at a P concentration in solution of 0.2 µg/ml.

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In Table 5 P sorption values for the Chinese soils have been compared with those for comparable Australian soils rich in Fe and Al oxides (Probert 1983). The more highly weathered soils are classified as Oxisols, the less weathered as Ultisols. The values for the Australian topsoils are appreciably lower than those for the Chinese topsoils, but subsoil values for the Ultisols are closer. The Chinese red soils in Table 5 are also classified as Ultisols. Erosion has removed the topsoil from the Chinese profiles, leaving behind a subsoil more acidic and richer in Fe and Al oxides, properties which are conducive to strong P sorption.

Isotherms are used to calculate the amount of P sorbed when the P concentration of an equilibrating solution is 0.2 µg/ml. It is commonly assumed that this concentration has to be maintained for satisfactory growth of a range of crops. P sorption values are then used to calculate the amount of fertiliser P that has to be applied to the soil to attain this solution concentration. The cost of using Chinese superphosphate containing 8% P to achieve this has been calculated in Table 5. Costs range from 3480 to 6180 Yuan/ha. These costs are clearly prohibitive. Fortunately isotherms give an exaggerated estimate of the amount of P that has to be added because, unlike the laboratory determination of P sorption, soils in the field are not mixed and shaken with P in solution. Nevertheless, the red soils do sorb P strongly, and achieving a level of available P for satisfactory forage growth is a major item of expense.

Management strategies for improving P status

A number of strategies can be adopted to increase the efficiency of P fertilisers and to reduce costs.

1. Surface application of fertiliser with minimum disturbance of the soil. P fertiliser should be applied to the soil surface and not incorporated into the soil in order to reduce contact with the soil. Superficial roots of forages appear to be able to absorb and utilise surface-placed P, although the mechanism is not well understood (Sanchez and Salinas 1981).
2. Timing of fertiliser application. P fertiliser should be applied shortly before sowing. Forage species have their greatest need of P a few weeks after germination before a deep rooting system develops. Also, less time is available for applied P to be made unavailable by P sorption. Initially P may be adsorbed on soil surfaces in a labile readily available form. With time, it may become occluded within Fe and Al oxides and be only slowly available.
3. Fertiliser placement. It is commonly recommended that for pasture establishment P fertiliser be banded rather than broadcast, particularly for low P application rates and where seeds are sown in bands (Sanchez and Salinas 1981). Our findings from forage establishment and management trials in Fujian and Hunan do not support this recommendation. In a low input trial in Hunan, Premier finger grass and Wynn cassia were grown in combination with P applied at 2 and 10 kg/ha. Available P of the soil was 5.5 µg/g (Olsen method). Seeds were broadcast-sown, row-sown grass and legume in separate alternate rows, and row-sown with legume and grass mixed with rows. P fertiliser was broadcast in the first treatment and banded for the row-sown treatments. Table 6 shows that the yield and P uptake by the grass was more than double for the broadcast treatment compared with the banded treatments. In contrast Wynn yield was much higher when it was grown in separate rows. This is probably due to an absence of competition from the vigorous Premier finger grass, which has been shown by Ying et al. (2002) to depress the yield of Wynn. Although Premier grows rapidly, it did not spread far from rows, possibly because of acute P deficiency in inter-row areas not receiving fertiliser. Due to the poor spread of forages from rows, weed infestation was higher for the banded treatments (Table 6).

   The effect of fertiliser placement is likely to vary with the adaptation of the planted forages to low P availability. Those with very low P requirements such as many Stylos could spread out from rows. However, one potential drawback of banding is that roots become concentrated around the fertiliser bands and plants can become more vulnerable to drought. Broadcasting of fertiliser

Table 6. Effect of fertiliser placement (10 kg/ha) on a Premier-Wynn combination in a low input experiment, Hunan for 1995–1996.

Placement method	Premier finger grass		Wynn cassia	Weeds
	DM (kg/ha)	P uptake (kg/ha)	DM (kg/ha)	DM (kg/ha)
Broadcast	2138	2.65	990	126
Banded: grass and legume mixed within rows	793	0.95	762	273
Banded: grass and legume grown in separate alternate rows	968	1.23	1829	482

would allow a more extensive root system to develop. This is an important consideration in the red soils region, where severe moisture stress occurs in late summer and autumn, and could explain why broadcasting gave higher yields and persistence in our trials.

4. Application rates of P fertiliser. Two strategies have been proposed for dealing with the problem of P unavailability in soils which sorb P strongly: (1) apply high amounts of P initially to largely satisfy P sorbing capacity and to rely on adequate release for a number of years, without further application; (2) apply low amounts frequently to slowly saturate the P fixing capacity (Sanchez 1976). It is most unlikely that livestock producers on the red soils would be able to afford the cost of high initial application rates, which can exceed 300 kg P/ha. Moderate rates of application might be more feasible. In a trial at Mengongshan, the temperate grass Porto cocksfoot (*Dactylis glomerata*) was grown on a P deficient soil (Olsen P 3 μg/g) with P applied at rates of O to 120 kg/ha (Figure 2). Yields obtained at 20 kg/ha were half those at 120 kg/ha, but at the latter P rate, the fertiliser cost for each kg of grass produced was three times as high. Figure 2 also shows that the benefits of reapplying P at 20 kg/ha in the second year were only fully realised for initial application rates of 80 kg/ha and above. Up to this point the reapplied P was still being sorbed and largely unavailable.

   The most realistic approach for the degraded red soils would seem to be the low input strategy of applying small amounts of P frequently and growing species adapted to low P soils. In the low input trial described above, P was applied at 2 and 10 kg/ha. When averaged over fertiliser placement method, the higher P rate gave double the yield of grass (833 and 403 kg/ha) and legume (933 and 470 kg/ha). However, the high rate of P was five times greater than the low rate, so the cost of each kg of forage produced was 2.5 times as much for the higher P rate.

5. Build up soil organic matter. Organic matter can reduce P sorption in these ways:

   - Organic anions form stable complexes with Fe and Al thus preventing reaction with phosphate ions;
   - Organic compounds can form a protective cover on the surfaces of Fe and Al particles thus reducing P sorption; and
   - Organic anions can replace phosphate ions on adsorbed sites.

   Organic matter also increases the soil's organic P pool, from which P is released in available forms by mineralisation. Strategies for building up soil organic matter are discussed later.

6. Use of manures. Manures produced by livestock fed on forages should be returned to areas from which the forages have been harvested or grazed. As discussed later, improving the cycling of nutrients in the soil-plant-animal system requires that manures be returned. Manures should add soluble organic P compounds to the soil. As these are not readily sorbed they are reported to be able to move to depths of 0.5 to 1.0 m down the profile. Movement of organic P should increase root development in the soil and thus moisture availability.

7. Use of rock phosphate. Ground rock phosphate applied directly to the soil is less costly than more soluble processed forms of P fertiliser such as superphosphate. Compared with more soluble P

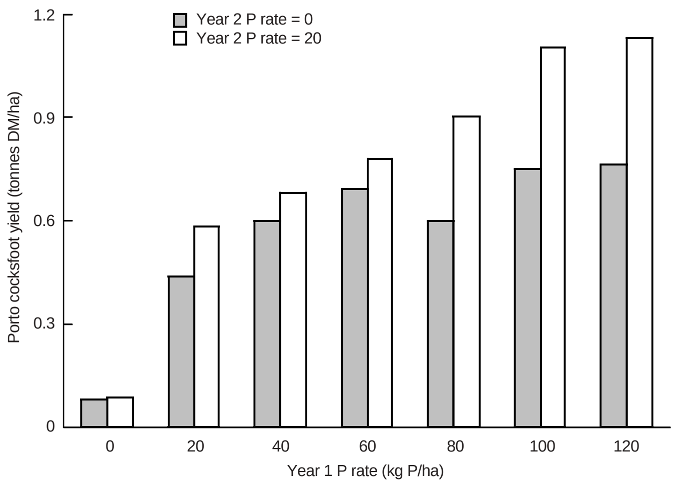

Figure 2. Porto cocksfoot yields for P treatments imposed over two years.

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fertilisers, because P is released slowly over a period of time, a higher proportion of the P content should be taken up by plant roots before it is made unavailable by sorption. The suitability of rock phosphate to be applied directly depends on: (i) the reactivity of the rock phosphate; (ii) environmental conditions, particularly soil pH; and (iii) the ability of plants to extract P from rock phosphate. China is fortunate in having widely distributed deposits of rock phosphate. In an evaluation of 45 deposits Jiang et al. (1986) found that a quarter of them were highly reactive (60–80% in comparison with calcium magnesium phosphate fertiliser) and half had moderate reactivity (30–60%). The conditions of low soil pH, and high rainfall and temperatures characteristic of the red soil region favour the use of rock phosphate. Bryan and Andrew (1971) have reported that *Lotononis*, found to be promising for use in orchards (Luo et al. 2002), is capable of extracting more P from rock phosphate than other tropical forage legumes. A trial has been established in Jiangkou, Fujian to assess the ability of Wynn cassia to extract P from rock phosphate.

POTASSIUM AND MAGNESIUM

Potassium deficiency in the red soils is widely recognised. In the low input trial in Hunan the K concentration of Premier finger grass was well below optimal (Table 2). Symptoms of Mg deficiency were observed in forages in Hunan during the cold wet spring of 1994. Leaves of Premier were bleached in colour and the leaves of white clover turned reddish.

Highly significant correlations ($P < 0.01$) were found between concentrations of K and Mg in leaves and DM production for both Premier finger grass and Wynn cassia. An interaction between K + Mg and P applications was found in a fertiliser trial at Mengongshan, Hunan (Figure 3). A significant effect of K + Mg on the growth of Porto cocksfoot was only found at high rates of P application, the greatest effect being observed for P applications of l00 kg/ha in successive years. Once the major limitation of P deficiency had been removed, increased demand for K and Mg restricted growth. Omission pot trials on the same soil showed that both K and Mg were deficient.

Causes of K and Mg deficiency

1. Low effective cation exchange capacity (ECEC) limits the ability of the soil to store nutrient cations such as K and Mg against leaching loss. The low ECEC is mainly due to low organic matter contents, the dominance of kaolinite and sesquioxides in the clay fraction (Alter and MacLeod 1991). Also the soil has a pH dependent charge and low pH decreases net negative charge and hence ECEC. The low ability of the Hunan soil to store cations results in the low levels of exchangeable K and Mg (Table 1).

2. Unlike clay minerals with a 2:1 crystalline structure, kaolinite, the dominant clay mineral in the red soils, does not contain K and Mg in its crystal structure. This, together with the loss by strong weathering of minerals containing K and Mg, means the red soils have low reserves of these nutrients.

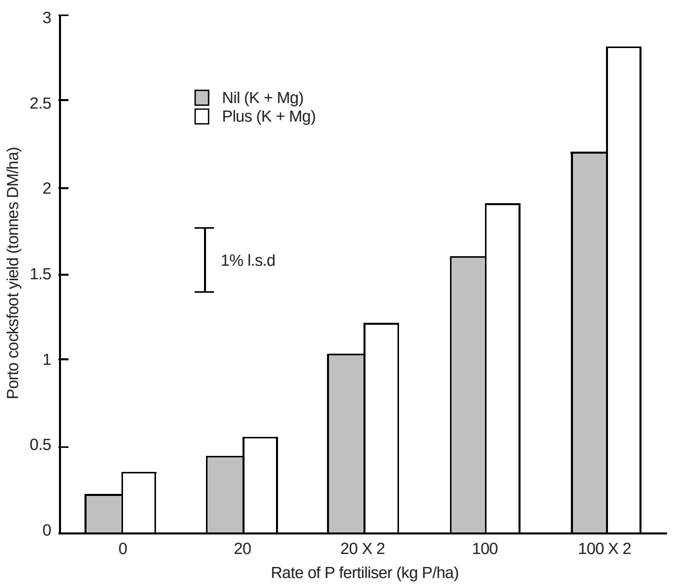

Figure 3. Effect of adding potassium and magnesium at different rates of P application on the dry matter yield of Porto cocksfoot.

3. High levels of exchangeable Al reduce the availability of K and Mg due to competition for nutrients on colloidal surfaces and restricted root development arising from Al toxicity.
4. Cold, wet conditions in spring slow down plant processes resulting in reduced nutrient uptake. Mg deficiency symptoms for the tropical Premier finger grass become less marked as temperatures rose after spring.
5. The ratio of exchangeable K to Mg can be unbalanced by inappropriate application of fertiliser. Liming may also create imbalances due to increased exchangeable Ca.
6. Harvesting of forages by cut-and-carry without returning manures leads to nutrient impoverishment.

Management of K and Mg fertility

China has to import most of its K fertiliser due to lack of its own K deposits. This creates a major cost for developing forages on the red soils and it is important that efficient management of fertility is adopted.

Strategies include:

1. Increasing ECEC so that more K and Mg are stored against leaching. This is achieved by increasing soil organic matter, as discussed later. Raising soil pH by liming will increase net negative charge and hence ECEC of these variable charge soils.
2. As K and Mg compete with each other for uptake by plants, the correct K:Mg ratio should be attained when applying fertiliser. Thus high levels of exchangeable K induce Mg deficiency so the exchangeable K to Mg ratio should be kept below 5 (Tisdale and Nelson 1976).
3. Liming can improve K and Mg nutrition through (i) increasing plant production and soil organic matter and ECEC, (ii) raising soil pH and hence ECEC of variable charge soils, and (iii) reducing exchangeable Al and improving root development. Liming can, however, create Mg deficiencies if the exchangeable Ca to Mg ratio exceeds 10 to 15. This problem can be overcome by using dolomite limestone ((Ca,Mg)CO3).
4. Returning manures to areas where forages are grown and/or grazing pastures in situ.

LIMING

The red soils are acid and have high levels of exchangeable Al so that liming is needed in most situations. Vast deposits of limestone occur in the red soil region, particularly in Hunan and Guizhou Provinces. However, limestone is expensive to grind to a suitably fine particle size, transport and spread. The higher the desired pH, the greater is the cost of liming.

Benefits of liming

The benefits of liming are well recognised. Those most pertinent for management of the red soils include:

- Increased root development due to reduction of Al toxicity;
- If liming reduces subsoil acidity and aluminium, moisture and nutrients stored in the subsoil can be utilised;
- The supply of Ca is increased, and also Mg when dolomitic limestone is used; and
- Decrease of P sorption. Studies of the effect of lime on P sorption have, however, given conflicting results. Several studies have shown that liming reduced the P sorption capacity of acid soils in tropical America (Sanchez and Salinas 1981). Liming, however, appears to have little effect in soils with pH 5–6. It has been reported, in fact, to increase P sorption through the formation of precipitated Al and Fe oxides, which initially are amorphous and have a large surface area on which sorption can occur. Our studies have shown that liming decreases P sorption (Table 5). In Hunan soils the reduction was 11% and in the more highly weathered Fujian soils it was 27%.

In our studies we adopted two strategies to overcome soil acidity. First, the soils were limed to pH_{H2O} 5.6 in order to reduce Al to non-toxic levels. The red soils are not strongly buffered and an application of 1.5 to 2.0 t/ha of lime was sufficient to achieve pH 5.6 in the soils used in our trials. Lime would also increase available Ca. Second, we concentrated on forages found to have good tolerance of soil acidity. The most productive forages identified in evaluation trials were Premier finger grass and Wynn cassia. The growth of Wynn was, in fact, reduced by liming to above pH 5.6, indicating that it is somewhat acidophilic.

Movement or lime down the profile

A commonly reported limitation of liming is that application at the surface and mixing with the topsoil does not ameliorate subsoil acidity due to the slow rate of movement down the profile. For a Hunan soil we found that pH had increased to a depth of almost

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40 cm one year after liming. Michalk et al. (1988) also found that Ca had moved to 40 cm after 14 months.

The chemical and physical properties of the red soils permit the relative ease of downward movement of dissolved lime. Their ECEC allows Ca and Mg to move into the subsoil. Their stable micro-aggregates favour leaching during wetter times of the year, particularly in spring. Subsoil amelioration leads to deeper root growth so that plant available water capacity of the profile is increased. This increases the survival of plants during periods of drought.

INCREASING SOIL ORGANIC MATTER AND NUTRIENT CYCLING

Two factors are central to the efficient management of fertility of the red soils: increasing soil organic matter and nutrient cycling.

Soil organic matter

The importance of soil organic matter for soil fertility has been referred to throughout the previous discussion. Its benefits include:

- Storage of nutrients, particularly N, P and S;
- Reduced P sorption;
- Increased ECEC and thus the soil's ability to store K, Mg, Ca against leaching; and
- Complexing of Al, thus reduced Al toxicity.

The low organic matter content of the red soils has arisen from loss of topsoil by erosion, low inputs of plant debris from vegetation growing on degraded soils and through human activity when litter is gathered as a fuel source. Sustainable productivity depends on maintaining adequate soil organic matter. Restoration of organic matter requires time and inputs but it should be a main priority in the regeneration of red soils.

Table 3 shows how Premier finger grass and Wynn cassia have increased organic C levels in Hunan and Fujian. The levels of forage growth attained in these trials required the addition of 25 N, 40 P, 50 K and 25 Mg kg/ha and liming to increase soil pH to 5.6 (Ying et al. 2002). To be economically viable these inputs have to produce forages capable of supporting, at least in part, profitable livestock production (Casanova 2002).

The objective of the above approach is to produce productive forages straight away with high inputs. An alternative approach, particularly suited to badly degraded soils, is to build up organic matter and fertility gradually by growing pioneer species that can grow in infertile soil with low inputs. The prime concern here is not initially to produce productive forages for animal feed. The objective is to stabilise the soil against erosion and to raise organic matter and fertility so that better quality forages can be produced at a later stage. This approach was adopted by Michalk et al. (1994) in Guangdong Province where pioneer species, such as molasses grass (*Melinis minutiflora*), were grown as a first essential step in a reclamation program.

Sanchez and Salinas (1981) have listed a range of tropical grasses and legumes adapted to acid, infertile soil conditions. The genus *Stylosanthes* has been found to be outstanding in its ability to grow well under conditions of low soil pH (Jones 1990). In a preliminary evaluation program we found that the stylos tested, such as *S. guianensis* and *S. scabra*, failed to survive winter at the Fujian and Hunan sites. In later trials a stylo growing locally, possible a CIAT derivative, performed well. Even though stylos failed to persist, their ability to tolerate low soil P gives them the potential to be used as regenerating annuals (D. Michalk, pers. comm.). Other grasses which we have found to have potential as pioneering species include elephant grass (*Pennisetum purpureum*), broadleaf paspalum (*Paspalum wettsteinii*), Narok and Solander setaria (*Setaria sphacelata*) and kikuyu grass (*Pennisetum clandestinum*). Of the local grasses tested *Hemarthria compressa* grew well during spring and summer. The best legumes were Wynn cassia and *Lespedeza cuneata*.

Nutrient cycling

In the regeneration of the red soils it is important the efficient cycling of nutrients is achieved. Strategies to improve nutrient cycling include:

1. Retain topsoil against erosion loss. Loss of nutrients and organic matter in eroded soil has to be countered by a protective cover of vegetation. The role of forages in reducing erosion and runoff has been well demonstrated on runoff plots in Hunan (Wen et al. 2002). In Fujian serious erosion from orchards planted on steep hill slopes has been effectively controlled by terracing and planting forages beneath fruit trees and on the faces of terraces (Liu et al. 2002).
2. Liming to ameliorate infertility of subsoil. Because of the dominance of low activity clays in the red soils and high permeability, an improvement in the fertility of subsoil has been observed a year after applying lime at the surface. This permits roots to extend into the subsoil and tap nutrients leached from above. Nitrate, the most readily leached

major nutrient, is thus recycled and acidity arising from nitrate leaching is reduced.

3. Returning animal manures to forages. In a grazing system roughly 80% of N, P and K consumed by cattle are returned to the soil via excreta (Sanchez and Salinas 1981). This proportion varies with factors such as stocking rate and grazing management Nevertheless, there is generally efficient natural cycling of nutrients. In a cut-and-carry system, unless manures are returned, there is a continued loss of nutrients from the forage producing areas. Table 7 shows the annual removal of nutrients by Premier finger grass and Wynn cassia in a high input system at Jiangkou, Fujian. The forages were harvested approximately every two months during the growing season, when they had reached the cutting height of 50 or l00 mm (Ying et al. 2002). Clearly, there is a serious loss of nutrients unless they are replaced by applying fertiliser or manure. Traditionally animal manures are added to rice paddy or upland cropping areas as farmers are reluctant, or fail to appreciate the need, to replace nutrients removed by forages. With this practice there is a continued drain of nutrients from forage areas so that fertility declines further, the forage cover is weakened and the erosion hazard increases.

Table 7. Loss of nutrients if forages are removed by cut-and-carry without returning manures, 1995, Jiangkou, Fujian.

	Premier finger grass (kg/ha/year)	**Wynn cassia (kg/ha/year)**
DM Yield	4592	2716
N	84	77
P	10	7
S	7	7
K	137	50
Ca	17	33
Mg	16	7

This trend need not occur, as has been demonstrated in northern Fujian where forages are grown in orchards. Forages are harvested for livestock production and the manures produced are returned to the orchards. Weng et al. (1995) have found significant increases in pH, organic matter, CEC and available N, P and K in the topsoil after orchards were under-planted with forages and integrated with livestock production.

4. Adoption of a forage-cropping rotation. Fertilisers are expensive and farmers are most reluctant to apply fertilisers to forages rather than to crops. Provided that sufficient arable land is available, rotating forages with crops could alleviate the problem. Fertilisers would be applied to crops as at present and their residual effects would benefit the following forages. Legumes grown in the rotation would add N to the soil. Increased soil organic matter under forages would benefit subsequent crops. As discussed previously, Wynn cassia and temperate forages are probably best grown as annuals or in short term rotations. They would readily fit into an integrated forage-cropping system.

CONCLUSIONS

1. Degraded red soils need time and inputs of fertiliser and lime to restore their fertility. Fertilisers must be managed efficiently. Processes that cause further degradation, such as soil erosion and failure to return nutrients removed in a cut-and-carry system, must be halted.

2. Building up soil organic matter is central to regeneration of the red soils.

3. Legumes to fix atmospheric N_2 have to be included in forage production.

4. Where loss of fertility has been severe, forages tolerant of low fertility should be grown as pioneer species in the first stage of restoring fertility.

5. Forages should be integrated with other forms of agricultural production. Examples are planting forages in orchards to reduce erosion and increase soil fertility, and growing forages and crops in rotation.

6. Forages will only be produced on the red soils if they can support profitable livestock production. Forages must be managed to produce good quality feed year-round. At the same time, if the system is to be sustainable, forages must provide adequate protection against soil erosion, which has been the fundamental cause of degradation of the red soils.

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MEETING THE FERTILISER REQUIREMENTS FOR FORAGE PRODUCTION IN THE RED SOIL REGION

Minggang Xu, Jiyun Jin and Zhang Jiuquan[1]

[1] Red Soil Experimental Station, Chinese Academy of Agricultural Sciences, Beijing 100081

Abstract

The red soil of southern China, in the tropical and subtropical zones, is of low fertility (especially available N, P, K, and Mg) because of strong weathering and leaching. In general, for pasture establishment on the red soils, approximately 25 kg N, 90 kg P_2O_5, 60 kg K_2O and 40 kg MgO per hectare are needed. To maintain pasture productivity after the first year, it is necessary to reapply various fertilisers annually at a rate equivalent to 60% of that used during establishment, until fertility is raised to an adequate level.

The grassland area in southern China comprises about 66 million ha, most of it consisting of hilly red and yellow soils. To date, only 0.47 million ha have been developed as pasture. It has been reported that 44.6 million ha of wasteland have high potential for pasture establishment. If 30% of these lands are used to establish highly productive pastures in the near future, an extra 200,000 t of N, 718,000 tonnes of P_2O_5, 482,000 t of K_2O and 334,000 t of MgO will be required annually. Mineral reserves in southern China are such that N, P and Mg fertiliser requirements for forage production can largely be met by production, although K fertiliser will need to be imported. Meeting fertiliser requirements for forage production can be done by three methods: increasing fertiliser production capacity, improving fertiliser application techniques and efficiency, and by importing.

INTRODUCTION

RED soil in the tropical and subtropical zones of southern China is low in soil fertility, including low levels of available P, K and Mg, because of strong weathering and leaching. These deficiencies present a major constraint for long-term forage production on these soils. This is particularly the case for those infertile wastelands that have been classified as land available for forage production. In order to maintain successful forage production and persistence, it is essential to apply N, P, K, Mg etc. fertilisers (Zhen and Tu 1988; He and Huang 1991; Huang and He 1992; Zhang et al. 1991). This paper discusses the feasibility of supplying fertilisers sufficient for successful forage production on a large scale in the red soil regions of southern China.

Whereas the population of China is some 22% of the total world population, the arable land in China is only 6.8% of the world's total. Therefore, the supply of food for this population is the most important problem in China. Fertilisers are currently applied mainly to paddy fields and uplands for grain and cash crops and for fruit production. China imports a large quantity of fertilisers, particularly K-fertilisers, because current fertiliser production capacity cannot meet the requirement, and some fertiliser mineral resources are very limited.

Nevertheless, in recent years, the demand for animal products such as meat, eggs, and milk has increased as living standards have increased. Thus, there is a need for greater production from the region, especially for forage and animal production. The limitations in the supply of fertilisers are considered here as a possible constraint to the expansion of forage production in the red soil region.

Land resources for forage production

The total grassland area in China is about 400 million ha, of which 66 million ha is in southern China. Most of those lands are hilly and mountainous red and yellow soils (Li 1986). The red soils region encompasses 12 provinces in southern China, with a population of some 600 million people. Because of inappropriate land use in the past and excessive deforestation, most of the land is now seriously eroded with little vegetation remaining.

The Chinese Government has been promoting the development of these wastelands for more than 10 years. Planting fruit trees has had some success, but their growth has faced the problems of high inputs, such as fertiliser, and unstable prices for the fruit produced.

Developing forages for livestock production has proven successful in some parts of the red soils region.

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In 12 southern provinces, 26% of the total land area is undeveloped wasteland (Li 1988). This 66 million ha of wasteland is equivalent to five times the total pasture area of New Zealand. Whereas, to date, only 0.47 million ha of land has been developed into pasture it is estimated that a further 44.6 million ha in the region can be developed as highly productive pasture in the future (Table 1). Provinces with great potential for forage production include Guangxi, Yunnan, Hunan, Hubei and Sichuan.

Fertiliser requirements for each province

For successful pasture establishment on the red soils, approximately 25 kg N, 90 kg P_2O_5, 60 kg K_2O and 40 kg MgO are needed per hectare. To maintain pasture productivity after the establishment year requires the application of maintenance fertilisers annually at 60% of the establishment rate application (Zhen and Tu 1988; He and Huang 1991; Zhang et al. 1991; Huang and He 1992). This means that the annual fertiliser demand is about 15 kg N, 54 kg P_2O_5, 36 kg K_2O and 24 kg MgO per hectare, in a five-year forage production program.

If 30% of the 44 million ha of wasteland having high potential for pasture establishment in the red soils region is used to establish highly productive pasture, an extra 200,000 tonnes of N, 723,000 tonnes of P_2O_5, 482,000 tonnes of K_2O and 335,000 tonnes of MgO will be required annually if fertiliser is to be applied according to the rate mentioned above. Among the 12 provinces described above in Table 1, Guangxi, Yunnan, Sichuan, Hunan and Hubei have the greatest need for fertiliser.

Table 1. Land resources in the red soil regions in southern China ('000 ha).

Province	Total land	Arable land	Forestry	Total grassland	Sown pasture	Potential pasture
Yunnan	38,361	4,716	17,516	14,667	86	6,000
Guizhou	17,622	3,033	6,425	5,333	62	3,733
Sichuan	56,547	13,066	1,948	6,819	200	5,076
Guangxi	23,641	3,714	9,709	12,854	10	7,993
Guangdong	21,303	5,410	9,200	2,900	8	2,320
Hunan	21,183	4,703	10,756	6,333	24	5,600
Hubei	18,595	6,614	6,881	6,419	33	5,077
Fujian	12,229	2,081	7,451	2,062	12	1,650
Jiangsu	10,505	6,131	273	413	3	325
Zhejiang	10,498	2,995	4,897	3,169	22	2,075
Anhui	14,017	6,771	3,334	1,663	1	1,485
Jiangxi	16,695	4,442	9,553	3,842	11	3,313
Total	261,197	63,678	10,593	66,474	472	44,649

Sources: Li 1988; NRCSC 1989.

Table 2. Major annual fertiliser requirements for pasture establishment and maintenance in 12 provinces of the red soils region (land area: '000 ha; fertilisers: '000 tonnes).

Province	Potential pasture[a]	Projected pasture[b]	N	P_2O_5	K_2O	MgO
Yunnan	6,000	1,800	27.0	97.2	64.8	45.1
Guizhou	3,733	1,120	16.8	60.3	40.3	28.0
Sichuan	5,076	1,523	22.8	82.1	54.8	38.1
Guangxi	7,993	2,398	36.0	129.4	86.3	60.1
Guangdong	2,320	696	10.4	37.6	25.1	17.4
Hunan	5,600	1,680	25.2	90.7	60.2	42.1
Hubei	5,077	1,523	22.8	82.3	54.8	38.1
Fujian	1,650	495	7.4	26.6	17.8	12.4
Jiangsu	325	98	1.5	5.2	3.5	2.5
Zhejiang	2,075	623	9.3	33.7	22.4	15.5
Anhui	1,485	446	6.7	24.1	16.1	11.2
Jiangxi	3,313	994	14.9	53.6	35.8	24.8
Total	44,649	13,395	200.8	722.8	481.9	335.4

[a] Source: Li (1986).
[b] 0.3 × potential pasture area, developed recently.

Meeting the fertiliser requirements

Current fertiliser production and consumption in China

Fertiliser has played an important role in agricultural production in China. Experimental results have shown that, among various agricultural practices, fertilisers contribute about 40% to grain production (Li and Lin 1996). Over the last 15 years, consumption of manufactured fertilisers has increased rapidly in China, from about 12.7 million tonnes in 1980 to nearly 36 million tonnes in 1995. Over the same period, fertiliser production capacity in China has remained relatively low, increasing from 12.3 million tonnes in 1980 to 25.9 million tonnes in 1995.

Fertiliser production in China has not been able to meet the demand for fertilisers for grain and cash crop production, and China has imported N, P and K fertilisers every year (Table 3). Since the beginning of the 1990s, the Chinese Government has been enlarging fertiliser production capacity, especially of N and P fertiliser, resulting in reduced imports of these fertilisers. However, K fertiliser production capacity is limited by low mineral reserves, and yet its consumption has increased rapidly during the 1990s, particularly in southern China. Thus, an increasing amount of fertiliser, especially K fertiliser, has had to be imported. The ratio of fertiliser shortage to consumption is rising gradually (Table 3), being 20% in the 1980s and greater than 30% in the 1990s.

There is no K fertiliser production in the 12 provinces of southern China, and K fertiliser has had to be fully imported. In 1994, 2.1 million tonnes K_2O was imported to meet requirements. In Yunan, Sichuan, Hunan and Anhui provinces, N fertiliser production capacity was able to meet the demand, but other provinces could not. The P fertiliser production capacity in Yunan and Hubei Provinces could meet requirements, but others could not. Generally speaking, in the red soil regions of southern China, nearly 15–20% consumption of N and P fertilisers must be imported (Table 4).

Currently, fertilisers are mainly used for grain and fruit production for human consumption. Little fertiliser is applied to uplands for forage production. Even so, domestic fertiliser production has not met the demand.

Mineral reserves for fertiliser production

In terms of mineral resources, fertiliser production capacity in China could be increased further (Zeng 1996). According to N, P and K fertiliser demand, for N fertiliser production capacity to reach 250 million tonnes annually by the year 2000 would require 8% of petroleum and natural gas reserves, and about 0.15% of coal reserves. Mineral reserves can ensure the N fertiliser production requirements. If P fertiliser (P_2O_5) production capacity is enhanced by 10 million tonnes by 2000, 50 million tonnes of standard P mineral, about 3% of readily exploitable reserves, will be needed. However, the P reserves are not evenly distributed and the P_2O_5 content in some is relatively low, though P mineral reserves can generally ensure the production need. If the K fertiliser (K_2O) production capacity increases annually by 5–6 million

Table 3. Fertiliser consumption, production, imports (million tonnes) and deficit in China in recent years.

Year	Fertiliser consumption				Fertiliser production				Fertiliser import				Shortage (%)
	Total	N	P_2O_5	K_2O	Total	N	P_2O_5	K_2O	Total	N	P_2O_5	K_2O	
1980	12.7	9.4	2.9	0.4	12.3	10.0	2.3	0.0	2.3	0.0	0.0	0.0	2.9
1981	13.4	9.6	3.3	0.5	12.4	9.9	2.5	0.0	2.6	1.5	0.4	0.7	7.2
1982	15.1	10.6	3.8	0.7	12.8	10.2	2.5	0.0	2.9	1.8	0.6	0.5	15.5
1983	16.6	11.9	4.0	0.7	13.8	11.1	2.7	0.0	4.0	2.4	1.0	0.6	15.3
1984	17.4	12.5	4.0	0.9	14.6	12.2	2.4	0.0	5.0	2.9	1.3	0.8	15.0
1985	17.8	12.6	3.1	1.1	13.2	11.4	1.8	0.0	3.1	2.1	0.9	0.2	25.5
1986	19.3	13.7	4.6	1.1	13.9	11.6	2.3	0.0	2.5	1.6	0.5	0.5	27.8
1987	20.0	13.9	4.8	1.2	16.7	13.4	3.2	0.0	5.3	2.9	1.2	1.2	16.4
1988	21.4	14.9	5.1	1.4	17.3	13.6	3.6	0.1	7.1	4.3	1.4	1.4	19.4
1989	23.6	16.2	5.7	1.7	17.9	14.2	3.7	0.0	6.7	4.0	1.6	1.2	23.9
1990	25.9	17.4	6.5	2.0	18.8	14.6	4.1	0.0	7.8	4.5	1.6	1.7	27.4
1991	28.1	18.5	7.2	2.4	19.8	15.1	4.6	0.1	9.4	4.6	2.8	1.9	29.7
1992	29.3	19.0	7.7	2.7	20.5	15.7	4.6	0.2	8.9	4.7	2.2	2.0	30.4
1993	31.5	19.9	8.6	3.0	19.6	15.3	4.2	0.1	5.1	2.3	1.3	1.5	37.9
1994	33.2	20.6	9.3	3.3	21.9	16.7	5.0	0.2	7.0	2.6	2.2	2.1	34.1
1995	36.0	22.2	10.0	3.8	25.9	0.0	0.0	0.0	10.6	0.0	0.0	0.0	31.4

Sources: Li and Lin (1996); Agricultural Yearbook of China 1981–1996.

tonnes to the year 2000, the required K mineral accounts for more than 20% of reserves. China is short of K mineral reserves, which cannot ensure K fertiliser production requirements.

China's major K mineral concentrates are in Qinghai Province, which has 95% of total reserves, there being no K mineral resource in the red soil regions of southern China.

The distribution of P mineral in the 12 provinces of the red soil region is uneven. P mineral occurs mainly in Yunan, Guizhou, Hubei, Sichuan and Hunan Provinces. This accounts for 96% of the total reserve (Table 5) (Zeng 1996). If P fertiliser production capacity were to increase by 5% each year, the P mineral production in these five provinces could meet the requirement and in Anhui, Jiangxi and Jiangsu basically ensure P fertiliser production needs. However, for other provinces it will be essential to import P mineral from neighbouring provinces.

Magnesite is mainly distributed in Liaoning and Shandong Provinces of northern China, with reserves of about 9.6 billion tonnes (about 45% MgO). To date, Mg has not been applied as a single fertiliser in China.

Table 4. Fertiliser consumption, production and shortage (million tonnes) in red soil regions in southern China in 1994.

Province	Consumption				Production[a]			Surplus/deficit	
	N	P_2O_5	K_2O	Total	N	P_2O_5	Total	N	P_2O_5
Yunnan	0.5	0.2	0.1	0.8	0.6	0.4	1.1	0.1	0.2
Guizhou	0.4	0.2	0.0	0.6	0.4	0.2	0.5	0.0	0.0
Sichuan	1.5	0.6	0.1	2.3	1.6	0.7	2.3	0.1	0.0
Guangxi	0.6	0.3	0.3	1.1	0.2	0.1	0.4	–0.3	–0.2
Guangdong	1.0	0.4	0.3	1.7	0.4	0.2	0.5	–0.6	–0.3
Hunan	1.0	0.4	0.3	1.6	1.0	0.3	1.3	0.0	–0.1
Hubei	1.3	0.6	0.2	2.0	1.0	0.6	1.6	–0.3	0.0
Fujian	0.6	0.3	0.2	1.0	0.4	0.1	0.5	–0.2	–0.2
Jiangsu	1.8	0.7	0.2	2.7	1.1	0.4	1.5	–0.3	–0.3
Zhejiang	0.6	0.2	0.1	0.9	0.6	0.2	0.7	–0.1	0.0
Anhui	11.2	0.6	0.2	1.9	1.6	0.3	2.0	0.5	–0.2
Jiangxi	0.6	0.3	0.2	1.1	0.2	0.1	0.3	–0.4	–0.1
Total	22.1	4.7	2.1	17.7	9.1	3.6	12.7	–1.8	–1.1

Source: Agricultural Yearbook of China 1995.
[a] There is no production capacity of K fertiliser in southern China. All K fertiliser is imported.

Table 5. Known mineral reserves that could contribute to fertiliser production and which might meet fertiliser needs for forage production in the 12 provinces of the red soil region in China ('000 tonnes) by production and import.

Province	P_2O_5		Meeting need by production or import					
	Mineral reserves	Production capacity	N		P_2O_5		MgO	K_2O
			Production	Import	Production	Import	Production	Import
Yunnan	454,430	560	10.0	17.0	97.2	0	45.1	64.8
Guizhou	220,690	210	8.0	8.8	60.3	0	28.0	40.3
Sichuan	176,890	850	22.8	0	82.1	0	38.1	54.8
Guangxi	90	190	11.0	25.0	0	129.4	60.1	86.3
Guangdong	250	210	10.4	0	0	37.6	17.4	25.1
Hunan	112,480	370	20.0	5.2	90.7	0	42.1	60.2
Hubei	564,000	740	22.8	0	82.3	0	38.1	54.8
Fujian	2,190	110	7.4	0	4.5	22.1	12.4	17.8
Jiangsu	16,710	540	1.5	0	25.0	0	2.5	3.5
Zhejiang	1,600	200	9.3	0	3.2	30.5	15.5	22.4
Anhui	11,890	450	6.7	0	15.1	9.0	11.2	16.1
Jiangxi	23,170	170	12.0	2.9	15.8	18.8	24.8	35.8
Total	1,584,390	460	141.9	58.9	476.2	246.6	335.4	481.9

Rather in southern China, Mg is applied to fields mainly as Ca–Mg–P fertiliser which is made from serpentine (hydrous magnesium silicate), chiefly derived from Guangxi, Jiangxi, Hunan, Sichuan, Yunan and Hubei Provinces.

Meeting fertiliser requirements for forage production

The N and P fertiliser requirements for forage production in southern China can largely be met by local production while K fertiliser must be imported.

China is a developing country, and thus social and economic constraints mean that its fertiliser production capacity cannot increase rapidly. Fertiliser will continue to be applied mainly for grain production (Li and Lin 1996; Zeng 1996). Fertiliser requirements for forage production will need to be met by:

- improving fertiliser application techniques and balancing the ratio of nutrients to increase fertiliser efficiency. The ratios of N, P (P_2O_5) and K (K_2O) fertiliser applied are typically not balanced in the red soil regions (Table 4), which has a considerable effect on the efficiency of fertiliser use. For example, balancing nutrient additions can increase N fertiliser use efficiency by more than 5% (Zhou 1996). It is estimated that nearly 2% of the current consumption of N fertiliser (about 200,000 tonnes) could be used for forage production;
- increasing P mineral exploration and increasing the production capacity of P fertiliser factories. During the period 1996–2000, the Chinese Government decided to increase P mineral extraction capacity to 8 million tonnes and P fertiliser (P_2O_5) production capacity by 1.5 million tonnes (Zeng 1996); and
- continuing to import to overcome the shortage of fertilisers for forage production, especially that of K fertiliser.

For forage production in southern China, Mg fertiliser requirements can be met by local production, but K fertiliser has to continue to be imported. For annual N fertiliser requirements, 140,000 tonnes can be produced locally and 60,000 tonnes imported. For P_2O_5, 470,000 tonnes will come from local production, and 250,000 tonnes from importation.

CONCLUSION

Southern China has a high population living on land which is largely non-arable and infertile. In recent years, the demand for animal products has increased. Thus, given the favourable climatic conditions of the region, it will be desirable to develop the red soil wastelands and develop forage systems and animal production. To maintain successful forage production and persistence, it will be necessary to apply fertilisers. In the initial years after establishment, annual applications of fertilisers at 60% of the establishment rates will be needed until adequate levels of soil fertility are achieved. However, in time these rates should decline if organic matter is retained and nutrient cycling improved.

The grassland area in southern China is about 66 million ha, most of it characterised by red or yellow soils in hilly and mountainous regions. Only 0.47 million ha have been developed into pasture. It has been reported that 44.6 million ha of wasteland have high potential for pasture establishment. If 30% of these lands are used to establish highly productive pasture, an extra 200,000 tonnes of N, 723,000 tonnes of P_2O_5, 482,000 tonnes of K_2O and 335,000 tonnes of MgO fertiliser will be required annually.

Mineral reserves in southern China are such that N, P and Mg fertiliser requirements for forage production can be met largely with local production, while K fertiliser will need to continue to be imported.

Meeting fertiliser requirement for forage production can be achieved by increasing local fertiliser production, improving fertiliser application techniques and increasing fertiliser use efficiency, and by importation.

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THE ROLE OF SOIL CARBON IN NUTRIENT CYCLING AND IN INFLUENCING THE SUSTAINABILITY OF AGRICULTURAL SYSTEMS

Graeme Blair[1], Anthony Whitbread[1], Chen Wen[1] and Rod Lefroy[2]

[1] Division of Agronomy and Soil Science, University of New England, Armidale, NSW, 2351
[2] IBSRAM, PO Box 9-109, Bangkhen, Bangkok, 10900

Abstract

An extensive review of the literature demonstrates the critical importance of maintaining sufficient soil organic matter and labile carbon in order to permit the cycling and release of nutrients as well as to enhance the soil's physical fertility. The rate of organic matter cycling depends on the degree of lignification and the quality of the organic matter. Adequate release of carbohydrates and nutrients from organic matter are essential if microbial turnover rates are to be maintained in sustainable farming systems.

The various techniques of assessing the sustainability of agricultural systems include a wide array for measuring productivity decline, nutrient balance, soil loss studies and carbon dynamics.

Controlled oxidation of organic matter was used to determine the labile carbon levels and the carbon management index of a range of soils from Australia and Fujian and Hunan Provinces, PR China. The clearing of land in Hunan and Fujian has led to extraordinarily low levels of total carbon (< 10 mg/g) compared to those found in two Australian soils (11–47 mg/g).

The sowing of grass and legume pastures in Hunan and Fujian was shown to increase the labile carbon and the carbon management index of soils in both provinces. Substantial increases in both total and labile carbon will be required in eroded soils in the red soil region of Hunan and Fujian to enhance the capacity of the soil to act as a reservoir of nutrients and to increase water infiltration and water holding capacity of the soil.

INTRODUCTION

FOR an agricultural system to be sustainable, the production must be stable and of an adequate level. Sustainable production is only possible if the supply of a broad set of resources is maintained. On the other hand, the stability of the system is strongly influenced by additional factors such as changes in fertiliser inputs, pests and extreme climatic events. Sanchez et al. (1989) indicated that soil organic matter (SOM) is a key material resource as it is a reservoir and source of key nutrients and a modifier of soil textural properties. Much of agriculture throughout the world has developed by opening up new land such that initial production is supported by the utilization of the nutrients released from the accumulated soil organic matter (SOM). This high initial level of SOM also contributes to the physical fertility of the soil. The release of nutrients from SOM is largely through microbial activity, so a supply of readily useable carbon (C) is essential to provide the energy source for the microbial population. Much of the world's agricultural area was originally under forest or natural grasslands, which had high SOM contents.

Mineralisation of SOM releases nutrients to the soil that are available for plant uptake, conversion to less available forms, loss to the atmosphere, and loss by erosion and leaching. The dominance of each process varies with the nutrient and is greatly affected by soil moisture conditions. For all nutrients the increased off-take in product places increased demands on SOM. As the labile SOM is depleted it becomes increasingly difficult to meet the demands of the crop, hence the increasing need for inorganic fertilisers. If the labile SOM and inorganic fertiliser cannot meet the needs of the crop, this places more demands on the less labile SOM, which will be slowly depleted. This depletion of SOM not only has implications for the nutrient cycles in the soil, but also for physical fertility, as organic matter is an important determinant of soil structure. If fertiliser input does not meet the quantity of nutrients removed in the harvest and lost through other means (leaching, sorption, etc.) the deficit must be made up by the SOM, thus reducing the size of this pool.

There are important changes in both the C pool size and turnover rate when natural systems, such as grassland, are converted to crop land and when

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legumes are incorporated into the system. In natural grassland systems there is a large pool of C with residues of different ages and quality which are turning over at varying rates. When the land is cultivated and cropped the rate of breakdown of organic debris is increased; although the amount of residue returned may be the same as, or in some cases higher than, in the grassland it all occurs at the one time and is all of a similar quality with a generally wide C:N ratio and low nutrient concentration. As C is lost from the system the remaining C becomes more resistant to breakdown. When a legume is introduced into the system the residues provide easily decomposable C and a ready supply of N for the microorganisms, which results in rapid breakdown of the organic matter.

Much of world agriculture is intensifying production to meet increasing internal demands and to produce exports to improve the balance of trade. This intensification, much of which is occurring on soils relatively low in organic matter and nutrient status and with poor physical properties, is becoming increasingly dependent on inorganic fertilisers. While this in itself is not a problem, it tends to reduce the ability of the cash poor small farmer to maintain soil fertility and thus production. It can also result in the lowering in SOM status, which results in soils with lower nutrient status and water holding capacity and in which toxicities of elements such as Al and Mn can become more acute.

The type of organic matter also affects the rate of organic matter breakdown. Plant material which is low in lignin and other polyphenols, and high in nitrogen and soluble carbohydrates, generally decomposes relatively quickly. Thus the rate of initial breakdown varies between immature and mature tissue as well as between species. Dung breakdown rate depends on its quality, hardness and the degree of contact with the soil surface.

Considering the above, it is not surprising that the organic matter content of soils declines rapidly after forests are cleared for agricultural production. The input of organic matter during clearing is high; much of the organic matter is of a type which is readily broken down and when burning has occurred the amount of organic matter which is relatively resistant to breakdown is reduced. The ash from burning also increases the level of available nutrients which make conditions for breakdown more favourable. Because of the different types of organic debris, different ages and quality of organic residues are present in the soil. Carbon is generally divided into different pools with widely differing turnover rates. In the CNSP cycling model for grazed pastures developed at UNE by McCaskill and Blair (1988) soil carbon is divided into seven pools based on those of van Veen and Paul (1981) and van Veen et al. (1985). The pools and decay rates are as follows:

Pool	Maximal decay rate (d^{-1})
Unprotected digestible	3.1×10^{-2}
Unprotected indigestible	1.6×10^{-3}
Clay protected indigestible	1.1×10^{-4}
Unprotected recalcitrant	4.46×10^{-5}
Protected recalcitrant	4.65×10^{-7}
Unprotected biomass	7.0×10^{-1}
Protected biomass	7.7×10^{-3}

MAINTAINING SOIL FERTILITY AND YIELD

Maintaining soil fertility clearly relies on balancing the input of nutrients with the off-take and loss of nutrients. The key management tool is to maximise the return of crop residues, or dung and uneaten herbage in pastures, as this both reduces the removal of nutrients and returns organic matter. In grazed pastures the recycling of nutrients and organic matter via animal dung and urine and unutilized leaf material is a major pathway of turnover (Catchpoole and Blair, 1990). With many nutrients, such as nitrogen, phosphorus, potassium and sulfur, as much as 80% of the nutrient ingested by the animal is returned in either dung or urine. In addition, a considerable proportion (upwards of 50%) of the ingested fibre material is returned in dung and this may act as a carbon residue which turns over slowly supporting microbial activity and the long-term build-up of organic matter.

There is a good deal of evidence for the accretion of organic matter under some temperate and tropical pasture systems (Clarke and Russell 1977; Ladd and Russell 1983). Most attention has been given to the accretion of nitrogen, and for practical purposes nitrogen accretion seems to be mainly affected by the amount of legume growth.

The cycling of nutrients can occur via various organic and inorganic pathways (Figure 1).

The importance of the release of nutrients from organic matter and the contribution that recycled nutrients from uneaten herbage, dung and urine makes to a grazed pasture is demonstrated by the data in Figure 2.

It can be seen from the amount of nutrient returned in dung, urine and uneaten residues that if these components are removed from the system, as in a cut-and-carry system where animals are housed and the residues returned to cropping lands, there is a substantial off-take of nutrients, and associated with

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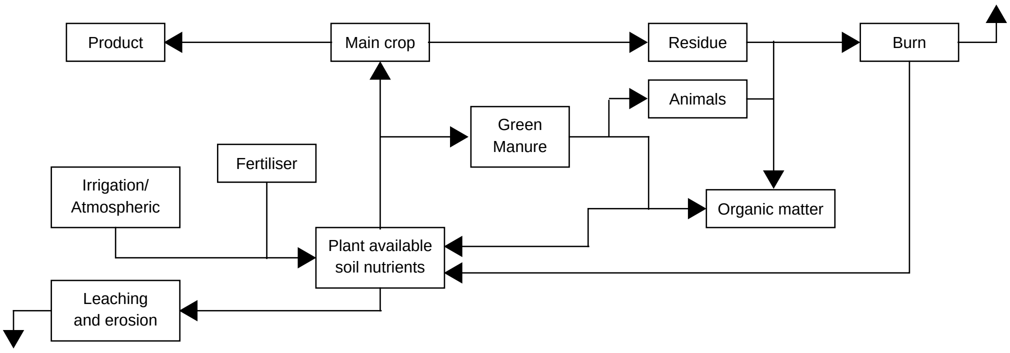

Figure 1. Cycling of nutrients in a cropping, green manuring and animal system.

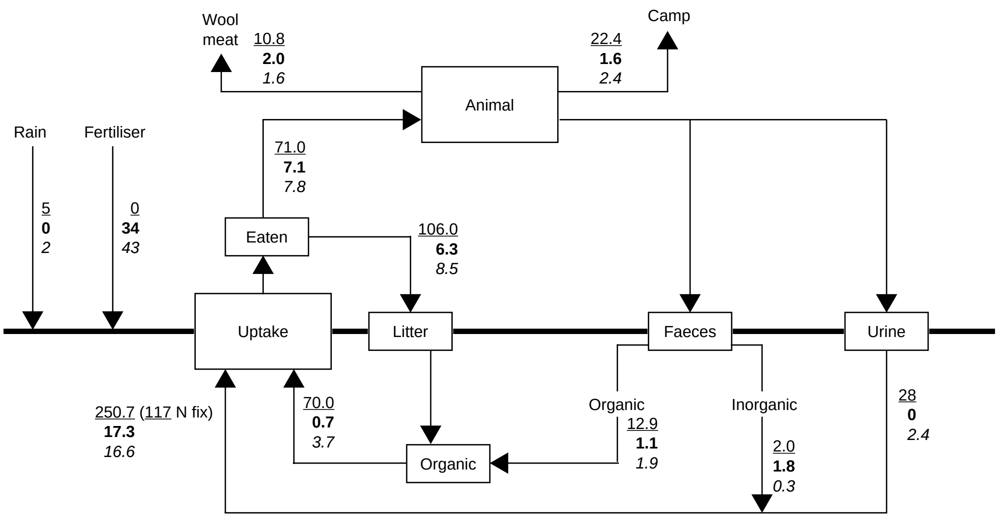

Figure 2. Simulated N, P and S flow rates in a temperate grass/white clover pasture grazed by 10 weaner lambs at Armidale NSW. Legend: Nitrogen underline, Phosphorus **bold,** Sulphur *italics*. (McCaskill, 1988).

this is a loss of carbon from the system; clearly, this system is not sustainable.

Nutrient content of SOM

SOM is a complex mixture of plant and animal residues in various stages of decomposition, of substances synthesised microbiologically and/or chemically from the breakdown products, and of the bodies of live and dead soil biota and their decomposition products (Schnitzer and Khan 1972). The main constituents of SOM are carbon, hydrogen and oxygen, but there are significant amounts of other elements essential for the nutrition of plants.

Nearly all of the N found in soils is associated with SOM (Schnitzer 1985). The main forms of N in SOM are proteins, peptides, amino acids, amino sugars, purines, pyrimidines and N in heterocyclic compounds (Schnitzer 1991).

Organic P constitutes between 20% and 80% of the total soil P in most surface soils. Organic P is present predominantly as complex organic esters, in which P is bonded to carbon via oxygen, in sugar phosphates, phosphoproteins, phospholipids, glycerophosphates, nucleotides and a substantial portion of unidentified compounds (Schnitzer 1991).

Over 90% of the total S in most non-calcareous soils is present in organic forms. There are two main forms of organic S (Freney 1986). The sulfate esters account for 30% to 70% of the organic S in soils and are considered to include the most labile forms of organic S. Carbon-bonded S includes the S containing amino acids, mercaptans, disulfides, sulfones and sulfonic acids.

The content of other important plant nutrients in SOM are less frequently studied. Clearly the plant and animal residues added to the soil will contain the other macro and micronutrients in the ratios found in most living organisms. As these residues are broken down, many of the nutrients will be incorporated into living biota and significant amounts of most plant nutrients will be part of, or associated with, the residue breakdown products in the SOM.

TECHNIQUES TO ASSESS THE SUSTAINABILITY OF AGRICULTURAL SYSTEMS WITH RESPECT TO THEIR NUTRIENT STATUS

There is a range of techniques available to assess the nutrient status of natural or agricultural systems. These are:

a) Long term plots where changes in crop productivity and soil chemical and physical characteristics are monitored and these changes used to calculate rates of change in that system (Odell et al. 1984).

b) Collection and analysis of "paired samples" obtained from cropped and uncropped areas within a location. Differences in soil depth, organic matter and nutrient status between the pairs are used to estimate the consequences of agricultural practice on the sustainability of the system. This technique lacks precision as the changes in factors such as total organic carbon, nitrogen and phosphorus are generally small relative to the large pool size present in the soil and spatial heterogeneity makes comparisons difficult.

c) Studies of the erosion and nutrient losses from a catchment. These provide an estimate of the sustainability of the catchment and information on the factors that affect the sustainability of the particular agricultural systems.

d) Nutrient balance studies have been used by Lefroy (1990) and Lefroy and Hussin (1991) to assess the stability of upland agricultural systems in southeast Asia. These studies have utilised data on inputs from fertilisers, crop residues and accessions in rainfall and outputs in crop products. They have not taken changes in soil nutrient pools into account.

e) When plants fix C there is a degree of discrimination between ^{13}C and ^{12}C, and the degree of this discrimination varies between C3 and C4 plants. In a crop such as corn $d^{13}C = -12\%$ whereas in C3 species such as rice and wheat $d^{13}C = -26\%$. This means that when C3 plants are grown in soils that had previously been under C4 vegetation, such as in some rice production areas in southeast Asia and wheat production in northern NSW and southern Queensland, there is virtually an *in situ* labelling of the organic matter incorporated into the soil.

   After a time t of cultivation, if A is the ratio $^{13}C/[^{12}C + ^{13}C]$ of soil carbon at time t, A_0 is the ratio for the initial soil at $t = 0$, or the ratio for a similar soil under C4 vegetation, and A_1 is the ratio for the C3 plant, then the percentage x of carbon coming from the C3 plant can be deduced from

$$A = A_1(x/100) + A_0(1 - x/100). \quad (1)$$

   Cerri et al. (1985) first used this method in order to measure the turnover rate of organic matter in a 50-year-old cane field, after forest clearing.

f) ^{14}C and ^{137}Cs were deposited over the entire surface of the earth from atmospheric testing of nuclear devices in the 1950s and 60s. The ^{137}Cs technique has been used widely to assess the amount of soil deposition that has occurred by measuring how deep the ^{137}Cs layer is beneath the current soil surface.

CHEMICAL FRACTIONATION OF SOIL ORGANIC MATTER

In investigating the effect of management on SOM, it is important that appropriate measurements of SOM are made (Syers and Craswell 1995). To this end, changes in SOM can be measured as changes in total SOM, chemical fractions of SOM, based on chemical groups through to specific compounds, physical fractions or combinations of these fractions.

Measurement of total soil carbon

The status of the SOM resource base can be assessed by measurement of the total amount of organic carbon in the soil. The most commonly used techniques for measuring organic carbon in soil is based on the dichromate oxidation procedure of Walkley and Black (1934). The principle of this method is that all organic carbon is oxidised by the dichromate under acid conditions, and the amount of reduced dichromate gives an indication of the organic carbon content. Total carbon measurements have been improved by dynamic flash catalytic combustion.

Although these methods provide an improvement on measurements of total carbon by oxidation, measurement of total carbon, or total organic carbon, is not sensitive to short term changes in the amount or, more particularly, the forms of SOM which result from changes in soil management.

Rather than assessing the chemical forms of SOM by fractionation techniques or techniques that analyse different functional groups, measurements of the rate of breakdown have been used to assess the quality of SOM.

Oxidising agents can be used to assess the relative proportions of different forms of SOM in terms of the

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ease with which they are broken down. Solutions of potassium permanganate ($KMnO_4$) have been extensively used for the oxidation of organic compounds. The rates and extent of oxidation of different substrates is governed by their chemical composition (Hayes and Swift 1978) and the concentration of permanganate. Oxidation with less than the amount of permanganate required for complete oxidation should reveal the quantity of readily oxidisable components in the SOM.

Loginow et al. (1987) developed a method of fractionating based on susceptibility to oxidation by permanganate. The method is based on the supposition that the oxidative action of potassium permanganate on soil organic carbon under neutral conditions is comparable to that of the enzymes of soil microorganisms and other enzymes present in the soil.

Modification and standardization of the KMnO4 oxidation technique by Blair et al. (1995) have increased the precision and simplified the technique to use only one concentration of permanganate, thereby dividing soil carbon into labile (C_L) and non-labile (C_{NL}) carbon. These measurements of labile carbon have been used, in combination with similar data from a soil of an uncropped reference area, to calculate a Carbon Management Index (CMI), as a measure of the relative sustainability of different agricultural systems (Blair et al. 1995). This index compares the changes that occur in the total and labile carbon as a result of the agricultural practice, with increased importance attached to changes in the labile, as opposed to the non-labile, component of the SOM.

CMI = CPI × LI × 100 where:

$$\text{CPI} = \text{Carbon Pool Index} = \frac{C_T \text{ cropped soil}}{C_T \text{ reference sample}}$$

$$\text{LI} = \text{Liability Index} = \frac{C_{L/NL} \text{ cropped soil}}{C_{L/NL} \text{ reference soil}}$$

EFFECT OF AGRICULTURAL ACTIVITIES ON SOIL CARBON DYNAMICS IN CHINA AND AUSTRALIA

The clearing of land in Hunan and Fujian has left soil with extraordinarily low total carbon (C_T) as shown in Table 1. These values are among the lowest we have recorded throughout the world. Although the eroded soils are low in total carbon they have a reasonable amount of labile carbon which results in a lability of 0.17 in Hunan and 0.12 in Fujian. These data suggest recent inputs of organic matter that are breaking down rapidly and this is confirmed by the fact that the site from where the sample was collected had been cultivated in spring and left fallow for approximately two months

In Hunan the introduction of the Premier finger grass has lead to a substantial increase in both total and labile carbon. The rate of increase of non-labile carbon has been greater than that of labile carbon, which has resulted in a decrease in the lability and in the lability

Table 1. Carbon dynamics in soils from Hunan and Fujian, China and from the Northern Tablelands of NSW, Australia.

Location/System		C_T	C_L	C_{NL}	L	LI	CPI	CMI
			mg/g					
CHINA								
Hunan								
Eroded land		5.48	0.80	4.68	0.17	—	—	—
Premier finger grass	5/94	12.43	0.98	11.44	0.09	0.53	2.26	120
Premier grass	5/96	15.77	1.19	14.58	0.08	0.47	2.87	135
Fujian	3/95							
Eroded land		8.21	0.90	7.31	0.12	—	—	—
Premier finger grass		10.19	0.80	9.40	0.09	0.75	1.24	93
Wynn cassia		11.10	1.02	10.08	0.10	0.83	1.35	112
AUSTRALIA								
Glen Innes								
Native Pasture		47.2	7.9	39.9	0.20	—	—	—
Maize/Spring Oats/Red Clover		20.7	6.3	14.4	0.44	2.19	0.44	96
Armidale								
Native Pasture		11.2	2.24	8.96	0.20	—	—	—
Degraded Pasture		29.4	4.5	24.9	0.19	0.95	2.63	249
Phalaris/White Clover		34.7	5.2	29.5	0.18	0.90	3.99	279

index. This suggests that a significant portion of the carbon accumulating in the soil is as a lignified material that is not participating actively in carbon cycling.

The large increase in total carbon has led to an increase in the CPI to in excess of 2.0. This, together with the change in LI, has resulted in a CMI in excess of 100, meaning that carbon dynamics in the Premier finger grass soil are better than in the eroded land. Continued cropping with Premier finger grass from 1994–96 has resulted in a further increase in both the LI and CPI, and hence the CMI.

A similar pattern emerges in Fujian. Cropping with either Premier finger grass or Wynn Cassia has resulted in an increase in total carbon. Where Premier finger grass is grown there is a reduction in the amount of labile carbon compared with the eroded land but there is an increase where Wynn cassia was grown. In both instances the lability of the carbon is lower in the pasture soils than in the eroded soils. These changes in carbon result in a CMI below 100 in the Premier finger grass treatment and a slight increase above 100 where Wynn cassia was grown.

These data contrast markedly with those with extremes of climate from an area of eastern Australia although not as extreme as in Hunan or Fujian. The Native Grass pasture at Glen Innes had a C_T concentration almost five times that of the Hunan eroded land. The C_L concentration in this soil is approximately ten times that in Hunan. Cropping this soil continuously since 1921 with a Maize/Spring Oats/Red Clover rotation has resulted in a decrease in both C_T and C_L. The decrease in C_T has been greater than that in C_L, hence the lability of the carbon has more than doubled indicating a more rapid cycling of carbon in this system. Although the CMI in the cropped soil is at 96 the system is functioning more efficiently because of the more rapid cycling of carbon as indicated by the substantial increase in LI.

The situation at Armidale is somewhat similar to that in Hunan and Fujian except that the starting values of C_T and C_L are substantially higher in the Native Pasture than in the eroded land in China. Pastures have increased C_T and C_L at Armidale, with the greatest increase being where the introduced species of phalaris and white clover have been sown. The rate of increase of both C_T and C_L have been similar, resulting in no change in L. The marked increases in C_T are reflected in the CPI values exceeding 2.5 in both systems. This results in a substantial increase in the CMI above 100 in the Native Pasture in both systems.

The analysis of Total and Labile C used in this study has shown the value in making these measurements when attempting to monitor the changes in soil C as a result of agricultural practice. If the eroded red soils of Hunan and Fujian are ever to reach their full production potential both Labile and Total C pools will have to be increased so as to provide a reservoir of plant nutrients and to increase the water infiltration and holding capacity of the soil.

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OPPORTUNITIES FOR SELECTING IMPROVED LINES OF *CHAMAECRISTA ROTUNDIFOLIA* FOR SOUTHERN CHINA

J.B. Hacker[1], Chunji Liu[1], Liu Chungchu[2] and Xu Minggang[3]

[1] CSIRO Tropical Agriculture, 306 Carmody Rd, St Lucia, Qld 4067, Australia
[2] National Azolla Research Centre, Fujian Academy of Agricultural Sciences, 247 Wushi Rd, Fuzhou, Fujian, 350003, China
[3] Soils and Fertilizer Institute, Chinese Academy of Agricultural Sciences, 30 Baishiqiao Rd, Beijing, 100081, China

Abstract

The eroded soils of the red soil region require substantial inputs of nutrients to support forage growth and, in particular, nitrogen supplied through legumes. The origins of the tropical legume, *Chamaecrista rotundifolia* cv. Wynn, are described and evidence for its adaptation to acid soils in the red soil region provided. The attributes of Wynn cassia growing in Fujian and Hunan Provinces, PR China, suggest that it has poor palatability and persistence compared to its performance in Queensland, Australia.

Preliminary trials of 39 lines of *Chamaecrista rotundifolia* carried out in Hunan and Fujian suggest that six lines are superior in performance to cv. Wynn. One line in particular, CPI 86134, showed superior early growth and nodulation compared to cv. Wynn.

Persistence of Wynn Cassia may be improved by allowing some seed set to occur prior to cutting whilst its palatability may be improved by making silage from cut forage.

INTRODUCTION

GROWTH and persistence of forage species in the red soils region of southern China (latitude 24–32°N) are limited by extreme acidity and infertility, low winter temperatures (mean daily temperature in January c. 6°C) and high summer temperatures (mean daily temperature in July c. 29°C) (Leng et al. 1991). Research conducted by specialists in forages from the University of New England and Chinese scientists has been directed towards identifying adapted forage species and c. 300 accessions of tropical and temperate forage species have been evaluated at sites in Fujian and Hunan Provinces (Zhang et al. 2002). Although some adapted grasses have been identified (including the temperate species *Dactylis glomerata* cv. Porto and the subtropical *Eragrostis curvula* cv. Consol, *Digitaria eriantha* cv. Premier and *Setaria sphacelata* cv. Solander), few adapted forage legumes have been noted. Amongst the most promising are *Chamaecrista rotundifolia* cv. Wynn, *Lotononis bainesii* cv. Miles and *Lespedeza bicolor*. Although it flowers successfully, *L. bicolor* fails to produce well-filled seed (Zhang Jiuquan, personal communication) and *L. bainesii* has only recently been evaluated, but is unlikely to yield a large bulk of dry matter, although it may have a place in soil stabilisation and improvement. *C. rotundifolia* cv. Wynn (Wynn cassia) is currently the best option for a legume (at least amongst the tropical species tested) and has been incorporated in a number of trials testing mixtures and response to defoliation (A.J. Casanova, personal communication).

Although Wynn cassia holds considerable promise, in southern China it suffers from a number of deficiencies:

- Few, if any, plants survive over winter — they persist through seedling regeneration in spring;
- When harvested for forage, regeneration from seed in the following spring is poor;
- Seedlings establish slowly in spring;
- Locally, forage is considered to be unpalatable to livestock.

The current “small project”, supported by ACIAR, aims to identify accessions of *C. rotundifolia* better adapted to the climate and management practices in the region.

THE ORIGINS OF WYNN CASSIA AND PERFORMANCE IN AUSTRALIA

Wynn cassia is an ecotype which originates from Sao Paulo Province, Brazil (latitude 22° 54′S). It was

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selected from a limited range of 18 accessions conserved by the Australian Tropical Forages Genetic Resource Centre (ATFGRC), Brisbane, Australia. Wynn was released as a legume for grazing lands on sandy, mildly acidic soils in south-eastern Queensland in 1983 (Oram 1990). Since its release, pastures from the NSW–Queensland border to northern parts of the Northern Territory (latitudes 28°–13°S) have been oversown with Wynn, and experimental trials have been sown in many tropical countries, giving better understanding of its adaptation and characteristics. In Australia reports vary concerning its acceptability to livestock. Graziers in the Northern Territory and through much of Queensland consider it to be a useful component of their pastures, but some in southern Queensland have expressed concern over its palatability. The only documented trial we are aware of that compares pastures with and without Wynn was sown in southern Queensland and showed a mean benefit over five years from sowing Wynn of 35 kg/hd/yr (Partridge and Wright 1992). Although in limited trials in southern China, Wynn was not eaten when hand-fed to cattle, buffalo, goats or pigs (Zhang Jiuquan, personal communication), it was readily eaten by both cattle and goats when made into silage as a mixture with 40% Wynn and 60% Premier (Bai Xue Fung, personal communication). It is possible that, as with other forages with novel flavour or smell, livestock will need to become acquainted with Wynn before eating it readily. There are also indications that unpalatability may be associated with low phosphorus status in the soil. Despite its shortcomings, it is currently second only to *Stylosanthes* spp., as a grazing legume in northern Australia. Clements (1996) recently predicted that, by the year 2000, there would be 200,000 ha of Wynn pastures in the region.

In the drier parts of the southern speargrass region of Australia, detailed demographic studies have shown that Wynn persists largely through seedling regeneration but also through perennation. Some plants survive over the winter dry season and a limited proportion of these survive into a third growing season. Wynn produces abundant seed during the growing season. A proportion of the seed is “soft” and will germinate with the first rain in spring; the remainder is “hard”, and the seed coat breaks down over time, resulting in flushes of germination in successive rainfall events. These characteristics have been integrated into a conceptual model for the cultivar (Jones et al. 1993) and this model is being extended into a mathematical model (C.K. McDonald, personal communication).

OPPORTUNITIES FOR IMPROVED CULTIVARS

Since the release of Wynn, the world collection of *C. rotundifolia* has been greatly extended. The collection conserved by CIAT, Colombia, has been combined with that of the ATFGRC, making a total of 130 accessions. These cover the geographic range of the species, from northern Mexico (latitude 21°N) to northern Argentina (latitude 29° S) (Figure 1). Based on phytogeographic criteria, a core set has been identified (Pengelly et al. 1997), and Whitty et al. (1994) have demonstrated variation at a molecular level in a limited collection of 18 accessions. Some accessions are much later flowering than Wynn, both in Australia (B.C. Pengelly, personal communication) and southern China (Luo Tao, personal communication). Accessions being grown in Queensland to produce seed for the current experimental program exhibit extensive variation in growth habit, yield and flowering date (C. Liu and J.B. Hacker, unpublished data).

THE CURRENT EXPERIMENTAL PROGRAM

The current program seeks to determine whether there are opportunities to select cultivars that are superior to Wynn. Based on phytogeographic information, but with emphasis on northern and southern latitudinal extremes for the species, a set of 40 accessions was grown for seed production in Australia (Figure 1). In addition, seed of several related species (*C. nictitans*, *C. pilosa* and *C. serpens*) was produced. Replicated trials were sown at Qiyang (Hunan Province) and Jianyang (Fujian Province) in the northern spring, 1997.

The emphasis in these trials was to assess variation in attributes associated with rapidity of establishment and persistence rather than yield *per se*. During the establishment phase, the following attributes were assessed:

- establishment;
- earliness of nodulation;
- rate of shoot elongation;
- rate of root elongation.

During the main growing season, the date of the first flowering and of the first ripe pod were recorded, yield was rated at intervals, and seed yield (pod number) will be estimated at the end of the growing season.

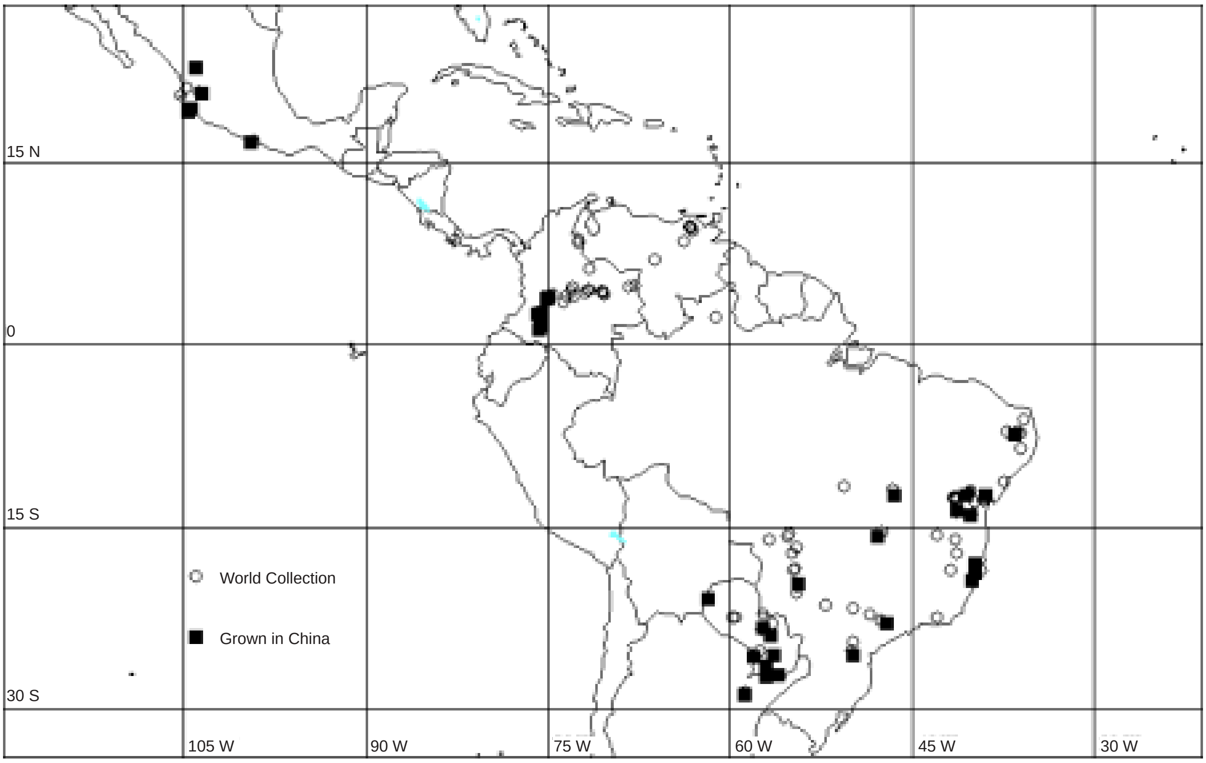

Figure 1. Natural distribution of the world collection of *Chamaecrista rotundifolia* and accessions selected for evaluation in southern China.

The following spring, perennation and seedling replenishment will be assessed:

- percentage of plants surviving the winter;
- number of seedlings germinated and timing of germination.

Apart from persistence/perennation, the main concern about Wynn cassia is palatability. Based on data from the 1997 season, accessions will be selected for a palatability trial in 1998. *C. pilosa* will be included in this trial, as there is circumstantial evidence from Queensland that this species may be more acceptable to cattle than is Wynn (R.M. Jones, personal communication). The design of the palatability trial is being discussed with experts in animal nutrition.

PRELIMINARY RESULTS

Early results from both sites have been subjected to preliminary analysis. Data from the Jianyang site were ranked for each attribute and the values summed. The best accession overall was identified on the basis of having the lowest value. Six of the 39 entries were rated better than Wynn, the lowest value being for CPI 86134. This accession had more rapid shoot and root growth than Wynn, and developed effective (red-coloured) nodules more rapidly (Table 1).

Table 1. Shoot and root data and nodule numbers for *Chamaecrista rotundifolia* cv. Wynn and CPI 86134 from 20–46 days after sowing on 28 April 1997 at Jianyang (means and standard deviations).

	18/5	1/6	13/6	18/5	1/6	13/6
		Wynn			*CPI 86134*	
Yield rating	3.7	4.3	4.3	4.7	4.7	4.7
Dry wt tops (g)	0.02	0.16	0.49	0.01	0.19	0.72
		(0.08)	(0.24)		(0.08)	(0.53)
Max. stem	2.5	6.8	16.7	3.7	8.2	19.1
length (cm)	(0.5)	(1.5)	(4.1)	(4.0)	(2.0)	(5.5)
Max. root	10.0	17.9	20.0	8.3	17.3	22.1
length (cm)	(1.2)	(4.1)	(3.4)	(2.2)	(3.2)	(1.9)
Root dry wt (g)	0.01	0.03	0.12	0.01	0.03	0.17
Total nodules	0.2	7.4	14.7	0.7	11.6	23.4
	(0.4)	(3.7)	(11.7)	(1.1)	(4.4)	(8.1)
Red nodules	0	5.0	10.4	0	10.4	17.7
		(3.0)	(8.6)		(4.7)	(7.9)

The results from the Guanshanping site were more difficult to assess as germination over the experiment was patchy. As a result, destructive harvests were not taken from all plots. However, when stem lengths and yield ratings on a single plant basis were ranked and the ranks combined, Wynn had the lowest value. The accession which ranked second was CPI 86134, which was the best entry at Jianyang (Table 2).

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Table 2. Shoot data for *Chamaecrista rotundifolia* cv. Wynn and CPI 86134 from 28–56 days after sowing on 30 April 1997 at Guanshanping (means and standard deviations).

	18/5	1/6	13/6	18/5	1/6	13/6
		Wynn			*CPI 86134*	
Yield rating	—	4.3	4.0	—	4.0	4.0
Max. stem	4.7	7.7	19.7	4.1	7.3	20.7
length (cm)	(1.0)	(1.4)	(0.6)	(0.1)	(1.0)	(2.5)

The preliminary results suggest that there are accessions with more rapid early establishment than Wynn, at least at the Jianyang site. More detailed analyses are needed before any recommendations can be made for the development of an alternative cultivar to Wynn.

LONG-TERM PROSPECTS

In the longer term, diseases from the Americas are likely to appear in the Old World. Several have been reported by Lenné (1990) and most genotypes are seriously affected by anthracnose in Colombia (B.L. Maass, personal communication). We are planning a comprehensive analysis of variation, at a molecular level, of the entire available collection. Grouping based on these data should provide a basis for identifying centres of genetic variation for further collection and also for selecting accessions for disease resistance.

In the meantime, there are good opportunities for utilising Wynn, as annual forage and for soil improvement in orchards. As a cut-and-carry forage, persistence can be improved by allowing a small proportion of plants to mature and set seed. Palatability problems may be addressed in two ways: first, young livestock may become acquainted with the species by including it in their diet with more palatable species; second, it can be fed in winter as silage, which is palatable to livestock. Discussions with several scientists in Hunan and Fujian Provinces indicated that lack of winter feed is the most serious limitation to developing a livestock industry and silage may offer a means of overcoming this problem.

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MANAGEMENT OF NATURAL GRASSLANDS ON RED SOIL AREAS OF HUNAN

Gao Chunshi[1]

[1]Animal Husbandry Bureau of Hunan Province, Rongwanzhen, Changsha, Hunan Province 410006 P. R. China

Abstract

Improved management systems are required for natural grasslands in the red soil regions of Hunan. The critical factors determining the productivity of natural grasslands are those relating to the soil, the species of grasses, the most suitable animals and the grazing system and stocking rate. Grasslands in Hunan Province are extensive and have a high productive potential. The effective utilisation of grasslands is important in the development of the rural economy and to increase the income of farmers. The core of modern grassland production is to produce a large mass of feed of sufficient quality to feed a wide variety of herbivorous animals and poultry in order to produce high-quality animal products. Productive management of grasslands includes combining soil, forage and animal management. Grassland is the largest photosynthetic area in the world, playing an important role in global climate and ecology. Grassland production is readily combined with other kinds of agriculture, and it can supply food for human consumption as well as raw materials for industry. The further development of animal husbandry will require improvements in grassland production.

INTRODUCTION

THE natural grassland areas of Hunan currently support a wide range of local animals including Xiang Xi cattle, Xiangnan cattle, Binhu bulls, Matou goats, and Xiangdong black goats. The main animals introduced are milking cows, Chendu goats, Nanjing yellow goats and Yingui black goats. The main poultry are Daozhou gray geese, Wugan cotton geese and Xupu white geese. By breeding and hybridising local strains with introduced high-quality strains, the productivity of cross-bred animals can be increased by 15–25%, with finishing occurring 1.5–2 months earlier, leading to an increase in economic returns of 22%. Currently, approximately 30% of animals in Hunan are of a crossbred or hybrid type.

The natural grasslands of Hunan have been created as secondary communities after the initial destruction of the original forest. The area is now dominated by grasses and shrubs as a result of human activity. As the climate experiences 80% of the annual rainfall in the period from March to July, there is serious soil erosion and the soil fertility is declining. Because of the uneven distribution of rainfall, there are distinct dry and wet seasons. The cold weather in winter limits crop growth. However, the natural grassland is relatively stable over long periods thus providing a sound basis for grazing enterprises.

In the mountainous regions in the west and south of Hunan Province, at altitudes from 200 m to 800 m, there are relatively few people and thus there is little cropping. About 64% of the natural grasslands in Hunan Province are in such regions. The dominant plants are *Miscanthus floridulus*, *Miscanthus sinensis*, *Arundinella hirta*, *Eulalia speciosa*, *Heteropogon contortus*, *Pteridophytes*, *Lespedeza davidii* and *Smilax* spp.

In general, the yield of fresh biomass derived from grassland can be improved into a good pasture. Some shrub and meadow lands are located in the low mountains and hilly regions at an altitude of 700 m to 900 m. The main grasses are *Miscanthus sinensis*, *Bothriochloa ischaemeum* and *Themeda triandra*. The dominant shrubs are *Lespedeza davidii*, *Vitex negundo* and *Albizia kalkora*. These grasslands have been used mainly to graze cattle. However, only 30% of the grassland and shrubs are utilised. The hilly region at an altitude of 500 m to 800 m has more shrubs, vines, herbs and grasses such as *Imperata cylindrica*, *Setaria viridis*, *Indigofera bungeana* and *Miscanthus floridulus*. These grasslands provide feed largely for goats. The dominant plant of the meadow around Dondlin Lake is *Carex cinerascens*. Grasslands also occur between cropping or woodlot areas in Hunan, where cattle and goats can be fed in large numbers. However, because of overgrazing, the dominant plant of this grassland is grazing-resistant short grass together with a few legume plants. These main grass

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varieties are *Cynodon dactylon*, *Digitaria sanguinalis*, *Setaria viridis* and some legumes such as *Kummerowia striata*.

The main methods of using natural grasslands in Hunan include:

1. *Uncontrolled grazing:* This is the main type of grassland use. Cattle and goats are fed freely on the grassland especially when grass growth commences in the warm season. The herd owner tends the animals but this type of grazing can cause serious damage through overexploitation.
2. *Grazing in continuous mountain areas:* Here, the mountain grasslands are extensive with relatively few animals. After grazing over a certain distance, the animals are controlled in limited areas overnight before being moved to a new area. Under this system, much of the grassland is wasted because it is not fully grazed by the animals.
3. *Grazing in non-continuous mountain terrain:* The terrain in the south and east of Hunan is largely a series of separate mountain peaks with cropping regions between the mountains. The herd-owner makes full use of special grazing terrain and moves animals to different mountains, according to a schedule.
4. *Grazing for specific times:* This method of grazing is used in some counties in hilly and plains regions, where the animals are fed in the barnyard after grazing for a certain limited time.
5. *Cutting or mowing:* Some grasslands are small in area, and hence it is inconvenient to graze animals there. Animals are therefore fed in the barnyard with mown grass. Grasses growing in meadows with fertile soils grow well with high yields. The fresh grass is mown and dried to provide usable stored feed.

UTILISATION OF NATURAL GRASSLANDS

For optimum results, it is important that economic outcomes are considered together with ecological factors. Critical factors to consider for utilising natural grasslands include the soil type, animal species, the stocking capacity, the grazing time and methods of controlling grazing pressure.

CHOICE OF ANIMAL SPECIES

The main natural grasslands of Hunan in mountainous regions provide low quality herbage, often with a protein content no more than 8%. Thus, it is very important to choose animals that can grow on poor quality feed. Local yellow cattle have a high capacity to digest fibrous vegetation. According to investigations in Baojin and Janyang counties, during the major growth period from April to November the weight increase of cattle ranges from 190 to 290 grams/day. Hybrid cattle tend to be better suited to these conditions. Short grasslands tend to be better for goat production, whereas tall meadow grasslands are better suited to cattle.

CONTROLLING THE STOCKING RATE

The grass yield needs to be matched to the numbers of animals grazed if the vegetation is to be protected from overgrazing. Experiments have shown that cattle weighing approximately 200 kg require 0.5–2.5 ha of grassland. The grass yield during the period from March to July is high and more cattle can be stocked at this time. However, in summer with dry conditions and high temperatures, the number of animals grazed needs to be reduced. This applies also during the cold winter period. Hence, these natural grasslands need to be grazed seasonally.

Grazing can normally commence 15 to 20 days after spring growth begins. This can vary, depending on altitude, from mid-March to mid-April, and grazing can continue through until the end of December.

CONTROLLING GRAZING PRESSURE

Choosing a suitable grazing pressure is an effective way of protecting against the degeneration of grasslands. Because of high temperatures and rainfall in the south, the persistence of grasses can be limited. In order to keep grasses actively growing it is necessary to graze down to a height no less than 5 cm to 7 cm. The grazing interval is usually around 45 to 50 days.

THE INTEGRATION OF ANIMALS INTO DIFFERENT LANDSCAPE ECOSYSTEMS IN HUBEI PROVINCE

Xiang Yuanqing[1] and Hong Qi[2]

[1] Livestock Breeding Centre of Hubei Province, Wuhan, 430070, P. R. China
[2] Animal Husbandry Bureau of Hubei Province, Wuhan, 430064, P. R. China

Abstract

Hubei Province has a large proportion of mountainous terrain, which accounts for 56% of the total land area. Approaches to derive plant and animal products from different landscape ecosystems suited to the natural conditions and resources of the mountain areas have been studied, using symbiotic principles. Four ecological and symbiotic patterns of organisms: (i) timber tree–forage–animal–medicinal herbs; (ii) crop–forage–animal; (iii) fruit tree–forage–animal and (iv) forage–animal–fish are proposed. Using the symbiotic and mutually beneficial interactions of plant species, the limited land and animal resources can be more fully utilised. Increases in the biological yield of land, many new products, control of soil erosion and improved soil fertility could be achieved by developing a high-production, high-efficiency, material-recycling and sustainable agro-ecosystem in the mountainous region.

INTRODUCTION

HUBEI Province has many types of landform that can be divided into three parts: mountains, hills and plains. They account for 56%, 24% and 20% respectively of the total landform. The climate is subtropical monsoonal and because of the range of altitudes there are many differences in climate, soil, plant and cultivation patterns. The average arable land per person is only 0.058 ha, which is lower than the national average of 0.13 ha. The unused grassy mountain and slope areas are estimated at 0.088 ha per person, which is one-third of the national average of 0.273 ha. In light of the conflicting demands of population, resource, environment, grain and energy, it is important to increase the utilisation efficiency of resources and exploit the potential of differing agricultural landscape ecosystems. Developing animal husbandry on mountain forage land, by combining planting and animal husbandry, and building adaptable mountain agro-ecosystems is the only way to resolve the deficit in agricultural resources. Only by doing this can we improve the utilisation ratio of resources, achieve improved ecological and economic benefits, and reach the target of sustainable agricultural development.

In Hubei Province, for reasons of history and the varying natural conditions, there has been a serious imbalance in the development of the rural economy. Mountain development has lagged behind, and the farmers' standard of living and technology were at a low level. In the early 1980s, scientists carried out research into developing and utilising mountain resources. The research work included resource investigation, agricultural structure, forage development, ecosystem modifications, and inputs to and outputs from agriculture. Some forage and plant species with good adaptability and high yield were selected. In the 1990s, traditional ecosystem models were changed from the models in which developing forage land was the only way to feed animals, to models in which trees, grains, forages, and animals were combined in integrated development.

This paper discusses results that focus on the improvement of the structure and function of mountain agro-ecosystems. More attention needs to be paid to integrated development models adapted to different landscapes and technologies and which benefit from symbiotic relationships between species.

MODELS AND METHODS

Experimental region and natural conditions

In different landscapes, the ecosystems have different structures and functions. Experiments were conducted in typical western mountain regions above 1000 m, with complex terrain and various landscapes. The regions can be divided into three elevation zones: the first is the mountain region above 1200 m. This area is vast and has low temperatures. It is suitable for forestry and forage-based animal husbandry. The second is sub-mountainous regions with elevations between 800–1200 m. This vast area has a good climate and high quality soil, and therefore has the best potential for integrated development of agriculture, forestry and animal husbandry. The third is hills and plains at elevations below 800 m. This area

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has the best conditions for agricultural production, but is small in area and densely populated.

The experimental regions have a temperate climate and abundant precipitation. Average annual temperature is 16°C and annual precipitation 1400 mm. Because of the complexity of the area, there are many different types of climate. Generally, average temperature drops by 0.6°C and the frost-free period decreases 4–6 days for each 100 m increase in elevation. Above 300 m, the yearly precipitation increases by 100 mm per 100 m elevation.

The regions have abundant natural resources. There are many types of good soil in these regions, such as 'zhugantu' on the hills and plains, 'mountain yellow soil', 'yellow sandy soil' and 'grey sandy soil' in the sub-mountains, and 'grey soil' on the mountains. There are many plant species present that are adapted to the subtropical, warm temperate and cool temperate zones. The total of 1000–2000 species includes 40 species that can be used in forests. These species include *Cunninghamia lanceolata*, *Pinus massoniana*, *Cypress funebris*, bamboos, *Cinnamomum camphora*, *Machilus namu*, and *Betula*. The 400 species of medicinal plants include the rhizome of Chinese goldthread (*Coptis trifolia*), 'dansheng'(*Radix salviate mycorrhizae*), 'danggui'(*medicinal herb angelica*), the bark of eucommia (*Eucommia ulmoides*) and 'tianma'(*gastrodia mushroom*). The main herbs include pteridophytes, *Anaphalis contorta*, *Scinacalia tangutica*, *Deyeuxia clarion*, *Agrostis perlaxa* and *Trisetum altaicum*. Herbs cover 80–90% of the soil and there are more than 10 species of herbs per square metre.

Although there are good natural conditions and abundant resources, the farmers' lives are very poor because of the mountainous terrain. As a result of heavy precipitation, soil erosion is very serious and some soils are infertile. The agricultural production level is low and overall production is limited. It has been demonstrated that planting forages is an efficient way to control soil erosion and improve the lives of farmers provided that they return animal manure to the field and plan development in an integrated way.

Mountain eco-models in different landscapes

Because of the complex patterns and the difference in heights of mountains, there are many vertical differences in different landscapes. Among all the resources, the areas of unused land are vast. The species in these unused lands are the fundamental unit to form a new ecosystem. In mountain and agricultural systems, there are close relationships among the different resources and between resources and the environment. It is important to maintain the fine balance of mountain ecosystems in developing the mountain resources and utilising the symbiosis between species. To illustrate the specificity and superiority of different landscapes according to these principles, four different eco-models have been successfully built.

(i) Tree–forage–animal–medicinal herbs model

The four species in this model are related by matter and energy exchange. The model was constructed in a 20 ha forest of 'China fir' (*Cunninghamia lanceolata*) of row spacing 4 × 4 m, slope 5–15°, crown canopy covering 50%. Red clover (*Trifolium pratense*) and the rhizome of Chinese goldthread (*Coptis trifolia*) were planted among the forest. The rhizome of Chinese goldthread is adapted to shady conditions as it can utilise the scattered light for photosynthesis. Red clover is a biennial legume that grows to nearly one metre in height and covers a low area of soil. The stem and leaf are good fodder, and it fixes nitrogen from the air.

In this interplanting system, using the shade of the canopy, the cost of building a cover to shade the rhizome of Chinese goldthread was saved. Using fixation of nitrogen from the red clover and returning animal manure to the field, soil fertility was improved and less fertiliser had to be applied. The research results indicated that in this interplanting the biological output and the utilisation ratio of effective irradiance were twice that of the control. Combining forestry and animal husbandry greatly improved the soil in this model, increasing the soil organic matter by 17–20%. Cutting the red clover four times a year produced 30 t of fresh herbage per hectare, which was sufficient to feed two cows or ten goats.

Red clover is the key in this symbiotic model. By using it to feed animals and returning the animal manure to the herbs and trees, primary and secondary production were combined and the production system of tree–forage–animal–medicinal herbs was successfully enhanced.

(ii) Crop–forage–animal model

In mountain regions, the main crops are wheat, maize, potato and tobacco. These crops normally impoverish the soil. By building a symbiotic system of crops, forages and animals, we can return straw to the field to improve soil fertility and preserve soil water. Crop straw and forage were used to feed animals, whose excrement was returned to the field to improve soil fertility and structure. This builds a closed system in which the main energy is organic energy. This system improved the utilisation ratio of soil and changed the ecosystem circulation from poor to good. The model area was 30 ha in the mountain region at an elevation of 1000–1200 m and slope 3–5°. The treatments included: (a) interplanting crop and forage plants, namely maize and red clover planted in alternating rows. Red clover was planted in the autumn of the first year and the maize in the spring of the next year. (b) Intercropping forage and crop. White clover was planted first for several years, and after harvesting, potato was planted. In these treatments white clover, red clover and maize straw were processed to feed animals, and the animal excrement returned to the fields. The experiment continued for three years and provided the following results.

- The model improved soil fertility. For example, in intercropping forage and crop, in contrast with the tobacco land, planting white clover for five years increased soil organic matter and soil nitrogen by 50% and 36.2%, respectively.
- It also increased crop output. For example, potato yield in the white clover land was higher than that in tobacco land. After interplanting clover, the diameter of the corn stem, the length of the corn tassel and the weight of 1000 grains were all markedly improved.
- Soil erosion was also reduced because the legume forages have dense roots, so the soil is held tightly. By interplanting red clover with maize, run-off was decreased by 40% and soil erosion by 72%.

(iii) Fruit–forage–animal–methane model

This model was used in a 3 ha area in the mountain region at an elevation of 300–500 m. The treatments were: interplanting white clover with red clover among the orange trees; feeding pigs with white and red clover; returning pig excrement to a methane-generating pit and using the methane as fuel; and putting the methane residue into the orange and tea fields as manure.

The results indicate that clover can greatly improve the tea and fruit tree eco-environment. The clover increases soil cover which decreases soil erosion, modifies soil temperature and preserves soil moisture. For example, in summer it can reduce water evaporation and prevent drought, and in winter it can increase soil temperature and help plants through the colder weather. The legume forage improves soil fertility and can boost orange growth. The diameter, height and extension of orange branches were increased by 96%, 47% and 30%, respectively, compared with the control.

This model shows that returning the methane residue to orange orchards can increase the volume of branches, the number of flowers, the fruit ratio and the output of oranges by 12%, 12%, 2% and 43%, respectively.

Because the circulation of energy and matter was beneficial, output was improved. The yield of oranges was 35 t/ha, 4 t higher than the control. The yield of tea was 25 t, 1.3 t higher than the control. Feeding pigs with white clover can reduce fodder bills by 20%.

(iv) Forage–animal–fish model

Owing to a lack of reliable water, the value of fish is very low, lagging behind other industries. Therefore, people often ignore the relationships among fish, crops and animals. In the region where fish culture is advanced, the pond provides fish to the farmer, and improves the organic matter of the pools and the number of zooplankton and phytoplankton. The fish pond is an area for recycling organic matter. Where there is abundant water, recycled methane residue and waste water are used to feed fish. This adaptable ecosystem can enhance aquatic products and socioeconomic wealth and improve the farmer’s life. For example, in the fruit–forage–animal–methane model, we can add fish after producing methane. This multi-level utility can ensure good recycling and improved economic benefits.

CONCLUSION

The mountain ecosystem consists of many subsystems of trees, fruits, fields, forages, animals and energy. Depending on the particular landscape, all subsystems can be organised rationally. There is a need to efficiently utilise soil and climate resources and combine artificial and natural factors successfully to build an organic system. Only by doing this can we optimise the outputs from the system, changing the natural resources into products and gaining greater benefits.

The four ecosystems outlined here can improve the utilisation of light, heat, water, air and soil. Moreover, due to the development of trees and forages, soil erosion can be reduced.

In all models, the crops, trees and forages are the foundation to maintain stability. The animal is the main link to enhance the value. By planting crops and fruit, using forage to feed animals, putting excrement into methane-generating pits and returning methane residue to fields, high yields, high efficiency and sustainable development can be achieved.

In all systems, the main plant to improve soil fertility and structure is a forage legume. In China's traditional agricultural system, forage legume is the main source of nitrogen. It is low cost, requires little energy and creates no pollution and thus it is preferable to manufactured nitrogen fertilisers. Developing forage legume improves the agricultural structure and builds the cycle of 'planting forage, feeding animal, fertilising field, improving yield'. Different regions need to choose adaptable legumes.

In a mountain ecosystem, natural resources should be used and developed systematically. Because of the developing economy, agriculture, forestry, animal husbandry, fishery, processing and energy properties should be constituted rationally. Extending the ecosystem function can improve the utilisation of energy and matter, so the adaptable ecosystem can be maintained in accordance with the peculiarities of the region.

We now have a great deal of information from the experiment about species symbiosis in different landscapes. These eco-models are very helpful in improving the agricultural economy. These research experiments must continue, and all the achievements put into practice. Education and science for the people must also be developed to meet the needs of the developing economy.

AN ECONOMIC COMPARISON OF ANIMAL SYSTEMS FOR UTILISATION OF RED SOIL FORAGES

Anthony J. Casanova

School of Rural Science and Agriculture, University of New England, Armidale 2351, Australia

Abstract

Potential yield and costs of five forage systems were determined for Fujian and Hunan. Linear programming was then used to compare the feed utilisation and profitability of breeding goat and cattle herds that could graze these forages. All viable systems included perennial tropical grasses, which have maximum growth in summer. Goats and cattle required silage or other supplementary feed during winter in order to be productive.

Potential net annual income ranged from 137–284 Yuan/ha (20–37% return on expenses), excluding land costs. Goats were more profitable than cattle because of their lower winter feed requirements, due to the smaller proportion of breeding animals needed. This advantage was greater in Hunan, which has the greatest winter feed gap. Goats would be less profitable than cattle if goat meat prices declined by a small amount due to market saturation. In integrated farming systems, forage-based animal production would have beneficial effects on other system components that are not considered here.

There is less potential for grazing-based forage systems in Fujian. Wages are higher than in Hunan, so that only mechanised pasture establishment would be viable. However, the steep terrain in Fujian severely restricts opportunities for this practice. The lowest feed cost per unit energy in both provinces was for low input perennial forages, established by machine. This system would be useful where return on money invested is more important than income per hectare. Forages have become more economical over the last five years because fertiliser prices increased below the general inflation rate. All forages tested were cheaper than grain on a per unit energy basis. Therefore, pig diets could include some forage to reduce feeding costs.

INTRODUCTION

SUBSTANTIAL increases in forage yields can be achieved on the red soils by sowing well adapted grass and legume varieties, and through the application of fertilisers. This is not an end in itself, as farmer incomes depend on the sale of animal products grown from the forages. Therefore, forages should be evaluated in terms of the animal production they can support.

For pig production, it is easy to determine the potential benefits of forages. If grain is more expensive than forages, then the latter should be included in the diet to a level just below that where growth rates are depressed. A more considered evaluation is required for ruminant production. Ruminants depend mostly on forages to supply their dietary needs. They are most profitable when their intake of supplements, such as compound feed, is minimised. This means that the limit to stocking rates is the feed requirements during the time of the year of minimum forage growth.

It is possible to manipulate both forage production and feed requirements throughout the year in order to maximise feed utilisation, and therefore, profits. Forage production can be changed by manipulating the proportion of area sown to cultivars that differ in growth patterns, by delaying grazing, or by conserving forage as hay or silage. Feed requirements in different seasons can be controlled through the choice of whether to have a self-replacing (breeding) herd or flock compared with buying animals to grow for sale, by choosing the timing of parturition, and by selection of the selling date.

This paper illustrates these points by comparing hypothetical grazing goat and beef systems, based on forage production strategies developed as part of ACIAR Project 9309. The optimum combination of forages that maximise stocking rates and profit is determined using linear programming (LP). This method enables the variables of monthly forage production, monthly feed requirements, provision of silage, the cost of forage production, and income from the sale of animals to be considered simultaneously. These components are detailed before being brought together in the final section.

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In practice, forage-based animal production would form part of integrated farming systems, as this has been the trend of red soil development over the last decade (Chisholm and Stemp 2004). Inclusion of forages would have flow-on benefits for other system components, due to reduced soil erosion rates and increased crop yields from improved soil fertility. These aspects are beyond the scope of this paper.

MONTHLY FORAGE PRODUCTION

Results from plot experiments conducted in Fujian and Hunan Provinces were used to generate annual forage growth curves. Plots were 2 × 3 m in size, and were harvested to 10–15 cm height. Harvest data from 1994 to 1996 were averaged for corresponding months across years where the swards were well established. This was done for each of three species, representing three of four major sward categories for the red soils (Table 1). Annual temperate pastures were not tested, but would be a potential replacement for silage, which is evaluated here. Values in the resulting annual curves were further refined, using running averages over three consecutive monthly periods to reduce the variability due to periodic harvest measurements. Raw averages were used at the ends of growing seasons, where production dropped quickly due to climatic constraints.

Table 1. Forage production systems for the red soils.

Forage system	Characteristics
Perennial temperate	Grass dominant, declining persistence over time
Annual temperate	Grass, legume or cereal
Perennial tropical	Grass dominant, highly persistent
Annual tropical	Especially suited to legumes

Yields (kg DM/ha) were scaled (100–260%) to account for N fertiliser responses determined in separate experiments. Estimates of the metabolisable energy content of the forages were made for each month, using values from Anon. (1991), Göht (1981) and Smith (1980a). These values range from 6 to 11 megajoules of metabolisable energy per kg (MJ ME/kg) for senescent reproductive grasses through to young vegetative shoots respectively. Figure 1 shows the feed value per hectare of each of the tested forage types throughout the year, consisting of yields multiplied by their respective energy contents. Perennial temperate species were the first to begin growing after winter. By mid spring their production rates were overtaken by that of tropical grasses. Annual tropical legumes were slow to become productive, and reached a peak in autumn. Yields of tropical species grown with low fertiliser inputs are expected to be 28% of that of high input grasses, and 53% for low input compared with high input legumes. Low input temperate perennial species were not considered because they are unlikely to persist without high fertiliser inputs.

The production rates of perennial systems shown in Figure 1 are for established forages. This analysis used the production values of forages for five years following establishment. Figure 2 shows the expected production for the three perennial systems over time, extrapolated from yield trends in our experiments over three years. Temperate species were more productive in their first year than were the perennial tropicals. However, temperate forages were less persistent, especially in Fujian. Tropical species also died sooner when they had lower fertiliser inputs.

Tropical legumes such as *Chamaecrista rotundifolia* cv Wynn behave as annuals in Fujian and Hunan because

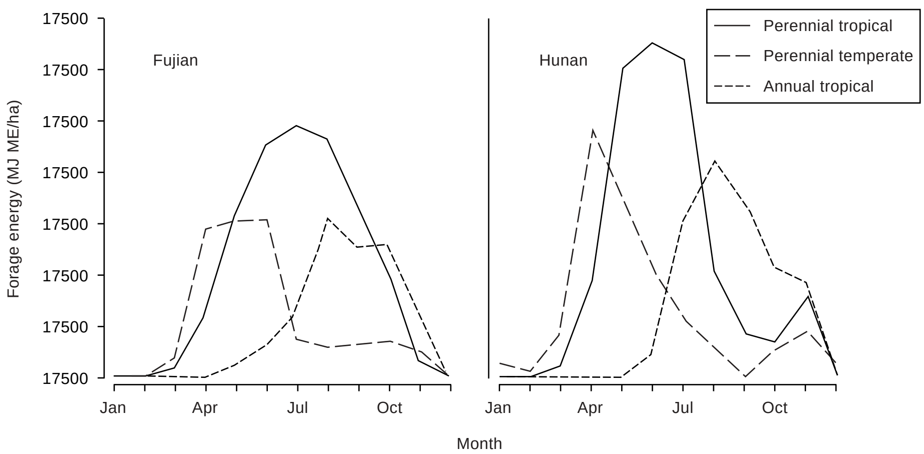

Figure 1. Calculated monthly production of three forages at Jianyang (Fujian) and Guanshanping (Hunan). Feed available for ruminants is megajoules of metabolisable energy (MJ ME/ha = [kg DM/ha * MJ ME/kg]).

of the cold winters. They are able to re-establish from seed in the following year, but with a slightly weaker stand. Re-establishment was not included as an option in this analysis because we have not found Wynn to persist well where it was subject to cutting.

Only a proportion of feed that is produced in a year can be consumed and converted into animal product. For example, a common stocking rates of 10 DSE/ha at Armidale, NSW accounts for about 50% of the metabolisable energy contained in forages produced. In more extensive grazing systems such as in tropical northern Australia, utilisation of greater than 10% of primary productivity is thought to put persistence of the native grasses at risk (Ash and McIvor, 1993). Much of this stems from the need to maintain a feed buffer for unexpected drought seasons. Also, utilisation depends on the type of feed, and can vary between materials of the same digestibility. The intake of legumes has been found to be 40% higher than grasses, and grass leaf intake 100% greater than for grass stem, for materials of the same metabolisable energy content (Poppi et al. 1987). LP allows for more efficient utilisation by optimising feed production and requirements within seasons. Taking these factors into account, the utilisation values that have been used here were 80% for legumes, 70% for vegetative grasses and 50% for mature grasses.

If there is a surplus of feed in one month, it can be left ungrazed until a later month. However, there is a loss in feed value when this occurs. The extent of loss is difficult to quantify, as it depends on metabolic and death rates of herbage, which in turn depend on seasonal conditions. A loss in quality of 20% per month was used in the analyses, except during autumn when the rate was set at 50% per month to account for the loss in quality of maturing grasses.

HERD STRUCTURES AND FEED REQUIREMENTS

Theoretical self-replacing goat and cattle herds were used to contrast the effects of their differing reproduction and growth rates on seasonal feed requirements. Table 2 summarises the expected growth and reproductive characteristics of these herds. Growth rates are dependant on forage quality, and rates here have been calculated using estimates of forage digestibility and crude protein values (Rickards and Passmore 1977; Smith 1980b). The values in Table 2 are based on young being born in April, and sales occurring at the end of October.

Table 2. Growth and reproduction characteristics of self-replacing goat and cattle herds.

	Goats	Cattle
Sale age of young	7 months	31 months
Sale weight of young	22 kg	400 kg
Age at first calf/kid	24 months	36 months
Breeder weight	50 kg	380 kg
Calving/kidding rate	150%	80%
Annual mortality rate	2% adults, 5% young	2% adults, 5% young

The herd characteristics in Table 2 determine the number of animals in each age group. Table 3 shows the resulting herd sizes at the time of sale. The total herd size comprises breeding animals, young animals for sale and young animals kept for replacement of old breeding animals. There is a lower ratio of animals sold to total herd size for cattle compared with goats. This is because of their lower reproduction rates and slower maturation. The ratio of the winter herd numbers to that at the time of sale is lower for goats than for cattle (58% compared with 82%) (Table 3).

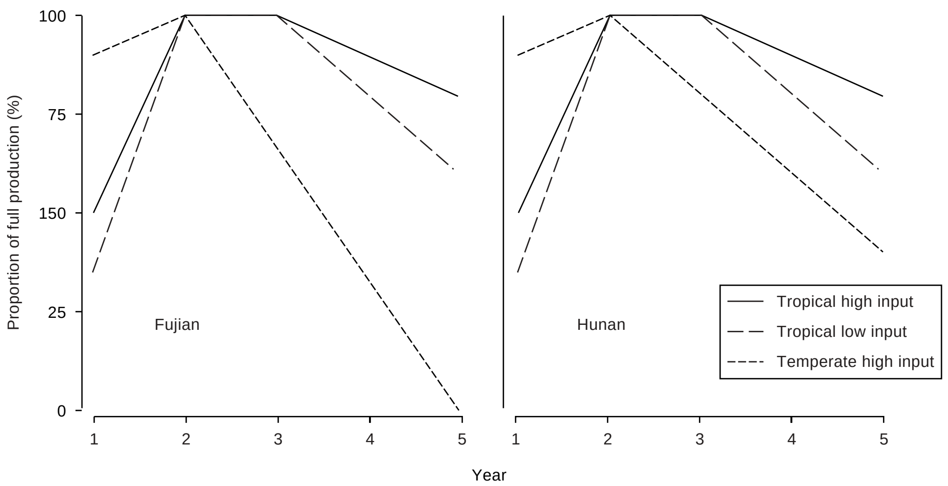

Figure 2. Expected annual production of perennial forages for Fujian and Hunan in the five years following establishment.

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This is because all young goats for sale are sold in the first autumn after they are born, whereas young cattle for sale must be kept through two winters.

Table 3. Age structure for self-replacing goat and cattle herds.

Herd number	Goats	Cattle
Total herd size	274	333
Young animals sold	118	58
Old animals sold	24	13
Total sold	142	71
Ratio of annual number sold/total herd	51.8%	21.3%
Winter total herd size	158	274

There is seasonal variation in the feed requirements of the grazing goat and cattle herds (Figure 3). Monthly requirements depend on the number of animals in each age group, their maintenance and growth requirements, and needs during pregnancy and lactation. Goats have more variation in their feed requirements throughout the year than cattle, because only breeding goats are kept through winter and they have more offspring per year than cattle.

FORAGE COSTS AND INCOME FROM ANIMALS

Gross margin budgets were prepared for all potential forage and animal enterprises using mid-1997 prices. Forages and animals were treated as separate enterprises to enable consideration of different combinations of forages to supply the animals' feed requirements. The costs of growing perennial forages were amortised over five years (@5% interest cost) to give annual averages. Prices are given in Chinese Yuan RMB (A$1.00 = 5.99 Y in September 1997). The cost of leasing or buying land was not included.

The major costs of producing forages are for establishment and fertilisers. Fertiliser rates and their costs are shown in Table 4. These rates match those of Minggang Xu et al. (2004), with the exception of higher rates of N being applied here. Temperate forages also require 2000 kg/ha of lime, applied in year 1. The time required for manual cultivation and sowing has been estimated at 60 days/ha. Labour costs are 9.00 and 22.50 Y/day in Hunan and Fujian respectively. As an alternative, mechanical cultivation was also considered, at 4.5 h/ha, which costs 225 and 300 Y/ha in Hunan and Fujian respectively.

The average annual forage costs and the average annual feed available to be utilised by animals for all enterprises are shown in Table 5. Perennial pastures have lower costs than the annual legumes because establishment costs are amortised over five years. Temperate pastures have high costs per unit feed value because their yields are low relative to the quantity of inputs required. Farmers would benefit from inclusion of forages in their systems even where the returns from animals are low. This is because the improvements to soil stability and fertility from forages would lead to increased crop yields.

For the LP analysis, silage making was allowed as an option during mid to late summer, when tropical species are at the late vegetative stage of growth. A constraint was made to limit the amount of silage produced to 6220 MJ ME/ha, which is 25–30% of the forage growth in these months. This was done to keep the animal systems predominantly grazing-based, and because there is likely to be a shortage of labour at that time, due to rice harvesting and replanting requirements. A loss of nutrient value during storage of 15% was included. The cost of silage is calculated

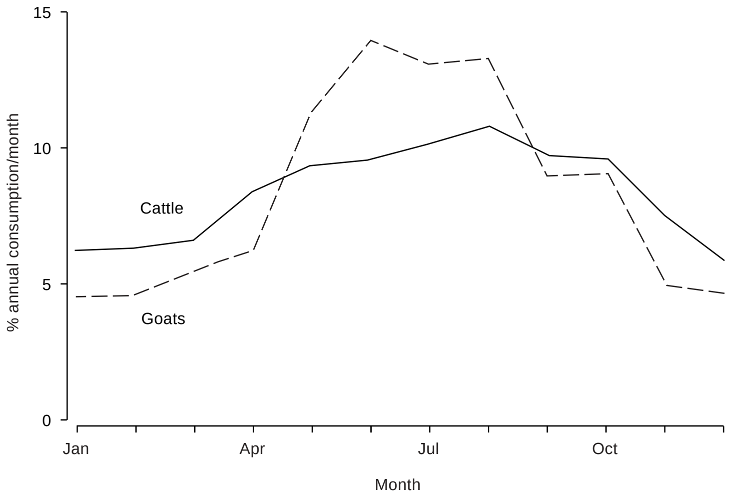

Figure 3. Calculated monthly feed requirements for goat and cattle herds, as a proportion of annual intake. Feed requirements are calculated as MJ ME/month.

Table 4. Fertiliser application rates and costs for forage production. Within application rate columns, the first number refers to the rate for the first year, with following numbers referring to rates for subsequent years.

	Annual application (kg/ha)				Cost (Y/kg)	
	High input perennial grass	High input annual legume	Low input perennial grass	Low input annual legume	Fujian	Hunan
N	50/50	25	0	0	4.71	3.00
P	40/24	40	10/0/10/0/0	10	12.00	7.33
K	50/30	50	0	0	3.00	2.60

Table 5. Average annual forage yields and annual amortised costs. Gross margins (GMs) are for establishment using manual cultivation.

System	Fertiliser input	Yield utilised (MJ ME/ha)	GM (Y/ha)	Rice/forage cost ratio (manual)	Rice/forage cost ratio (mechanised)
Fujian					
Perennial tropical	High	33,607	1001	5.94	7.69
Perennial tropical	Low	8,596	383	3.97	10.03
Annual tropical	High	23,129	2218	1.85	3.51
Annual tropical	Low	12,258	1590	1.36	4.03
Perennial temperate	High	13,021	1179	1.96	2.44
Hunan					
Perennial tropical	High	37,394	590	9.75	11.06
Perennial tropical	Low	9,564	180	8.20	13.39
Annual tropical	High	30,125	1128	4.11	5.70
Annual tropical	Low	15,966	703	3.49	5.48
Perennial temperate	High	19,568	678	4.46	1.96

as the sum of harvest and cartage costs, plus depreciation on silage pits. This totalled 0.0186 and 0.0270 Y/MJ ME for Fujian and Hunan respectively.

The gross margin budgets for goats and cattle account for income from the sale of animals less operating costs (Table 6). Meat prices used for young animals were 25, 22, 17 and 16 (Y/kg) for Fujian and Hunan beef, and Fujian and Hunan goat meat respectively. Meat from adults was discounted 10% and a dressing percentage of 55% was used. Husbandry requirements used were 30 breeding cattle or 90 breeding goats per person. A capital cost of 5% of the value of the animals was also included. Feed costs were not included at this stage, as they are allocated in the LP analyses.

Table 6. Stock gross margin (GM) budgets (Y/breeding animal) Y = Yuan (currency).

	Gross income	Husbandry costs	Capital costs	Net gross margin
Fujian				
Cattle	3808	82	553	3173
Goats	351	22	38	291
Hunan				
Cattle	3368	82	502	2784
Goats	332	22	36	274

USING FORAGES TO MEET ANIMAL FEED REQUIREMENTS

All forages considered here were cheaper than grain per unit of metabolisable energy. Therefore, forages could profitably be grown as a feed for pigs, to replace a proportion of the grain in their diets. For the ruminant systems, the data was tested using LP to show the stocking rate and feed supply methods that maximised income from 100 ha of land. Although this is greater than the area available for actual development in most cases, the relative results are applicable on a smaller scale. Each LP run allowed all forage options to be available in separate areas, plus silage limited to 6220 MJ ME/ha and unrestricted deferred grazing.

Goats were more profitable than beef cattle (Table 7). Goat feed requirements are better matched to the feed supply pattern, and so less silage and less deferred grazing were needed (Figure 4). Goats had a greater advantage over cattle in Hunan compared with Fujian. This is because more forage conservation was required in Hunan. Perennial tropical forages were the cheapest feed source in both provinces (Table 5), and so predominate as the preferred feeding method (Table 7). They have a shorter growing season in Hunan

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(Figure 1), and so a greater proportion of annual feed must be conserved there. Therefore, the reduced winter feed requirements of goats compared with cattle had a greater effect on their relative profitability in Hunan.

Production systems that meet animal feed requirements need a greater summer feed surplus than the winter deficit to be filled, to compensate for losses in feed quality over time. Cattle have greater feed losses compared with goats, because cattle have a greater proportion of their feed grown in months that are different to the month of consumption. For the two systems in Figure 4, 27% of feed grown for cattle was not utilised due to silage and deferred grazing losses, compared with 9% for goats.

No animal enterprises were feasible without silage, or some other supplementation, as a feed supply during winter. Autumn-grown forage that is left ungrazed would have a high loss in feed value that would make it inefficient as a source of winter feed. In addition, both beef cattle and goats were unprofitable if winter feed was supplied by grain. Other winter feeds, such as annual temperate pastures, would be a suitable replacement for silage, provided they are cheaper than grain.

Low input forages formed part of the optimum plan in some cases, as this increased returns by overcoming the silage production constraint. Inclusion of a proportion of low input forages meant that the ratio of silage/total forage per 100 ha was increased, thereby allowing animal feed demands during winter to be better met. This was not required for goats grown in Hunan. In that case high input pastures were best, because the feed demands of the goats better match the feed supply compared with cattle and so less silage was needed during winter (Figure 4).

Table 7 shows that returns were greater where machinery, rather than manual labour, was used for establishment. Switching from hand to machine

Table 7. Summary of optimal forage based animal production systems.

	Forage establishment method	**Optimum forage combinations***	**Stocking rate (breeders/ha)**	**Net revenue (Y/ha)**	**Return on expenses (%)**
Fujian					
Cattle	Manual		—	0	—
Cattle	Machine	L and H Peren Trop	0.2	137	24.4
Goats	Manual		—	0	—
Goats	Machine	L and H Peren Trop	3.1	153	20.3
Hunan					
Cattle	Manual	L and H Peren Trop	0.3	162	23.7
Cattle	Machine	L and H Peren Trop	0.3	202	33.3
Goats	Manual	H Peren Trop	3.5	218	30.9
Goats	Machine	H Peren and Ann Trop, H Peren Temp	4.0	284	37.2

* Optimum forage combination codes: H = high inputs and L = low inputs. Peren = perennial. Ann = annual. Trop = tropical. Temp = temperate.

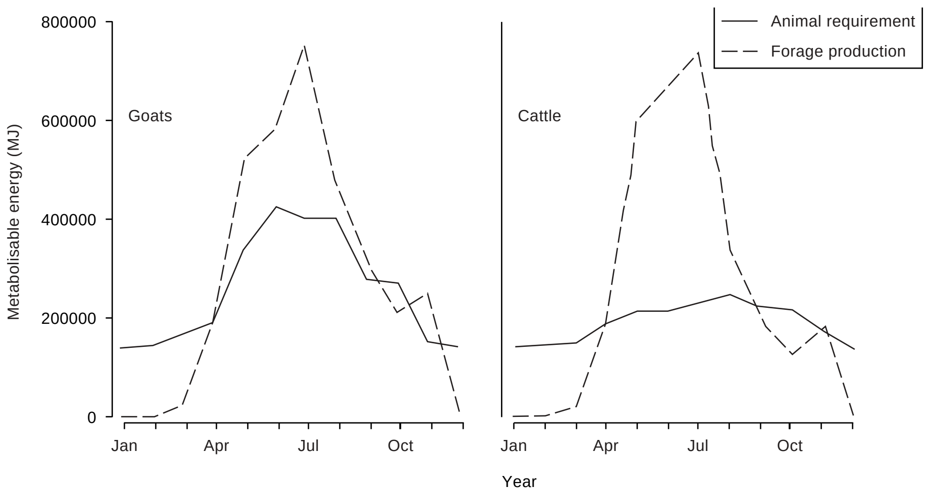

Figure 4. Optimal solution for forage production and animal feed requirements for 100 ha in Hunan, with mechanised pasture establishment. The surplus of summer forage is needed for silage and deferred grazing to satisfy winter feed requirements.

establishment had the greatest percentage decrease in costs for low fertiliser input pastures, where labour was the highest proportion of costs (Table 5). Neither cattle nor goats were feasible in Fujian if pasture was to be established manually. In this case, forage costs would need to drop 3% for income to cover costs. Because of the predominantly steep terrain there will be few situations where pastures can be established by machine in Fujian. The net gross margins for other options across both provinces ranged from 137 to 284 Y/ha. Most solutions show that perennial tropical grasses were the best source of feed. This is because they have the highest yield and longest seasonal growth of the forage types considered (Figure 1).

As is the case here, an analysis of red soil forage profitability using 1992 data showed that labour costs for forages were critical to their profitability (Casanova et al. 1995). In that analysis, beef cattle were not feasible. The difference here is that no allowance has been made for annual weed control. Even allowing for reduced pasture persistence from 10 to 5 years as a result of reduced maintenance, there has been a significant lowering of feed costs. Between 1992 and 1997, wages and food prices doubled in Fujian and Hunan, but fertiliser prices increased 40–80%. This means that on balance, forage development is more favourable now than five years ago.

Both low and high input forages have potential roles in wasteland development to meet different requirements. This is because of the distinction between return per hectare and return per unit expense. For perennial tropical pastures that were sown by machine, the MJ ME/kg cost was less for low input compared with high input pastures (Table 7). This means that if capital is limited and there is a large area of land to be developed, then the greatest return on investment would be to grow low input pastures. However, if wasteland is limited and the highest priority is income per unit area, then high input pastures are best because they give the greatest yield, and therefore income per hectare.

Running goats and cattle together did not increase income. Profit would be depressed in this case because of the winter feed that would be diverted to the lower income animal species. The potential income from goats was higher than that for cattle. However, these relative differences are sensitive to the number of person hours required for herding each species, and so there may be little difference in income in real-life developments.

The most profitable ruminant system per hectare in Fujian would be based on perennial tropical grass pastures with supplementary feeding during winter. Figure 1 shows that the annual growth curve of perennial tropical grasses in Fujian is broad enough to subsume those of temperate and legume species. This was verified in the analysis, where the latter pastures were too expensive per MJ ME to be worth considering (Table 7). In contrast, a mixture of forage species, grown in separate areas, provided the optimum feed supply for Hunan goats where mechanised pasture establishment was used. These pastures differed enough in their growth patterns, and had low enough production costs, to be preferable over extra deferred grazing or silage.

This analysis considered the profitability of forage-based animal systems over a five year average, with breeding herds at equilibrium. In practice, farmers starting to develop wasteland would also need to consider the lower yields that would occur during the establishment year, so that young plants are not damaged by overgrazing. They would also need to be aware of price risk, which was not evaluated here. For example, the current advantage of goats over cattle could be eroded quickly if the supply of goat meat increases, and if goat meat has a low elasticity of demand. Goats in other areas have been found to cause more environmental damage than cattle if not managed carefully.

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ECONOMIC BENEFITS OF GRAZING LIVESTOCK ENTERPRISES IN THE HILLY RED SOIL REGIONS OF SOUTH CHINA

Li Zhou and Sun Ruomei[1]

[1] Rural Development Institute, Chinese Academy of Social Science, No. 5, Jiangguomennei Dajie, Beijing, China

Abstract

This paper analyses the historical reasons why large hilly areas of the red soils of southern China are underutilised. The quality of pastures, the technology available and agricultural policies are three key factors. Current reform in land-use systems has created favourable conditions for developing animal husbandry enterprises. At the same time, grass-planting technology in the red soils of southern China has been improved. Nevertheless, large efforts are still required to turn the advantages of these productive resources into economic benefits. The difficulties that farmers face will need to be overcome through assistance with the initial investment, the development of markets and agricultural extension.

INTRODUCTION

RED SOIL areas account for 46 to 66% of the land area in Hunan, Jiangxi and Fujian, 32% in Zhejiang and 18% in Anhui. The total area of red soil is about 10.7 million ha. Red earth soils have developed under a subtropical biological climate — warm temperatures, sufficient rain and a long frost-free period. The annual average temperature is 16–26°C, whereas the accumulated temperature above 10°C is 5800°C to 6500°C. Annual rainfall is about 1500 mm. The original vegetation was subtropical evergreen broadleaf forest. The topography features low mountains, hills and plateaus.

The red soil areas in south China have rich grassland resources on hilly land. These have developed following the removal of the original forests. These grasslands intersect farmland and forests, mostly small and numerous in regions below 1000 m asl and larger above 1000 m asl. For example, there is a total of 6.4 million ha pastures in Hunan, comprising 30% of the total area of the province. Of this area, about 34,000 ha is meadow (0.53%), 910,000 ha is thick-grassed pasture (14.3%); 916,000 ha is shrub (14.4%), 657,000 ha is open grassland (10.3%); 1.50 million ha are grass pastures (24%), and 2.4 million ha is the grazed pasture located between farmland and forests (37%).

Although the red soil areas experience high rainfall, it is concentrated in the spring and early summer, and thus dry periods are common. Also, red earth soils do not have a high water-holding capacity. These factors have led to serious soil erosion which has limited the potential for annual grain crops. However, the hilly red soils are suited to growing perennial pastures for livestock production. In spite of this, local farmers do not have any tradition of planting grass and raising livestock (especially ruminants) even though areas exist with suitable abundant meadows for such livestock.

Technical experts have claimed that local farmers do not perceive raising stock as a significant means of earning income, and thus it is difficult to get pasture technology adopted (Zhang and Liu 1993). The reasons for this are discussed below.

One significant constraint is that the hilly red soils are largely covered with unstable, low-quality natural meadows. Of that herbage which is edible, more than 80% is grass, while there are few legumes. There are two criteria for judging the quality and quantity of a pasture. ‘Class’ reflects its quality, and ‘grade’ reflects the grass-yielding volume per unit area. For example, in Hunan Province the first-class meadows account for 13% of the total pasture, while the first-grade is as high as 44%. Of the first-grade meadows, only 10% is of first-class grass, mainly in the pastures between farmland and forest, while the proportions of second- and third-class pasture are 17.2% and 15.6%, respectively. Considering the usable parts of natural pastures, 4 ha of grass is generally enough to raise one cow. Comparatively speaking, the productivity of traditional cropland is much higher than that of traditional livestock grazing. An area of 4 ha of red soils land can, with extensive crop cultivation, meet the basic living demands of one family. If the land is used only for animal husbandry, the economic returns are insufficient to support a family. As the region is densely

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populated, and the animal productivity is low, it is not possible for local people to support their families by relying solely on traditional animal husbandry. As far as the local people are concerned, traditional crop cultivation is superior to animal husbandry and this is the main reason why locals have not planted grasses to raise livestock (especially ruminants).

Second, because of serious soil erosion and a lack of vegetation, a considerable proportion of the red soils land cannot be used. Grass-planting technology for such hilly land was not available until the late 1980s. Although the total areas of the original pastures are not small, there are few large aggregated areas that can be used for livestock farming. In Guangdong Province, there are only 400,000 ha of pastures in areas of 300 ha or larger, comprising only 10% of the total pasture (4 million ha) in the province (Xie et al. 1993). Of the total 6.37 million ha of meadow in Hunan Province, 4.01 million ha is located in 'large' areas as classified in Table 1. The fragmentation of pasture areas into many smallholdings suggests that the area is not ideal for the development of large-scale animal husbandry.

Table 1. Classes and number of 'large' pasture areas in Hunan Province.

Classes of pasture areas (ha)	No. of pasture areas	Total area (ha)	Proportion of total area (%)
'Small' areas			
<67	32,226	—	—
'Large' areas			
68–667	42,465	3,150,000	78.5
667–3333	558	628,667	15.7
3333–6667	31	140,000	3.5
>6667	7	94,667	2.4
Total 'large' areas	43,061	4,013,334	100.0

Third, government policy over the past three decades has restricted the prices of farm produce and the salaries of urban workers, thus restricting the demand for meat. Again, this has resulted in there being little motivation to plant grass to raise livestock in these areas.

FAVOURABLE FACTORS EMERGING WITH ECONOMIC REFORM

Since China adopted a policy of opening markets to the outside world, research into improving the productivity of red soils hilly land has accelerated. Experiments investigating the establishment of pastures have been successful. This and the autonomy given to farmers in allocating agricultural resources are internal factors that are encouraging the development of livestock farming. Also, the past 20 years have seen a rapid increase in people's incomes, thus providing a positive external factor which has encouraged such development.

In the past few years, some barren hills have been auctioned to farmers, and the trend has spread to the red soils areas. The new land-use system commenced in 1992 in Shanxi Province and soon became popular in most parts of northern China, because many barren hills in the north are linked and easy to develop. In red soils areas, the practice of auctioning barren hills has been rapidly adopted in Yunnan, Guizhou and Anhui Provinces. Jiangxi and Hunan Provinces adopted the system in 1996.

The fixed lease contracts for barren land are for periods of up to 100 years and the land-use contract can be inherited by subsequent generations. This is leading to a rapid increase in interest for livestock production.

Farmers are now responsible for all profits and losses associated with raising animals and this has greatly promoted initiatives by farmers. However, pastures, which are the basic means of production in the development of livestock husbandry, are still public property. Excessive grazing has caused desertification and deterioration of pastures. Thus, the government has adopted a 'user-pays' system for pastures, initially in northern pastoral areas. The fee charged is 1–3% of the actual value of grass, which is about US$0.19/ha. This system has been applied in grassy hilly areas in the south in recent years, and thus excessive grazing has been controlled. For example, 1667 ha of aerially sown pastures have been contracted by 63 rural households on a user-pays basis to raise goats, sheep and cows in Qujing, Yunnan Province. About 1333 ha of aerial-sown pastures have been contracted by local farmers in Changyang, Hubei Province. In Chengbu County, Hunan Province, the Nanshan pasture region has kept increasing its output over 10 years since a contract system was applied.

Achievements have been made in the development of large pastures, household pastures and additional livestock raising. As for large pastures, the government departments concerned have set up managerial bodies and service systems. The pastures are contracted by rural households, which pay a grass-use fee. For example, in Zhuopu township, Weining Yi, Hui and Miao autonomous county in Wumeng, where the first aerially sown pasture achieved success, the annual net income per capita of the rural households that contract the pasture is several thousand yuan, eight times as much as the average annual income of local farmers. In this township, there are state-owned and household-contracted pastures. Each household contracts an

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average of 33.3 ha pasture and raises 200 sheep. It is reported that in Guizhou Province there are more than 10,000 household-contracted pastures, which have resulted in animal husbandry that is more economical of grain use. These pastures are developed by the government and managed by farmers who have appropriate educational backgrounds and economic resources. According to a survey of 695 household-contracted pastures in Ceheng County, each pasture feeds an average of 40 commercial cows. Thirteen counties have become commercial cow and sheep raising bases, and six counties have become key grass planting and animal raising bases.

Some technology has been developed, thanks to many years of experimentation. Although it is only an initial success, it has laid the foundation for future improvement and popularisation. In recent years, the technology has been used to develop the grassy hilly land in the subtropical areas in Yunnan, Guizhou, Hunan, Hubei and Guangxi Provinces. What is more important is that the project relating to wool and mutton production in the grassy hilly land in the south was listed in the 'General Plan for Regional Development at the End of the Century'. The project is of two parts, including 41 counties in eastern Sichuan, western Hubei and western Hunan Provinces, and 28 counties on the Yunnan–Guizhou Plateau and southeastern Sichuan Province, where 10 million ha of pastures will be sown, 3.05 million sheep raised, and 50,000 to 60,000 t of high-quality wool and 120,000 t of mutton produced. Thus, there is a continuing need for improvements in pasture technology to support such ventures.

FUTURE NEEDS

In spite of excellent development work over the past 10 years, there is still much more effort needed to develop the hilly red soils of the south.

First, the problem of the initial investment by farmers in livestock husbandry needs to be solved. Thus far, over 99% of the pastures in hilly areas have very low productivity (Xie et al. 1993) and must be improved before livestock production can be successful. For example, legume growth is generally poor. Although effective methods of improving the pasture land have been found, large investments will be needed. For example, approximately 0.13 ha of sown pasture is needed to raise one sheep. Pasture sowing can cost as much as US$657/ha (Qiu 1992). If the more than 100 million ha low-quality pastures are to be upgraded to high quality pastures, nearly US$5.0 billion investment will be needed. The project list in the 'General Plan for Regional Development at the End of the Century' covers 667,000 ha. Even so, US$43.75 million will be needed. Moreover, farmers need money to purchase breeding animals and young stock which they currently cannot afford. All the successful projects have received financial support from some Chinese and international organisations. For example, the World Bank provided aid for the first-phase projects in Fujian and Jiangxi Provinces.

A second issue that needs to be resolved is the method of getting technology adopted by farmers. In China, the research and agricultural extension systems are separate. The successes so far achieved are only small-scale, and large-scale experiments have not yet been conducted, let alone popularised. There must be technicians and funding for the work and hence government support will be needed.

The third need is for markets to be developed. It is also important for farmers to have access to market information, sales channels, transportation and knowledge about the dairy and meat processing industries. Until these problems are solved, the farmers' wait-and-see attitude is quite rational.

Also, financial and insurance companies need to support animal husbandry, since the application of technology requires large investments. It is hard for farmers, many of whom are poor, to raise money to improve pastures and to buy breeding animals and young stock.

Finally, research institutes, technology-adoption organisations and financial companies need to cooperate and provide comprehensive services to farmers to develop profitable livestock grazing enterprises in the red soils areas.

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SUSTAINABLE GRASSLAND PRODUCTION SYSTEMS AND THEIR EXTENSION IN SOUTHERN CHINA: AN EXAMPLE FROM GUIZHOU PROVINCE

Jiang Wenlan

Gansu Grassland Ecological Research Institute, Lanzhou, China

Abstract

Grassland occupies 67.2 million km^2 in southern China, making up 17% of China's total grassland area. Due to favourable climatic conditions the potential productivity of the southern grassland zone is estimated to be 34% of the country's total grassland productivity. Since the early 1980s the southern grassland area has undergone marked development so that it now supports almost half of the total grazing animal population in China. Thus Sichuan, Yunnan and Hunan, major crop-producing provinces, are now larger producers of cattle and sheep than the traditional livestock-producing provinces of Inner Mongolia, Xingjiang, Qinghai and Gansu.

The speed of this development has created a number of problems. The southern grassland ecosystem is fragile and prone to degradation, and insufficient attention has been given to developing a sustainable system of production. There have been large inputs of capital and labour but the development of suitable management systems has been neglected. Although research programs have addressed key issues for achieving a sustainable pasture-livestock system the lack of extension services has hindered the adoption of research findings.

Since 1983 the Gansu Grassland Ecological Research Institute has conducted a long-term research and extension program in the Yunnan–Guizhou Plateau, with the aims of effectively utilising limited capital, achieving maximum production within the limits of protecting the environment and promptly extending research results to farmers. These improved production systems have been developed for sheep, dairy and beef cattle. More than 2000 farm households have benefited directly from the project, with their incomes significantly increased. Even though sown pastures have a strong tendency to degrade, increased economic returns have been shown to be compatible with land improvement and protection through the adoption of sound management practices. This is particularly important for the poverty stricken mountainous regions of Guizhou, where cropland is scarce but potentially productive grasslands abound. Traditionally farmland and forestry have been managed as separate entities. In the mountainous area of southern China, where topography, climate and soils change rapidly over short distances, rural enterprises must be integrated to achieve improved sustainable productivity.

INTRODUCTION

TWO of China's major grassland regions occur in southern China: regions VI and VII (Table 1). The total area of the two regions is about 67.2 m ha. This is 17% of the total grassland area of China, but the potential productivity is about 34% of Chinese grassland. Thus the south China grassland area is an important sector of Chinese grassland.

The Southern Grassland area contains the grasslands distributed among mountains and hills in 15 provinces to the south of the Qinling Mountain Range and the Huaihe River. Of its total area of 67.2 m ha, about 40 million ha can be utilised for livestock production. On the Yunnan-Guizhou Plateau, the area of utilisable grassland is 9.5 times as large as that of local farmlands (Ren 1996), while in the east and south, where population density is high and intensive agriculture prevails, the area of utilisable grassland still makes up between 20% and 40% of the local agricultural land resources (Ren and Shen 1993).

The climate of the Southern Grassland area is characterised by monsoons from the Pacific and Indian Oceans, with an annual rainfall of more than 800 mm (as high as 2000 mm in some regions). In most of the regions where grassland occurs the average temperature in January is above 0°C and the annual accumulated temperature (>10°C) is more than 5000°C (Zhang 1984). Thus, compared with most regions of the world located at the same latitude, the Southern Grassland enjoys climatic advantages for growing a wide range of pasture species and raising herbivorous animals.

Table 1. The grassland resources of China.

Ecological-economic regions	Total area ($\times 10^4$ km^2)	Natural grassland area (M ha)	Natural grassland as percentage of total (%)	Potential productivity (10^6 t DM/ year)	Percentage of potential productivity (%)
I. Ning-Meng steppe	80.2	57.2	14.5	255.6	10.8
II. North-west arid semi-arid	222.3	88.6	22.5	214.3	9.0
III. Tibetan plateau tundra steppe	221.0	135.6	34.5	810.1	34.1
IV. North-east forest-steppe	96.6	21.5	5.5	122.4	5.2
V. Loess plateau — north China shrub-steppe	87.5	23.0	5.9	164.7	6.9
VI. South-west karst shrub land	84.8	31.6	8.1	371.4	15.6
VII. South-east evergreen broad leaf forest — hill land	159.2	35.6	9.1	436.3	18.4
Total	951.6	393.1	100	2374.8	100

INCREASE OF ANIMAL HUSBANDRY IN THE SOUTHERN GRASSLAND REGION

The Southern Grassland region has undergone a booming development since the early 1980s facilitated by a series of development projects and the establishment of a group of pasture seed producing bases, pasture seed testing centres and pasture-livestock experimental stations. The projects implemented include six international joint research projects and more than 30 integrated development projects for crop, forest, livestock and fish-farming industries with grassland as the project focus. Aerial sowing has also been adopted in regions where the conditions are suitable for pasture establishment. Since the effort has been focused on the establishment of sown pastures and their intensive management, the area of sown pastures in the south and the south-west of China has been increasing at a rate of 66.7 thousand ha per year, over the past 10 years. By the end of 1987 the total area of sown pastures had reached 575,300 ha, accounting for 1.1% of the area of natural grasslands (Hung Huang 1991). This boom in grassland development, along with the by-products of local crop production (crop residues such as rice and wheat straw), has led to a rapid increase in the number of livestock raised in the southern provinces of China. At the end of 1993 the region supported 58.1 million cattle and 40.7 million sheep (and goats), so that the Southern Grassland region supports almost half of the total grazing livestock population in China. The three provinces of Sichuan, Yunnan and Hunan, where crop production is the dominant form of agriculture, have become larger producers of cattle and sheep than the traditional livestock producing provinces, such as Inner Mongolia, Xingjiang, Qinghai and Gansu. However, in terms of long-term sustainable development, the rapid growth of the local livestock sector has brought about some serious problems that must be addressed in the near future.

PROBLEMS FACED BY ANIMAL HUSBANDRY IN THE SOUTHERN GRASSLAND REGION

The south and south-west in particular are classified as the major region of karst landforms and red soil in China, with a total area of more than 500,000 km^2. The topography is complex with steep slopes; the red soils are shallow and poor in nutrients; the vegetation succession develops slowly and is rapidly degraded; soil erosion due to runoff is serious within many local ecosystems. The strategy for the exploitation of the local grassland resources and the establishment of a stable pasture-livestock production system must be based on the concept of 'ecological agriculture'. That is, the achievement of integrated ecological-social-economic benefits through promoting agricultural productivity while protecting the environment and maintaining the sustainability of the resources. This important issue, however, has not yet been seriously addressed and has only received attention recently.

In comparison to the extensive management style prevailing in regions of the Northern Grassland region, the model of management adopted for the Southern Grassland region can be described as a primitive but intensive one. The major shortcomings of such a primitive system of management are that, while there have been intensive inputs of capital and labour, the need for inputs of technology, information and management knowledge has been neglected. Thus, the established pasture-livestock system is the result of intensive capital inputs combined with extensive management, and there would be no doubt

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that such a system can neither be sustainable nor be capable of achieving the expected goals of economic development. This problem has affected the development strategy in the whole of the Southern Grassland region.

Another problem that has arisen during the recent boom of animal husbandry in the Southern Grassland region is the lack of a system of technical extension services. A series of research programs has been conducted in various ecological zones of the Southern Grassland to address key technical issues related to the establishment of a sustainable pasture-livestock system and thereby some important results have been obtained and applied through demonstration. However, the lack of planning and provision for extension services has, on the whole, hindered research results from being applied to actual productivity. For example, the technical problems of how to decrease costs, simplify key techniques, increase vegetation stability for establishing sown pastures and maintain the established plant community have been solved through the above mentioned research programs, but in practice, due to lack of extension, these problems are still serious obstacles to the Southern Grassland region achieving a higher level of development.

GUIZHOU INTEGRATED DEVELOPMENT PROJECT FOR SUSTAINABLE GRASSLAND PRODUCTION SYSTEMS

Guizhou Province is located on the Yunnan-Guizhou Plateau in the south-west of China. The land above 1500 m is characterised by open rolling flats with rich pasture resources. The total area of native grassland is about 19 m ha, of which 15 m ha are utilisable. The local climatic conditions are also favourable for pasture-livestock production with an annual rainfall above 1000 mm and a monthly average temperature above 10°C.

Since 1983 the Gansu Grassland Ecological Research Institute (GGERI) has been assigned by the Ministry of Agriculture of China to conduct a long-term research and extension program in the central part of the Yunnan-Guizhou Plateau. The program was given high priority by the Ministry through successive five-year plans (sixth to the ninth from 1981 to 2000 inclusive) for nationwide research and development activities. The program was combined with an internationally sponsored poverty alleviation project and a UNDP grassland development project after 1989 and hence it has developed into its current form of an integrated research and development project. Correspondingly, the project sites for research, demonstration and extension have been expanded from the north-west of Guizhou Province (Weining County) into the central and southern parts of the province (Qingzhen County and Dushan County) and Qujing County in the east of neighbouring Yunnan Province. The integrated research and development project has concentrated on three aspects: (a) research on techniques of pasture establishment and management, (b) system studies for establishing improved pasture-livestock production and (c) the establishment of an extension system for facilitating the transfer of research results from experimental stations to farms.

The following results have been obtained from research aimed at finding techniques suitable for pasture establishment and management under the local conditions:

1. Fourteen pasture species (listed below), have been selected through tests under grazing conditions, which have the merits of high yield, good nutritional quality, strong ability to compete with weeds, relatively high growth rate in early spring and late autumn and the potential to be used for more than 10 years (Jiang et al. 1996b).

Botanical Name	Common Name
Festuca arundinacea Schreb	Tall fescue
Lolium perenne L.	Perennial ryegrass
Poa pratensis L.	Bluegrass
Dactylis glomerata L.	Cocksfoot
Festuca rubra	Red fescue
Eragrostis nigra	Lovegrass
Bromus inermis Leyss	Smooth bromegrass
Phalaris arundinacea	Canary grass
Medicago sativa	Alfalfa
Medicago medium Pers.	Rambler
Coronilla varia L.	Crownvetch
Trifolium pratense L.	Red clover
Trifolium hybridum L.	Alsike clover
Trifolium repens L.	White clover

2. A low-cost technique for improving natural grassland or establishing sown pastures through camping sheep flocks at certain locations (the technique of ‘sheep night penning’) was developed for the specific conditions found in mountainous karst landforms. Without tillage, the technique can help in clearing native vegetation, improving soil fertility, increasing pasture yield and decreasing run-off and soil erosion. Compared with the traditional method, pasture establishment by tillage, the forage yield from the sown pastures established through the above technique can be increased by 32% while the cost decreased by 80% (Jiang et al. 1996c).

3. Instead of using pesticides, a technique for controlling grubs in sown pastures through camping sheep flocks and adjusting grazing intensity was tested and recommended for extension. It is simple to apply and it can control up to 84–93% of the pest population at a low cost of only 108 Yuan per ha. Also, the technique improves soil fertility, stimulates re-growth of pasture and increases yield (Yuan 1995; Yuan and Jiang 1995 and 1996).
4. Investigations into (a) the processes of and conditions favouring the deterioration of local sown pastures and (b) the type and numbers of invading plants and the conditions leading to their establishment has led to an effective means of preventing sown pastures from degradation, and for adjusting legume-grass ratios and maintaining the stability of the established plant community (Wang and Jiang 1995; Wang et al. 1995a and b).

The objective of the improved pasture-livestock production systems was effectively to utilize limited capital, promptly extend research results to farms, exploit maximum production potential of local natural resources while protecting the ecosystem from damage. The extension system developed to achieve this objective is summarized in Figure 1.

A two-stage analysis was adopted to improve (a) the allocations of grassland resources on the basis of ecological zones and (b) intensified inflows of information, technology, managerial skills and labour under the constraint of a reasonable level of capital input. Both theoretical analyses and actual experiments on farms were employed in the design for sheep, dairy and beef production systems. Special attention was given to the vertical and horizontal links within the individual systems. It was shown that the three improved production systems for sheep, dairy cattle and beef cattle increased production per ha of pasture by 125, 118 and 264 APU (Animal Product Unit: 1APU = 1 kg liveweight equivalent of grazing beef cattle) respectively, which were valued at 695, 3638 and 1597 Yuan at current prices. The pasture cover of the pastures under utilization was kept within the ranges of 1000–2000, 1000–2200 and

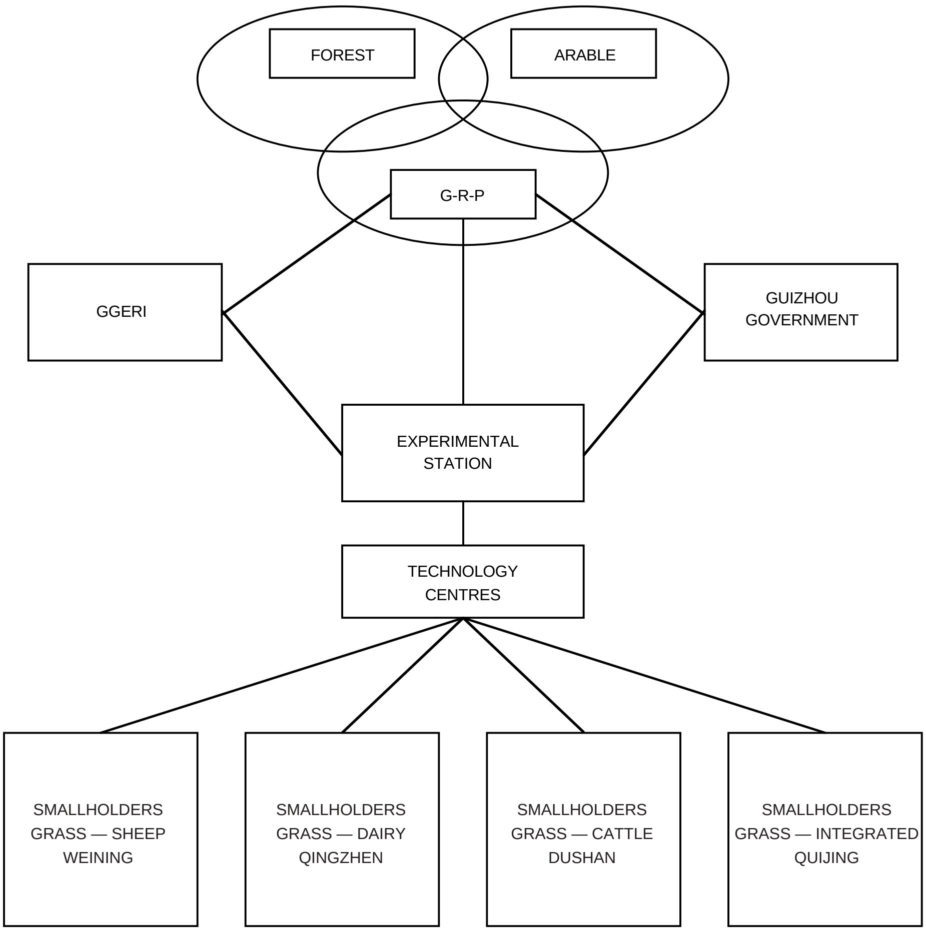

Figure 1. The extension system for sustainable grassland production in Guizhou Province (GRP = Grasslands–Resources–Pastures).

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1500–3000 kg of dry matter per ha, so that the optimized systems did not cause deterioration of the pastures while they achieved the above mentioned economic returns (Jiang, 1995; Jiang and Ren 1996; Jiang et al. 1996a). This means that the optimized systems can lead to a dynamic equilibrium between pastures and livestock and hence to the sustainability of the pasture-livestock production system.

Since 1985 the GGERI has made great efforts in Guizhou Province to establish a multi-ownership economic-technical complex, which combines activities of research, demonstration and extension into a network through which technical inputs flow from experimental stations to demonstration farms and further to individual farm households. The demonstration sites established have had a total area of more than 2000 ha, with a stocking rate of 7.5 head of sheep per ha, producing 2.5–3.3 kg of clean wool per head. The network has covered the counties of Weining, Qingzhen and Dushan in Guizhou Province and Quijing County in Yunnan Province (Figure 1). More than 2000 farm households have benefited directly from the project with their income increased to levels 6–10 times of those before the project began.

DISCUSSION AND CONCLUSIONS

The results from the Guizhou Integrated Grassland Development Project indicate that the exploitation of the production potential of the Southern Grassland region can bring about significant economic and ecological benefits when relevant research results are transferred to and adopted within local production systems. For example, if the technique of ‘sheep night penning’ were adopted at a rate of only 2% a year in the karst mountainous counties, where more than 2 million ha of native grasslands occurs, 0.4 million ha of sown pasture, which is 7.3 times as large as the existing area, would be established within 10 years, and would bring about a net economic benefit of 820 Yuan. At the same time, adoption of the technique would lead to run-off being decreased by 55% on the established pastures and soil erosion by 99% in comparison to areas where tillage is used to establish pasture. Also the botanical composition of the native grassland can be improved by the technique: the soil organic matter content can be increased by 2.6–4.0%, available nitrogen by 31–71 ppm, available phosphorus by 4.3–13.8 ppm and available potassium by 86–422 ppm. The native shrub species of low feed value can be replaced by quality forages such as ryegrass and white clover, whose proportion can reach as high as 95–100% in the improved pastures, and whose dry matter can reach over 11,000 kg per ha (Jiang et al. 1996c).

The research results also indicate that even though the established sown pastures have a strong tendency to degrade towards a sub-climax of the native vegetation (Jiang et al. 1996), a high degree of sustainability of the established pasture-livestock production system and a significant economic return can still be achieved by adopting appropriate technology and optimized management strategies.

The above conclusions are important to the poverty-stricken mountainous regions of Guizhou Province, where farmlands for food grain production are relatively scarce but rich grassland resources exist. Therefore, the establishment of sustainable pasture-livestock production systems can provide the local farm household with an important source of income and hence a way of alleviating poverty.

Over the long-term, the further development of the grassland resources needs to embrace a complete production system which includes not only existing pasture and livestock production, but also up-stream and down-stream industries, such as tourism and processing enterprises (Ren and Shen 1993). There exist certain ecological-economic zones in the south of China, where conditions are suitable for establishing such a four-component production system and, through this, achieving a much higher overall productivity and a more efficient use of the grassland resources.

Another consideration in the rational use of natural resources is to integrate different production systems (Ren and Shen 1993). In China, farmlands and forests have been traditionally separated into different management regimes isolated from each other, and thus exchanges of energy and materials between the systems are hindered. In the mountainous regions of south China, topography, climatic conditions and land types usually vary significantly within a short distance, forming many ecological-economic sub-systems. Therefore, the concept of linking these sub-systems may be easier to achieve than in the north of China and it would greatly increase overall productivity and economic returns. This direction should be regarded as an important aspect of modernization of agriculture in China. It has been estimated that fully utilizing the southern grassland could increase the stock capacity by 0.17 billion sheep units, thereby increasing the current capacity of 0.39 billion to 0.56 billion sheep units. This would amount to about half the herbivorous animals in China (Li 1996). Thus the development of a sustainable system of grassland animal production system would form an important component of modernizing agriculture in southern China. This can only be achieved through an effective extension system.

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NEED FOR NEW EXTENSION APPROACHES TO SOIL AND WATER CONSERVATION

Wang Wei Min[1], Malcolm Douglas[2], Garry Cummins[2] and KC Lai[2]

[1] National Consultant (Extension and Training), ADB PRC Capacity Building for Soil and Water Conservation, Technical Assistance No. 2407. Also Vice-Director Fujian Soil and Water Conservation Experimental Stations
[2] International Consultants, ADB PRC Capacity Building for Soil and Water Conservation, Technical Assistance No. 2407, Lincoln International, Christchurch, New Zealand

Abstract

In Fujian Province, extension services related to soil and water conservation, agriculture, livestock and forestry are organised along single commodity or separate subject matter lines in response to national and provincial planned development programmes. This fragmented and 'top-down' planning approach to development and extension to soil and water conservation has often meant inflexible projects and programmes with a heavy emphasis on engineering, reforestation and orchard development. Farmers have typically been offered one conservation package rather than a choice of alternative conservation-effective practices from which to choose those that match their particular needs and circumstances. Often soil and water conservation has been promoted as a separate land management exercise rather than an integral part of a productive farming system.

The Asian Development Bank funded Technical Assistance *Capacity Building for Soil and Water Conservation* has introduced a new approach to soil and water conservation extension in Fujian Province based on the concept of land husbandry. Approaches to sustainable land use, which have emerged from lessons learnt from past failures and successes elsewhere in the world, has two key elements, namely peoples' participation and land husbandry. The land husbandry approach is based on two key principles: it is possible to combat land degradation through the adoption of management practices which yield production and financial benefits while being conservation-effective; and, rural people have a greater ability than previously recognised by outside technicians and experts to analyse, plan, implement and evaluate their own research and development activities.

The introduction of land husbandry concepts to soil and water conservation requires the introduction of inter-disciplinary and multi-sectoral approaches and participatory processes at the community level to address soil and water conservation issues. The introduction of such an approach to the extension, technical and research services at the Fujian provincial, prefecture, county and township level Bureaux and organisations with the responsibility for the promotion of the care and management of the land for productive purposes has required the introduction of more participatory approaches to training and awareness building at all levels of government in the province as a precursor to change to soil and water conservation planning and extension.

THE ADB FUJIAN SOIL CONSERVATION AND RURAL DEVELOPMENT PROJECT

THE Peoples Republic of China (PRC) has taken a loan from the Asian Development Bank (ADB) to promote sustainable growth in the rural economy of Fujian with the aim of benefiting the poorer members of the rural community. The implementation of the Fujian Soil Conservation and Rural Development Project (FSCRDP) is supported by two ADB technical assistance grants: (i) TA No. 2407 — PRC *Capacity Building for Soil and Water Conservation* to develop the institutional capability of the Fujian Soil and Water Conservation Centre (FSWCC) and, through association, the capacity and skills of associated agencies, and (ii) TA No. 2408 — PRC *Land Use and Land Tenure Policy in Fujian Province* to assist the Fujian Provincial Government strengthen its land use and land tenure policies to achieve an optimal mix of incentives and disincentives for long-term sustainable land use throughout the province.

The FSCRDP is funding the establishment of the Fujian Soil Water Conservation Centre that will collect and disseminate information on alternative techniques of soil and water conservation, serve as a provincial soil and water conservation training centre, initiate and coordinate the monitoring of soil and water conservation activities within the province, and initiate and co-ordinate inter-agency collaborative soil and water conservation research. A major focus of the FSWCC will be to introduce new approaches to soil and water conservation research, extension and training, which are more appropriate to rapidly changing socio-economic circumstances within the province.

CHANGING SOCIO-ECONOMIC CIRCUMSTANCES WITHIN FUJIAN

Despite the major investment in soil conservation programmes, soil degradation still poses a threat to the livelihoods of many rural households engaged in small-scale farming in Fujian Province (Yang et al. 1997). This is particularly so in the upland areas of the Province. With the continued fall in the per capita availability of flat land suited to agriculture, the development of the uplands is becoming crucial to the Province's growth. While the adoption of the household responsibility system has led to substantial increases in rural wealth in many parts of the province, it is clear that the wealth poverty gradients, as in other parts of China (Hill 1994), have become greater in Fujian Province.

Initial pilot studies of TA 2407 indicate there is an increasing socio-economic differentiation occurring between and within villages. For example, in the same village in one of the pilot watersheds, there are reportedly more than ten specialist fruit growers, having 500 trees or more; ten commercial producers of poultry or pigs (100 head or more); and three households with large scale fish ponds. However, the other 700 households in the village typically have 30–40 orchard trees, 3-4 pigs, a few chickens and 0.3 mu/capita of paddy land. The variation in the resources and farming systems between adjacent villages is also increasing as individual farm family households pursue different opportunities according to their family's priorities and resources. In two adjacent villages in the same pilot sub-watershed, more than 50% of family farm households in one village owned cattle while in the other village, with visually similar land resources, less than 5% of farm family households owned cattle. A multitude of farming systems and land users is emerging within even small sub-watersheds, with differing impacts on land productivity and soil erosion. The current extension practice of applying "standard" prescriptions in tackling land productivity and degradation at the farmers' level is no longer applicable to the changing circumstances of the farm family households.

CURRENT EXTENSION SYSTEMS AND APPROACHES

The responsibility for extension is shared by a number of Bureaux but is the primary responsibility of the Fujian Agricultural Bureau (FAB) through its Agro-Technology Station network. There is little integration of activities and extension messages between the different extension subject matter specialists of the various Bureaux.

The organisation of extension for each of the Bureaux is similar. The main link between the farm family and the extension services of the various Bureaux is the Farm Technician (FT), who is appointed by the Village Committee, the principal institution responsible for village administration. The FT for each Bureaux is in most cases not the same person — in each village several FTs provide 'training' to farmers, usually through night meetings. The FT receives a small monthly allowance from the Township Extension Office. The FT usually has been educated to at least middle school level and often undergoes further training by linked radio and correspondence course, in addition to short courses and workshops in the Township Agro-Technical Extension Station (TATES) organised by the township agricultural extension officer twice per month, a system that has some of the characteristics of a traditional Training and Visit system, which is very 'top-down' in approach and methodology. The objectives of the extension service are: to impart topical information on techniques of local importance; to disseminate good planting material; and to demonstrate new techniques and ideas.

The FTs are supposed to make themselves available to give advice to village farmers on demand. However, it is reported that farmers seeking advice are often obliged to pay for it at the rate of RMB 20/day or enter into a crop sharing arrangement with the FT, who often acts (as in the case of mushrooms) as the local purchaser and marketing agent and derives most of the benefit. The FTs also provide skilled labour to the family farmers and are hired by farmers to undertake such tasks as tree pruning and alignment of terraces.

The orchard and bamboo plantation developments planned to be implemented through the FSCRDP are, in many cases, controlled by the Village and Township level Cooperatives through a collective process, with the family farmers having to make a considerable capital investment to partake in the development opportunities presented by the Project. As a result the poorer farm families are precluded from benefiting from the Project's interventions.

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Regarding extension in soil and water conservation, the Fujian Soil and Water Conservation Office (FSWCO) has the responsibility for supervising erosion control programmes and the work of the monitoring and enforcement staff within the area of the prefecture. Each prefecture has its own Soil Water Conservation Committee (SWCC) for coordinating activities of its Soil and Water Conversation Office (SWCO) with other government departments. This structure is repeated at the county level with county staff having a more direct responsibility for the design and implementation of field projects and for the enforcement and monitoring of soil and water conservation law. The county level SWCOs generally have between 3–5 technical staff with, in some cases, shared responsibilities in others tasks for soil conservation projects and law enforcement being held by different staff members.

Unlike the Agricultural, Livestock, Cash Crops and Forestry Bureaux, the county level SWCOs do not (with a few notable exceptions) have staff at the Township or Village level nor do they have a direct extension delivery capability and function. The FSWCO either implements its programmes and projects directly through its county level staff or through the FABs TATES and uses township and village level supervisors and investigators for monitoring and enforcement activities. For project implementation, the FSWCO relies on its own county staff for detailed planning, including identification of farm participants. Some of the county staff are based at the township level in some instances. The FSWCO has its own subject matter specialists in most areas, including orchard production and development, a role that traditionally belongs to the FAB. It is not clear how extension messages and extension activities are coordinated between FSWCO and FAB staff but there does appear to be considerable overlap in function and effort.

CURRENT APPROACHES TO SOIL AND WATER CONSERVATION

The approach to soil conservation as practised by the Soil and Water Conservation Department within Fujian Province follows what can be described as a conventional ‘top-down’ physical planning approach. Soil conservation is largely perceived as erosion control with attention very much focused on rates of soil loss (usually quoted as tonnes per km^2). The ideal situation is perceived as reducing soil losses to below 200 tonnes per km^2 (2 t/ha).

Because of the emphasis on soil loss the approach to soil and water conservation is largely geared to preventing erosion through controlling runoff by the use of such physical conservation measures as earth banks, bench terraces, check dams, cut-off drains etc. Whereas there is more reference in recent projects to the use of vegetative techniques for soil and water conservation, in practice this usually refers to the planting of fruit trees on hill slopes and the planting of forest trees and grasses for protection purposes on the upper slopes and hill tops.

FUJIAN EXPERIENCES WITH LARGE SCALE SOIL AND WATER CONSERVATION PROJECTS

Three major investment projects, which claim objectives in the development of underutilised and/or degraded soils in Fujian, are the World Bank funded Red Soils I and II Area Development Projects and the Asian Development Bank funded Fujian Soil Conservation and Rural Development Project. These three projects have included waste lands reclamation strategies, which have relied on a combination of engineering measures (backward sloping terraces) and soil amelioration measures (trenches to be dug along the bench and filled with animal manure, green manure and straw). Fruit trees are then planted on the terraces. The development costs associated with terrace construction, initial application of manure and fruit tree planting would be met by the project. Ultimately the farmers would be expected to repay these costs in order that the Government be able to repay the loans to the World Bank and the Asian Development Bank.

Observations at the field level, if the areas observed are typical of implementation in these three projects, indicate that these projects are a long way from being methods of farming and land use which are physically, economically and socially sustainable. Most of the physical development was done by contractors under supervision of project staff with no involvement of the farming community except in some cases to provide labour. Once the work was completed, an area of the prepared terraces and orchards was allocated to an individual farmer or a group of village farmers on the basis of a contract between the farmer and the township authorities. While having no say in the orchard development, the farmers are expected to pay back the development costs once the fruit trees are in production.

Project funded activities contrast to those in non-project areas. In non-project areas, farmers were observed to construct “slope separated terraces”. This involved the construction of small platform terraces on which were planted 1–2 fruit tree seedlings. These platforms were slowly expanded year by year, as the trees grew, until finally adjacent platforms would be linked to form a continuous bench terrace. This practice appears to be in response to a shortage of household labour for full terrace construction in the establishment year of the orchard.

In some cases observed, on both WBRS2P and ADB SCRDP, the farmers were discouraged from constructing their own terraces due to apparent concern about the quality of the final terraces and such an approach was contrary to the campaign style of soil and water conservation projects. This is despite the use of slope separated terraces being lower in cost to construct and as conservation-effective as full bench terraces (if constructed properly) with no penalty to production. The gradual land development approach of slope separated terraces is a lower cost approach than the campaign style land development projects and would require less financial support from the Projects leading to lower farmer debt (Douglas 1995).

The implementation of the ADB SCRDP is also being implemented through the county offices of the FSWCO with little input from other technical agencies, although FSWCO does not have extensive in-house technical expertise on forage crop development, crops and livestock .

NEED FOR CO-ORDINATION OF EXTENSION ACTIVITIES

Extension related to soil and water conservation, agriculture, forestry and livestock is organised along single commodity or separate subject matter lines in response to national and provincial planned development programmes. The ADB FSCRDP is an example of this fragmented and 'top-down' planning approach to development and extension. While 'comprehensive plans' are prepared by the Comprehensive Development Office at the Township level and 'integrated' plans are prepared at the county level, most plans are prepared independently by each Bureau with little evidence of consultation between the different Bureaux or with farmers.

Thus, for instance, orchard development, forest tree planting, animal husbandry, paddy rice, and dryland food crop production are dealt with by either separate agencies or by different subject matter specialists in the same agency, at the township and village level. At the village level, 'extension services' are delivered by several different FTs whose main task is to implement programmes planned at higher levels of government. There appears to be little coordination or integration of extension approaches or extension messages to the farm families, although most farm families operate in multi-enterprise and complex farming systems where activities and production systems of single enterprises impact on other enterprises within the farming system. Issues associated within soil and water conservation and strategies to improve the husbandry of land need to consider the whole farming system and the interrelationship between enterprises. The low levels of organic matter in the eroded red soils has to be addressed through an integrated approach, for example by sowing green manure and fodder crops, within the orchards, and making better use of limited animal manures, which are also in demand for paddy land fertilisation.

Funding of cooperative extension programmes, focused on the development of the whole farming system using participatory approaches with farmers, would encourage the pooling of the experience and expertise residing in the various Bureaux, research institutions and the farm family communities. There are considerable benefits to be realised from inter-agency collaboration.

NEED FOR NEW APPROACHES TO SOIL AND WATER CONSERVATION

Changing socio-economic circumstances of the farm family households in Fujian Province means that new approaches are needed for soil and water conservation project planning and extension. Fundamental to the new approaches is the need to understand the circumstances and farming systems of individual farm families. Such an understanding will only be achieved by technicians working with farmers to understand local problems and, jointly, finding solutions to these problems. The 'top-down' technology approach has even less application now to addressing land degradation and land productivity decline than it did during the times when Fujian's economy was centrally planned and controlled.

Underlying much of the soil and water conservation 'extension' programmes undertaken within Fujian, is still the assumption that, declining soil fertility and reduced crop yields, can be almost exclusively attributed to the effect of soil erosion. There is limited awareness of the major changes in thinking on approaches to soil and water conservation that has taken place within international soil conservation circles in recent years.

What is sometimes described as 'new thinking' suggests the focus for soil conservation should be on combating soil productivity decline, meaning more than just preventing soil loss. Soil degradation, that is a decline in the productive capacity of the soil, is the result not just of soil erosion, but also changes in a soil's biological, chemical and physical properties.

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In this context soil conservation becomes synonymous with the maintenance and enhancement of the soil's productive potential requiring: a) control of erosion; b) maintenance of organic matter; c) maintenance of soil physical properties; d) maintenance of nutrients; and e) avoidance of toxicities. To date, soil and water conservation in Fujian has focused on the first two of these, that is control of erosion, largely by physical means, and the creation of a favourable growing environment for fruit trees on bench terraces by incorporating into the soil large quantities of organic manure.

A key element in the 'new thinking' is recognising that farm household socio-economic circumstances may be more critical than their bio-physical circumstances in determining the manner in which land is used (choice of enterprise, management practices followed, technologies adopted). Hence an understanding of household socio-economic circumstances is important in identifying the underlying causes of soil erosion. Whereas the visible effect may be determined by the bio-physical properties of the land, the cause will often be found in the socio-economic, cultural and political environment in which farmers have to operate.

Soil degradation does not have to be an inevitable consequence of using land for agricultural purposes. There are a growing number of projects, from many different parts of the world, that have found successful ways of working with dryland farmers to promote the profitable and sustainable use of soils for crop, livestock and tree production (see for instance Harrison 1987, Hudson and Cheatle 1993, Hiemstra et al. 1994). The message is clear: if the circumstances are favourable, it is possible to farm in both a productive and conservation-effective manner (Douglas 1994).

THE KEY ELEMENTS OF THE NEW APPROACH

Lessons learnt from the past failures and successes have been instrumental in promoting a major change in thinking with regard to sustainable agricultural development. There are two key elements underlying the new approach that have emerged from this change in thinking — namely, peoples' participation and land husbandry (Douglas 1994, Shaxson 1995).

Land husbandry can be described as: the care and management of the land for productive purposes — only through sound land husbandry can the land's productive potential be sustained and enhanced (ABLH 1994).

The land husbandry idea derives from the belief that farmers can manage and improve (husband) their land resources thereby enabling their use for productive purposes on a sustainable basis.

What has been termed the land husbandry approach is based on two key principles:

1. that it is possible to combat land degradation through the adoption of management practices which yield production benefits while being conservation-effective;

2. that rural people, educated or not, have a greater ability than previously assumed by outside experts to analyse, plan, implement and evaluate their own research and development activities.

TERMINOLOGY

New approaches need new terminology that reflect the new thinking. Elsewhere in China, soil and water conservation scientists have been considering the need for Chinese soil and water conservation terminology that reflects the more holistic "land husbandry" approach to soil and water conservation. At the recent International Symposium on Soil Erosion and Dryland Farming held in Xi'an (September 1997), the following term was proposed for "land husbandry":

Tu Di Ying Yu 水 土 保 持

This term was suggested as more appropriate for discussion of soil and water conservation issues than the traditional term for soil and water conservation:

Shui Tu Bao Chi 土 地 营 育

REQUIREMENTS FOR THE PROMOTION OF BETTER LAND HUSBANDRY

Working with farmers for better land husbandry will require major changes on the part of those used to the more conventional approaches to soil conservation. Three particularly important ones are as follows (after Hudson and Cheatle 1993):

1. It is accepted that the farmer is in the 'driver's seat' as far as any changes are concerned. Thus, he/she has to be treated as a person who can interact constructively and cooperatively with outside experts. He/she can no longer be treated as an object or as part of the problem, but as a person who can suggest and implement strategies that can help solve the problem. For this to occur, the soil conservation specialist has to become an expert in communication, and work to develop his/her credibility in the eyes of farmers.

2. The new approach, which is more ‘holistic’ in nature, requires thinking in a systems and interdisciplinary context and necessitates the collection and analysis of many different types of data (i.e. both bio-physical and socio-economic).
3. Because of the need for greater amounts and types of data, much of which are obtained directly from farmers, unfamiliar methods are required for collecting and analysing the data. In particular, in the interests of using research and extension resources in a time-efficient manner, much greater reliance needs to be placed on Rapid Rural Appraisal (RRA)/PRA survey methods. There is less emphasis on formal natural resource or socio-economic (questionnaire based) surveys, which in most cases are likely to be unnecessary.

CONCLUSION

Past failures have led to questioning of the approaches used, and assumptions made, when promoting soil and water conservation at the small-scale farm level. This calls for a shift in emphasis away from focusing solely on soil erosion, to a more holistic approach, in which soil degradation problems (not just erosion) are tackled within the constraints and opportunities of small-scale farming systems.

Awareness is the first step in the change process. The activities of the FSWCC will in the first instance focus on building an awareness of the need for new approaches at all levels of government within the province to gain commitment from policy makers to new approaches while developing an appreciation with technicians of the implications of the new approaches to the planning and implementation of “soil and water” conservation projects at the village community level.

Soil conservation, *per se*, is not a priority goal for small-scale, resource-poor dryland farmers. Although they do not deliberately set out to degrade their land resources, they are often obliged to pursue land use practices, irrespective of whether or not they can be sustained, that best meet their family’s immediate needs for food, fuel, shelter and cash, as well as to meet their social and cultural obligations to the community in which they live (Douglas 1989).

So improved crop, pasture and tree management (increasing ground cover), improved soil management (increasing soil organic matter, nutrient levels and topsoil erosion resistance) and improved rainwater management (reducing runoff and increasing infiltration) not only become more significant for the soil conservation specialist than soil loss management (mechanical control of runoff and sediment traps) but from the farmers’ point of view they have direct production benefits (higher yields) (Hudson 1988).

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LET THEM EAT GRASS: EXPERIENCES IN USING PARTICIPATORY APPROACHES TO DEVELOP FORAGE TECHNOLOGIES

Peter Horne[1]

[1] Forages for Smallholders Project, PO Box 6766, Vientiane, Laos

Abstract

Over the past 20 years there have been predictions of approaching severe shortages of feed for ruminant animals in Asia, especially in upland areas. These predictions are now coming true to the extent that livestock farmers across a large number of different upland farming systems are looking for managed alternatives to their declining traditional feed resources. Many forage technologies exist that have potential to improve livestock production in these farming systems. However, to date, few of these technologies have been adopted.

Recent trends in rural development methodologies highlight the potential of improving agricultural technology adaptation and adoption by developing the technologies in partnership with farmers. Farmer participatory research, the approach described in this paper, is currently being used for developing forage technologies in four countries of southeast Asia (Indonesia, Laos, the Philippines, and Vietnam). The main advantage of farmer participatory research is substantially increased potential for impact beyond target villages or districts. However, early experience has also shown that careful selection of the initial farmers is critical for subsequent successful adaptation and adoption of the technologies. Methods of village and farmer selection are discussed.

INTRODUCTION

MARIE ANTOINETTE, the wife of Louis XIV of France, when told that the peasants were starving, is said to have replied 'Let them eat cake'. By her reply she demonstrated how removed from the needs and realities of the people the French aristocracy had become … and for this they lost their heads in the revolution of 1789. Fortunately, for people interested in rural development, the consequences of ignoring the perceptions and needs of farmers are not as serious as they were for Marie Antoinette. However, if our goal is to improve the livelihoods of resource-poor farmers, the message is the same: ignore farmers' needs and perceptions at your peril.

The focus of this paper is on how to better understand and incorporate farmers' needs into the process of developing forage technologies. Forage research and development in Asia have expanded considerably in the past two decades. In most countries, promising, adapted species have been identified from on-station and on-farm research. In some cases (notably Thailand and southern China), substantial quantities of seed are now being produced (Phaikaew et al. 1997). However, in general, adoption by farmers has been disappointing. This is despite the fact that in most countries of the region, there has been a recent explosion in demand from farmers for forages; not only to feed livestock but also to manage environmental problems (notably erosion, weeds and low soil fertility). The reasons for poor adoption have been partly (1) lack of planting material and (2) lack of expertise on forage management. However, even when these have been overcome, adoption has not improved.

The question that is now frequently being asked by researchers (and that is the central question addressed by this paper) is:

"Given that we have identified promising forage species from adaptation trials, how do we improve adoption by farmers?"

FORAGE TECHNOLOGIES ARE MORE THAN JUST THE SPECIES

A further reason for low adoption in the past is that forage technologies are more than just the species themselves. A forage technology is the combination of a forage species with how it can be grown within farming systems. Examples of successful forage technologies are:

- farmers in Bali using the tree legume *Gliricidia sepium* in fencelines to control animals and provide leaf for dry season feed supplementation;

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- farmers in Hainan using the legume *Stylosanthes guianensis* for leaf meal production for chickens and ground cover in fruit tree orchards; and
- farmers in Kalimantan using the legume *Centrosema pubescens* as a ground cover in maize crops, providing weed control, soil fertility improvement and animal feed.

It is the advantages and disadvantages of a forage technology as a whole that farmers will consider, not just the advantages and disadvantages of the species. It is not possible for researchers to predict beforehand which forage technologies farmers are likely to adopt without knowing their needs and criteria for judging these technologies.

This point was illustrated by Fujisaka (1993) and Fujisaka et al. (1994) for an upland mixed farming area of Mindanao in the southern Philippines. Farmers identified gully, rill and sheet erosion as major risks to their crop yields and wanted to test ways of minimising these problems. In response, the researchers introduced the approach being used by farmers in other parts of the Philippines of planting *Gliricidia sepium* and *Pennisetum purpureum* in contour rows, harnessing erosion to form natural terraces and providing animal feed and green manure. Sixty farmers decided to try these technologies on their own fields. Over a period of eight years, more than 250 farmers adopted the contour hedgerow system (S. Fujisaka, pers. comm.) but many rejected the species and methods of establishing the hedgerows, mainly because they were too labour-intensive to establish and maintain. The farmers recognised that the contour rows were extremely successful in controlling their major problem, erosion (reducing losses from 200 to 20 t/ha/year), and so searched for better species (including other forage species, wild sunflower, fruit trees and coffee). In the end, they developed a system of low-maintenance, natural vegetative strips (containing weed species) in contours.

The example illustrates how researchers initially used criteria for choosing the technologies to offer farmers (yield, potential value as green manure) that were not compatible with the farmers' criteria (labour requirement for establishment and maintenance, potential for competition with crops). The farmers innovated, adapting the contour system to their own needs and rejecting the species. Forage scientists might have been disappointed by the result but the outcome for the farmers was positive.

The example illustrates how involving farmers in the process of developing forage technologies encouraged innovation and incorporation of farmers' knowledge into the technologies. In the process, the researchers learned that one of the main reasons the farmers liked the contours, apart from erosion control, was providing dry season feed (Fujisaka 1993). Knowing the criteria the farmers used to reject the first group of forage species, researchers had the opportunity to identify other species that were less competitive with crops and less labour-intensive to establish, which the farmers could then test.

USING FARMER PARTICIPATORY RESEARCH FOR FORAGE TECHNOLOGY DEVELOPMENT

The farmers and researchers in Mindanao were involved in a process known as 'farmer participatory research' (FPR). The farmers identified and prioritised problems in their agricultural systems that they wanted to resolve and, with the assistance of the researchers, chose, tested and evaluated technologies that had the potential to alleviate these problems.

FPR is gaining acceptance as a powerful approach to developing agricultural technologies (including forage technologies) with resource-poor farmers (Horne and Stür, 1997). The strength of FPR comes from:

- acknowledging that the criteria farmers use for judging the value of forage technologies are frequently different from those of researchers;
- incorporating the knowledge of farmers for forage technology development;
- acknowledging that farmers can solve their own problems. Often all they lack is access to new information and planting material;
- encouraging farmers to experiment and innovate with potential new technologies; and
- improved chances of adoption of forage technologies, because farmers have been involved in developing and evaluating them from the beginning.

The principles, methods and skills of FPR (and similar approaches generically known as participatory technology development, PTD) are described in detail by Okali et al. (1994), van Veldhuizen et al. (1997a and b) and Horne et al. (1997). The main difference between FPR and previous approaches to forage technology development is that FPR is based on active, decision-making involvement of farmers in ALL stages of the technology development (Okali et al. 1994; Figure 1).

The first step in FPR will often be **Diagnosis** (similar to participatory rural appraisal) in which researchers

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work with a representative group of farmers to gain a greater understanding of their agricultural and livelihood systems and the farmers are encouraged to:

1. identify the problems that are of most concern within their agricultural and livelihood systems;
2. identify causal links between these problems;
3. describe what actions they have taken in the past to minimise each of the problems;
4. decide which of the problems are the highest priority for solution; and
5. discuss what actions they would like to take to solve these problems in future.

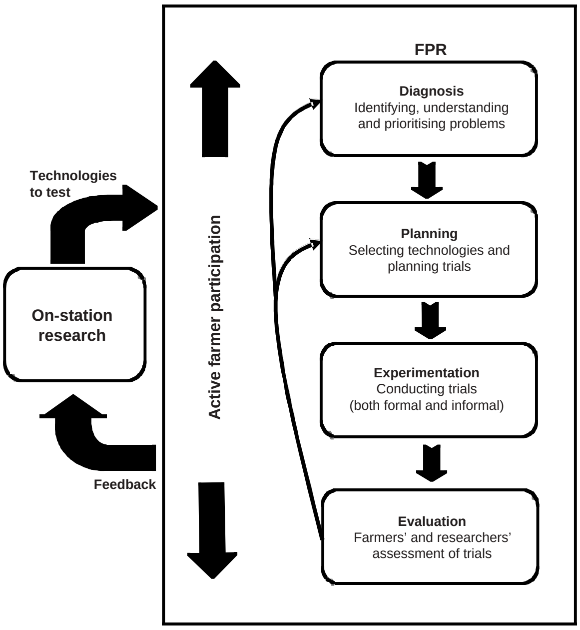

Figure 1. A model of farmer participatory research (FPR).

If researchers are interested in developing forage technologies, they should avoid narrowly focusing the diagnosis on livestock feeding, because there are important problems farmers experience, which forages can resolve, that are unrelated to livestock feeding. For example, in northern Laos, farmers practising shifting cultivation on steep slopes have to spend up to 200 days/ha/year weeding (Horne 1997). Some legumes have potential to be incorporated into the rice crops, reducing weeding time and erosion hazard.

If diagnosis identifies problems that the farmers want to try to resolve, **and** there are technologies with the potential to resolve those problems, the researchers can offer options for the farmers to test (**Planning**, Figure 1). The farmers might, for example, have identified dry-season feed shortages as their main problem for which the researchers offered fence lines of tree legumes, intensively managed plots of grasses and legumes, haymaking and rice-straw treatment as alternative solutions. The first two of these may have been developed successfully by farmers in a different district, offering an opportunity for farmer-to-farmer visits to discuss the technologies. The role of the researcher in planning is to introduce the farmers to as broad a range of suitable options as possible, not just a couple of preferred species. In south central China, for example, forage researchers introduced a broad range of forages into adaptation trials. This included one species, *Chamaecrista rotundifolia*, which was well adapted but which the researchers did not prefer because of its low feeding value. In the end, however, it was this species that has shown most promise, not primarily for animal feed but as a ground cover in fruit tree orchards (Hacker et al. 2004).

During planning, it is also the role of the researcher to provide enough neutral information about each option to allow the farmers to decide which ones they would like to test. What kinds of information are needed for farmers to decide on options to test? Farmers know how to grow crop plants well. What they may not know about forages is: (1) where species can grow (e.g. *Leucaena leucocephala* is not adapted to acid soils); (2) how they can be managed (e.g. fence lines, cover-crops); (3) how they can be used (e.g. *Gliricidia sepium* should not be cut lower than 50 cm; animals can be easily trained to eat *Gliricidia*); and (4) how they can be propagated (e.g. *Brachiaria decumbens* can be spread from rooted cuttings). There are also some common misconceptions about forages that should be dispelled, including those listed below.

- **There are no miracle species** that can produce high yields in adverse conditions. A common request is for grasses that produce, during long dry seasons, yields as high as they do during the wet season. Forages will usually not be the sole solution to problems of livestock feeding or natural resource management, but will supplement existing feed resources and management practices.
- **Many forage species are not broadly adapted** (e.g. *Brachiaria ruziziensis* needs fertile, well watered soils to give high yields). Species need to be matched to the soils and climate of an area.
- **Forages need management.** The most common causes of failure of farmer trials with forages are:
  - **sowing seeds too deep.** Forage seeds are small. They should be sown no deeper than 1 cm and preferably covered and compacted to improve soil seed contact and, hence, germination;
  - **too many weeds.** As their seeds are small, forages are slow to establish and can be defeated by a large number of rapidly growing

weeds. Even one round of early weeding will greatly enhance forage establishment; and

— **grazing of young seedlings.** Forage seedlings are susceptible to trampling and being eaten by livestock. Keep livestock away from newly establishing forage areas (<4 weeks old).

- **Continuous cutting of forages rapidly depletes soil nutrient reserves.** Large quantities of nutrients, especially N, P and K, are removed from cut plots of forages. Nutrients need to be returned if yields are to be maintained.
- **Communal grazing land cannot easily be improved with forages** unless free-grazing of livestock is controlled (either by fencing or prohibition).

In FPR, the stage of **Experimentation** (Figure 1) can take two forms. Many groups (e.g. Ashby et al. 1989; Lightfoot et al. 1993, cited in Okali et al. 1994) favour developing farmers' research skills to the point where they can conduct formal and statistically valid experiments on their own fields. Two major problems with this approach, however, are that (1) on-farm trials are frequently plagued by high variability, and (2) researchers will want to control these kinds of trials, being concerned more with statistical validity than encouraging farmer innovation. The approach being taken by the 'Forages for smallholders project' is to allow farmers to test the options freely on their farms in whatever way they like, at the same time providing them with information about other farmers' and researchers' experiences with each option. When promising options are identified by the farmers or when they have developed their own forage technologies, more-controlled experiments can be conducted to validate and quantify the farmers' experiences.

An example of this process of innovation followed by controlled experimentation comes from Makroman village in East Kalimantan where thirty farmers were offered a small range of promising forage species for backyard forage production (Tuhulele 1996). All species grew well in informal trials but the farmers rejected the technologies as they required too much labour for too little return. However, at the same time, two farmers complained of high labour requirements for weeding their maize. The development worker suggested trying two legumes (*Stylosanthes guianensis* and *Centrosema pubescens*) as cover crops. Over several years, these two farmers developed a system based on a permanent cover crop of *Centrosema* into which they sowed their maize. They claimed that the weeding requirements were lower, the yields higher and the soils were more fertile and did not require cultivation for the following crops. Other farmers in the village decided to take up the new technology. More formal experiments are now being planned with several of the farmers to quantify the extent of the benefits of this farmer-generated technology.

Once farmers are testing technologies, there follows a period of **Evaluation** (Figure 1) in which farmers describe which of the technologies they like and why, which they do not like and why, and what characteristics of the preferred technologies could be improved. Some of the many methods that exist for evaluating technologies with farmers have been described by Ashby (1990). Evaluation indicates not only which technologies are showing promise for expansion to other farmers, but also provides insights into farmers' criteria for judging forage technologies that can be used to guide on-station research.

WHAT MAKES FPR DIFFERENT FROM PREVIOUS APPROACHES TO FORAGE TECHNOLOGY DEVELOPMENT?

FPR is:

1. based on active, decision-making involvement of farmers at ALL stages of technology development (diagnosis, planning, experimentation and evaluation) (Figure 2). In previous approaches to forage technology development, 'finished' technologies were developed on research stations by researchers and given to extension workers to be delivered to farmers;
2. generally more time consuming than previous approaches to technology development but more likely to produce technologies that match farmers' needs.

FPR is NOT:

1. A 'production-line' process moving from a 'beginning' to an 'end'. Technologies offered by researchers may be rejected by farmers (as in the Mindanao example cited earlier) but this gives feedback to researchers allowing them to provide better alternatives for farmers to test.
2. A replacement for on-station research or for researcher-controlled on-farm trials. Researcher-controlled experiments are one source of potential technologies for farmers to test and are necessary to quantify technologies developed by farmers. FPR can provide feedback on farmers' criteria for judging technologies to guide the on-station research (Figure 1).

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3. A replacement for extension. However, it enhances the chances of success of extension of technologies to farmers with similar problems and agricultural conditions, since the technologies were developed by farmers to conform to their needs.

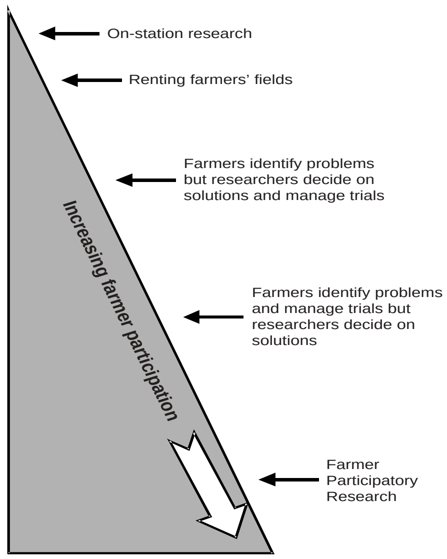

Figure 2. Extent of farmer participation in different kinds of research.

4. Necessarily capable of generating technologies with potential for wide adoption, although the underlying ideas may well find wider applicability (Fujisaka 1993). For example, in one location in central Vietnam, farmers are very interested in backyard plots of *Brachiaria* spp. for supplementing their cattle at night but this technology is of little interest to other farmers in a nearby area who want forage species to feed fish and pigs.

HOW DO WE CHOOSE FARMERS FOR FPR?

Given that the success of FPR is dependent on active farmer participation and experimentation, the method of selecting farmers is a critical issue. In the past it has been common for researchers to work with model farmers who receive substantial support from researchers to demonstrate 'successful' technologies. However, model farmers are often the wealthier farmers situated close to roads or towns. They receive substantial extra inputs from the researchers and can afford to make technologies 'appear' to work. For example, a model farmer may test forage technologies on the best cropland where all species will grow well and look impressive for visitors. However, this situation will not reflect the common problems and opportunities of most resource-poor farmers in the area.

Ideally, we want to work with those farmers who are innovative, natural researchers and representative of a broader group of farmers with common problems that forages might be able to resolve. The often-asked question is "How do you identify such farmers?". The approach being used by the 'Forages for smallholders' project is as follows:

1. Identify a village where the farmers appear to have a real need that can be addressed by forage technologies. This is achieved by using secondary information, consisting of both (1) **data** and (2) **key information and observations.** Examples of the kinds of secondary information that help identify places to start working are presented in Table 1. Ensure that there are enthusiastic development workers who will be able to conduct the work in that area.
2. Within each promising village confirm that the farmers are experiencing the problems identified from the secondary information by conducting a diagnosis with a representative group of farmers. What is meant by 'representative'? For example, if you found from the secondary information that weeds in upland crops are a major problem and women are responsible for most of the weeding work, then it would be essential to include women in the diagnosis. If you found that livestock feeding problems in the dry season are severe and 90% of the animals are kept by the poorest farmers, make sure they are present at the diagnosis.
3. During the diagnosis, identify those farmers who have been actively trying to solve their problems in the past. For example, in one village in Xieng Khouang Province of northern Laos, all the livestock keepers complained of dry-season feed shortages but four of them had actively sought solutions. They heard of a grass species that was growing well in another district so they travelled there, collected cuttings and spread them in their own village. These farmers had demonstrated their commitment to solving their own problems and willingness to innovate.
4. Visit the farms of these more-innovative farmers and assess their willingness to participate in FPR trials. Discuss their own particular set of problems and compare these with the problems identified by the diagnosis. Very often there will be a few innovative farmers who are willing to test a broad range of technologies and there will be other enthusiastic but less-innovative farmers who want to try one or two 'best-bet' technologies.
5. Before starting FPR with these farmers, describe and quantify the problems they have which you are targeting with forage technologies. This information is used to quantify impact of the technologies at a later stage.

Table 1. Suggested secondary information required to select locations for commencing FPR on forage technologies.

Data	Key information/observations
These are data and maps that are often available in district and provincial offices.	**These are results from personal observations and probing discussions with district officers, village heads and key farmers.**
Climate:	Brief description of the area focusing on key issues affecting development
long-term data (at least 10 years) for:	
Monthly rainfall	Description of topography
Number of rain days/month	
Monthly max and min temperatures	Land-use systems
Extreme monthly temperatures	Relative land area for each use (%)
Incidence of catastrophes (such as	Topographic location of each land use
typhoons and flooding)	What are the main land-use systems and their benefits/constraints?
	What inputs are used in agriculture?
Altitude range	How is non-cropped land used?
	What is the land-ownership system?
Soil:	
pH	Livestock farming systems
texture and drainage	Why are livestock kept?
broad fertility status	What proportion of farmers keep livestock?
known fertility deficiencies	Is shared ownership of livestock common?
	Are inputs used in raising livestock (e.g. supplementary feeding, veterinary
Livestock:	chemicals)?
Type	How are livestock managed? (where do they graze throughout the year, are they fed
Number	cut feed, who is involved in livestock management?)
	How are livestock marketed?
Topography	What/When are the main constraints and opportunities?
	How have farmers been dealing with these constraints until now?
Land-use systems	How do they want to deal with them in future?
	Trends in the farming system
	What changes are happening within the farming system?
	What changes are happening within the livestock raising system?
	What other rural development programs have been and are currently working in this area?

CONCLUSIONS

Identifying adapted and promising forage species is only the first step towards developing forage technologies that help resolve farmers' problems. Farmer participatory research provides a conceptual framework of methods, skills and principles that can help researchers work with farmers to develop forage technologies that will have a greater chance of wider adoption beyond target farmers or villagers.

The success of FPR for developing useful forage technologies will not depend on the quantity of seed distributed or on the number of farmers initially involved. It will depend more on the careful selection of motivated and innovative farmers from the beginning. A handful of seed of a few forage species given to a small group of motivated farmers will be more successful than large quantities of seed given to many farmers who do not have a need for forages.

Although FPR requires a substantial commitment of time from researchers to work directly with farmers, it has the potential to produce forage technologies that have a greater chance of adoption than in the past.

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GOAT PRODUCTION FROM FORAGES AT MENGONGSHAN FARM, HUNAN

Wang Baoli[1] and Wen Shilin[2]

[1] Lanzhou Animal Husbandry Institute, Chinese Academy of Agricultural Science, 30 Baishiqiao Road, Haidian District, Beijing 100081

[2] Red Soils Experimental Station, Chinese Academy of Agricultural Science, Quiyang, Hunan

Abstract

This paper discusses goat and forage production at Mengongshan farm, near Lengshuitan, Hunan. The yearly reproductive rate of goats exceeded 300%. Forage production provided sufficient forage quantity and quality for all seasons except winter when supplementary feeding was required. The profitability of the goat raising enterprise was high.

INTRODUCTION

MENGONGSHAN farm is one of the experimental farms of the Chinese Academy of Agricultural Science (CAAS) located at Mengongshan town (27.6 N, 116.6 E), near Lengshuitan city, Hunan Province. The climate of the region is classified as subtropical with four distinct seasons and a predominance of rain in spring–summer (65% of the annual total). Yearly average temperature is 17.8°C. The frost period extends four months from December to March with an average of 54 frosts per year.

SOIL AND NATURAL VEGETATION

The farm consists of four gently sloping hills at an altitude of about 130 m. The total area of the farm is 30 ha. The soil on the farm is a deep red clay soil developed from Quaternary clay. Most land on the farm is wasteland with about only 40% plant cover. The natural vegetation was dominated by the following plant species:

Grasses: *Imperata cylindrica*, *Eremochloa ophiuroides*, *Miscanthus sinensis* Anders, *Digitaria ischaemumi* Schreber, *Cymbopogon goeringii* and *Erigeron anouus* Pers.;

Shrubs: *Glochidion puberium* (L) Hutch, *Symplocos chinensis* (Lour) Druce, *Ilex cornute* Line, *Rosa laevigata*, *Clerodenrum cyrtophyllum* Turz and *Mallotus apelta*.

Most of above species ceased growing in December and commenced regrowth in March.

INTRODUCTION OF GOATS

Twenty-three local goats (7 males and 8 young and 8 adult does) were introduced in March 1995. They reproduced and 25 kids survived by the end of 1995. Thirty-four goats were sold in 1996. The goats belong to CAAS and were managed by a technician in an output-related system of contracted responsibility.

FEEDING MANAGEMENT

The herd was grazed for the whole day on wasteland except when very hot in summer, at which times they were grazed in the early morning and late afternoon. For pregnant goats or for those with kids, concentrates were fed during winter at a rate of 0.2 kg/head/day. The concentrates consisted of 40% maize, 40% rice chaff and 20% rice.

FORAGE PRODUCTION

Most of the naturalized plants at the farm were summer growing species. They typically grow well in spring and summer, and become dormant in winter. The quality and palatability of these plants were low. To improve feed quality and fill the winter gap with quality forage, 1 ha of pasture was established in autumn 1995 and spring 1996. On the basis of the results of ACIAR projects 8925 and 9303, eight promising species were chosen (Table 1). These species performed well and were palatable to goats except for Premier finger grass. Most species sown were tropical forage species. Ryegrass was the only temperate species sown, but it grew slowly during winter as a result of the low temperatures. As a result, there was still a deficiency of quality in winter feed. To overcome this, hay needed to be bought in or produced over summer.

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Table 1. Forage species sown and their characters.

Species sown	Type	Growth month	Yield	Crude Protein	Palatability to goats
Premier finger grass	Perennial tropical grass	March to November	High	7.0[1]	Moderate
Elephant grass	Perennial tropical grass	March to November	High	7.6[1]	Excellent
Broadleaf paspalum	Perennial tropical grass	April to November	High	10.0[1]	Excellent
Hemarthria compressus	Perennial tropical grass	February to December	High	5.7[2]	Excellent
Sudan grass	Annual tropical grass	April to October	Mid	13.1[1]	Excellent
Ryegrass	Annual temperate grass	October to June	Low	13.8[1]	Excellent
Lotononis	Perennial tropical legume	February to December	Mid	19.3[3]	Excellent
Lespedaza	Perennial tropical legume	April to October	Mid	17.3[2]	Excellent

[1] Xie et al. (1995); [2] Heng (1990); [3] Bryan (1961).

REPRODUCTIVE CHARACTERISTICS OF DOES

Most goats reached sexual maturity at four months of age. The first mating occurred as early as eight months. The oestrous cycle of a doe is 16–17 days and each lasts just 1–2 days. The gestation period is 148–152 days. After kidding, the first oestrus occurs within the first 16 to 40 days of kidding. Approximately 75% of the does were fertile at the first oestrus after kidding. The doe usually has no seasonal period of anoestrus and thus can be mated and is fertile in any season. The doe has good fecundity (Table 2) yielding nearly two kids per birth. Because of the short gestation and oestrus cycle, does can kid twice per year. Thus, if the survival rate of kids is 80%, then each doe can produce approximately three surviving kids per year. The weight of the kids at birth is approximately 1.4 kg. They weigh approximately 15 kg when they are one year old (Table 3).

Table 2. The number of kids per birth.

First kidding		Second kidding and thereafter	
Average	Range	Average	Range
1.8	1–2	2	1–3

Table 3. The growth rate of kids.

Weight	New birth	6 month old	12 month old
Average (kg)	1.4	6.5	15.1
Range (kg)	1.3–1.7	5.5–7	14.5–16.5

TREATMENT FOR DISEASES

The animal health policy was initially preventative with treatment only employed when necessary. Animals were vaccinated annually against the malignant contagious diseases such as contagious pleurisy and pneumonia. For the common diseases such as slomatitis, eye disease, dysentery and bloat, treatment was instigated without delay as necessary. For the parasitic diseases, animals were drenched and dipped twice per year. Through these measures, the goats remained generally healthy throughout the year.

ECONOMICS OF GOAT PRODUCTION

The details of the cost of feeding one doe and a kid grown to 12 months old are shown in Table 4. The gross sale price of the goats was 9 yuan per kg liveweight in December 1996. From the inputs listed in Table 4, it is estimated that, if each doe produces three kids per year and a goat weighs 15 kg at 12 months, then the yearly net income of each doe will be:

$$3 \times 15 \times 9 - 54.5 - (18.5 \times 3) = 295 \text{ yuan.}$$

Thus, if a farmer cares for 20 breeding does, he can earn 5900 yuan per year less the cost of replacement does.

Table 4. Annual costs (yuan) of inputs required for each doe and kid.

Input	Doe	Kid grown to 12 months old
Goat shed maintenance	12	5
Forage production	10	5
Concentrates	20	Nil
Milk powder	Nil	2
Share of buck (management fee)	5	Nil
Cure of diseases	4	3
Vaccine	1.5	1.5
Other	2	2
Total	54.5	18.5

MARKETING ASPECTS

The goats at Mengongshan farm were sold in winter. There was only a small number, so all were bought by local people. Goats from the mountain region are typically transported and sold to cities by dealers. More than 10,000 goats per year are transported and sold in Dongan County, which adjoins Lengshuitan. Goat meat is becoming increasingly popular, especially during winter. The cholesterol levels in goat meat are known to be low and the demand for goat meat is increasing rapidly, especially in economically developed areas. This will promote the development of a goat industry based on meat, hides and by-products in suitable areas.

There is a large area of natural grassland and wasteland suitable for producing goats in southern Hunan. Transport in this region is good, and it is close to economically developed areas such as Guangzhou, Hainan and Guilin. Goat production, therefore, has great potential in this region.

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IS THE RED SOIL REGION A RED DESERT OR A GREEN TREASURE-HOUSE?

Fu Jianjun[1]

[1] Red Star Enterprise of Jiangxi, Dongxiang County, Jiangxi Province, P. R. China
(translated by Liu Fulai)

Abstract

The red soil area is sometimes called a 'red desert' because of its acid and low fertility soil. Improvements such as 'one cow per three mu' and 'block ridging and damming' used by the Red Star Enterprise of Jiangxi Province have solved two key factors — water and fertiliser — which restrict the utilisation of the red soil area. Meanwhile, the enterprise has established processing industries, strengthened agricultural extension services, and followed an integrating policy for red soil development and use. Tree crops, forages and processing have become integrated, and agriculture, industry and commerce have become a whole system, and both the farmers' incomes and the enterprise's profit have increased. This has resulted in the red soil becoming a 'green treasure-house' of local economic development.

INTRODUCTION

OCCUPYING some 23% of the total land area, the red soil is an important land resource in China. Not only is its topsoil very thin, but also it is acidic and infertile, and very difficult to improve and utilise. The red soil area has been described by a Canadian soil scientist as a 'red desert'.

Red Star Enterprise is in Dongxiang County, Jiangxi Province. It is a multiple-business enterprise including agriculture, industry and commerce. The enterprise is situated within the typical red soil hilly land area in south China. The main soil type is red earth and the parent material is Quaternary red clay. The soil is mostly of heavy texture. In newly cultivated land, the organic matter content is generally about 0.3–1.0% and soil fertility is very poor. Also, the soil has poor physical properties.

When the enterprise was established in 1957, most land on the farm was wasteland. In the past 40 years, the enterprise has developed and used the red soil as the base for its economic development, and searched for new methods for red soil improvement. The enterprise currently occupies 2800 ha, of which 1200 ha is farmland. It has 27 sub-enterprises, including forage machinery, food, medicine, chemicals, building materials, packaging and other agricultural products. The annual value of agricultural outputs and industry is now 0.15 billion yuan. The wasteland of the past is becoming a modern city with a prosperous economy and a stable social environment. Red soil has become a 'green treasure-house' of benefit to Red Star's people and the economy. The improvement of the red soil has been systematic and undertaken in the context of overall planning, local conditions, and integration of farming and stockbreeding.

'ONE COW PER THREE MU'

For several decades red soil improvement was based on planting leguminous crops and green manure, and applying more organic fertiliser. While this played an important role in red soil amendment, the results were obtained at a high cost and with low efficiency. In 1980, development was reorganised according to the ecology–engineering theory, and an experiment of 'one cow per three mu' was carried out on dry land in the red soil area.

The experiment was conducted as follows. Three mu of red soil dryland was cultivated to plant forage crops, and these were harvested to raise one cow. The excreta of the cow was used to fertilise the soil, thus creating an eco-cycling system of 'forage–cow–excrement–red soil'. This system is an efficient way to improve the red soil. The experiment used the newly cultivated land to plant maize, ryegrass, cabbage, sweet potato and other green forage crops. They yielded about 90 t/ha/year, so the three mu can produce 18,000 kg forage, which can feed one cow producing about 25 kg milk/day. Meanwhile, one cow produces 20,000 kg of manure (including cowshed padding materials) and 10,000 kg of urine per year, for reapplication to the three mu red soil field improvement area. Thus, raising one cow can improve three mu of red soil, forming a beneficial ecocycling

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system of ‘one cow per three mu’. Practice has shown that using this method to amend red soil not only increases the soil organic matter content rapidly, it fertilises the soil and results in the sustainable development of agriculture, and returns greater economic benefits than traditional methods.

FOOD CROP PRODUCTION

Using red soil to grow peanuts, soybeans and sesame, as well as other food crops, the yield is 3750 kg/ha for peanut, 1500 kg/ha for soybean and 600 kg/ha for sesame. At current prices, the income is about 9000–11,250 yuan per ha. Using the red soil to plant green forage crops can yield 90 t/ha of forage. At a price of 0.24 yuan/kg this results in an income of 21,600 yuan/ha, which is about twice that from planting food crops. In addition, planting a green forage crop is less costly in labour and time. Moreover, the forage product in three mu can meet the food needs of one cow which produces about 6 t milk per year, with an output value of 13,500 yuan. The output value corresponds to 4500 yuan income per mu by the transformation of green forage to milk. Furthermore, the milk can be converted to 286 kg milk powder, and if the milk powder price is 6.5 yuan per kg, the income would be 8810 yuan, resulting in an overall output value of 8810 yuan through a series of transformations, which is about 12 times more than that from planting food crops. In addition, the excreta from one cow can produce 200 m^3 of methane, which can meet the daily needs of 2–3 people.

IRRIGATION STRATEGY

The lack of water is another key factor restricting the utilisation of red soil. To draw water to red soil uplands, the enterprise has built a multi-stage water-drawing system that collects water from several kilometres away to irrigate the fields. Because of its high investment and operating cost, the multi-stage water-drawing system has not been used on a large scale. After several decades of practical work, an irrigation method of ‘block ridging and damming, storing water up hill’ has been developed. The practice is to build a small dam between two hills, store the surface water in the valley as a small reservoir, plant grass on the slope and implement moving-spray irrigation through a small-scale irrigation system. Fish and ducks are raised in the dam and on the footslope, realising good land utilisation.

CATTLE PRODUCTION

In 1986, the enterprise established specialised households for cow raising with an investment loan from the World Bank. Every specialised household raises 10 cows and develops 2 ha of red soil. Every specialised household has built a house, cowshed, cistern and methane-generating pit, is equipped with a moving-spray irrigation system, and has developed integrated improvements to the hills, water, farmland, forest and road. The red soil land grows green forage to raise cows, the cow excreta produces methane as the energy resource, the residue of the methane-generating pit fertilises the field. Every specialised household has water, electricity and a road, and has planted fruit trees on the ridge of the field as a protective forest belt.

From 1986 to 1988, 600 ha red soil were developed and 275 specialised households founded. In order to increase profit, the enterprise established an agricultural service system that offers services to the specialised households. The agricultural machinery station is in charge of soil preparation for the households, the seed station is responsible for offering good seed, the forage factory is in charge of forage processing and supply, the red soil development company is in charge of advising the farmer how to plant crops and raise cows scientifically, and the dairy factory is responsible for purchasing and processing fresh milk. In each developing area, a local school and medical station have been constructed. Practice shows this developing model has benefits for the economy, society and ecology. By 1996, 5% of the specialised households had paid off all loans within seven years and income had reached 10,000 yuan/year, which is about 2.6 times higher than that of other households.

CONTRIBUTION TO ECONOMIC DEVELOPMENT

Developing the red soil region has promoted the economic development of the whole enterprise. Around a core of red soil utilisation and agricultural products processing, the enterprise has established and rebuilt a dairy factory which can process 40 t of fresh milk per day, and a forage processing factory which can produce 20,000 t of forage. The enterprise possesses the only starch factory in China. It can produce 5000 t of denatured starch per year by using the vacuum-drying denaturation technique. Also, a forage machinery factory that supplies 10% of the whole country’s forage processing machinery, and a pharmaceutical factory that can produce 5000 t glucose and 0.35 billion tablets per year has been established. Trees, breeding and processing have been linked together; agriculture, industry and commerce have formed a whole system. Hence, what was once described as a ‘red desert’ has become a ‘green treasure-house’.

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INTEGRATED PASTURE SYSTEMS FOR CATTLE PRODUCTION IN GUANGDONG AND HAINAN PROVINCES

D.L. Michalk

NSW Agriculture, Pasture Development Group, Orange Agricultural Institute, Forest Road, Orange, NSW, Australia 2800

Abstract

Guangdong and Hainan Provinces have a combined bovine herd exceeding 6 million head. While a large proportion of the cattle and buffaloes are used for draft power in cropping systems, the 2.2 million non-draft animals, composed mostly of yellow ox cattle, have the potential to supply the rapidly increasing demand for beef, provided pasture systems can be developed to supply high quality feed to livestock throughout the year. Target areas selected for pasture development as part of the national policies in 1981 to increase beef output include the subtropical, acid, red soil areas of north Guangdong Province, and the dry tropics of western Hainan Island. Both areas have large areas of wasteland and an abundance of cattle. However, cattle production from the unimproved rangelands was low (<30 kg LWG/ha) due mainly to inadequate nutrition and a cattle management system where beef output was considered a by-product to the supply of draft power and manure production. Based on research conducted at model farms in Guangdong and Hainan between 1981 and 1989, appropriate pasture mixtures were formulated to improve soil and to increase beef output several fold. To gain these improvements, however, it was necessary to integrate various pasture types into a “feed-year” to ensure a continuous supply of high quality forage. Successful integration is achieved when the growth and quality characteristics of each pasture type is matched with the specific nutritional needs of each class of livestock. The analysis presented demonstrates how the feed requirements of a 100-cow breeding-and-fattening herd (154 AU in total) can be supplied by sowing the appropriate areas of different pasture types. Based on the pasture budgeting analysis for north Guangdong Province where the cool winter limits production from tropical species, a ratio of 1:4:8.5 of forage oats, white clover-based temperate pasture and setaria-based summer pastures sown on about 160 ha should provide the needs of the breeding-and-fattening herd, provided pastures are moderately fertilised. In the dry tropics of western Hainan Island, where inadequate pasture growth over the protracted dry season is the main constraint to production, about 40 ha of Siratro-based pasture and 140 ha of stylo should furnish the needs of 154 AU herd. The value of stylo-based pastures is an ability to maintain high quality standing dry feed over the dry season. These systems are not designed for small subsistence landholders, but rather for specialised cattle farms where beef is the main focus for cattle production. This type of operation, where the entire beef production process is controlled in a single farm unit, is considered to be the most attractive option to supply beef to the rapidly expanding supermarket and fast-food trade in Guangdong and Hainan. However, as quality beef attracts a premium price, a diversified industry where breeding, fattening and feedlotting are undertaken on different farms is likely to evolve in which smallholders could play a significant part, particularly in cow/calf production. However, irrespective of the system that evolves over time, it is clear that the strength of the economies of Guangdong and Hainan, coupled with the rapid increase in disposal income and demands for beef, provide a tremendous stimulus for the development of better quality pastures and beef cattle management systems.

INTRODUCTION

LIVESTOCK production constitutes an important component of the agricultural economy of China, accounting for about 26% of the country’s agricultural output (Fitzhugh et al. 1992). In 1995, animal husbandry contributed Y604 billion (1 yuan [Y] = $US 8.50) to the gross output of the agricultural sector, of which ruminants accounted for 10% (Anon. 1996). Since raising livestock is a dominant feature of the culture and economy of China’s pastoral region, it is often assumed that most of the production from ruminants is derived from the large area of grassland steppes, which accounts for three-quarters of the country. However, according to statistics published in 1990, while the 12 northern pastoral provinces graze almost 90% of the nation’s sheep flock, the cattle raised in the grassland zone accounted for less than 40% (or 41 million) of the bovine herd even though cattle are regarded as the most important livestock

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found in the pastoral region (Longworth and Williamson 1993). This means that the major portion of the bovine herd is concentrated in China's agricultural zone where they are used primarily for draft purposes (Wang and Ding 1996).

Up until the late-1970s, when China embarked on an economic modernisation program to provide basic farm mechanisation (Hua 1978), draft animals provided most of the power for tillage of crop land (Feng 1984). In 1974, for example, the 52 million draft animals provided Chinese agriculture with 16×10^6 kW of power, which was about 20% greater than the aggregate power rating of pumps and tractors in use at that time (Smil 1979). As farm mechanisation and production reform policies took effect, the contribution of draft animals to the power inputs for crop production declined rapidly, and by 1990 the 24×10^6 kW of power produced by 76 million draft animals accounted for <8% of the 287×10^6 kW of power supplied from fossil fuel sources (China Agricultural Statistics 1992). However, since much of the mechanisation has occurred in the areas of transportation and irrigation, draft animals still make an important contribution to land preparation in cropping systems. In 1990, about 30% of area of crop land was still worked by draft power with machinery and human labour contributing 58% and 12%, respectively. While predictions indicate that the draft input will fall to <17% by 2000, bovines will continue to play a vital role in supplying draft power for crop production, particularly in poorer rural areas or where individual holdings are small (Wang and Ding 1996).

Mechanisation has proceeded at a faster rate in north China where the cropping areas are larger and the provision of adequate feed supplies for draft animals over winter poses a significant problem for producers (Li et al. 1996). In contrast, throughout south China where forages can be grown year round to sustain cattle and buffaloes (Michalk et al. 1994), reliance on draft power for cultivation of cropland is likely to remain at current levels for some time. However, as cattle and buffaloes are replaced by machines, there are definite advantages in keeping cattle within the agricultural systems of south China. In addition to the draft power they provide, bovines produce a significant proportion of China's red meat production, provide manure for fertiliser, and act as the major capital reserve of many farming households. In short, livestock enhance the economic viability and sustainability of the farming system to an extent that is vastly underestimated in China, as is also the case in other developing countries.

In 1990, for example, the cattle found in the agricultural provinces in the east and south of the country produced a meat output of 688,000 t or 55% of China's total beef production (China Agricultural Yearbook 1991). Further, draft animals also produce manure that is an important input for crop production. In the same year, the combined cattle and buffalo herd of 11.3 million head found in the provinces of Hunan, Fujian, Guangdong and Hainan produced about 40 million t of fresh waste available for recycling, assuming a 5 t/animal/year output of fresh waste and manure collection of 70% (Chao 1970). This is equivalent to a potential 160,000 t N, 200,000 t K and 40,000 t P, although due to volatilisation and leaching during fermentation and storage, a smaller and fluctuating proportion may actually reach crops (Smil 1981).

Nevertheless, despite these significant direct and indirect contributions made by draft cattle to China's food output, there has been little interest until recently in raising cattle specifically to produce good quality beef. Rather, beef is still considered by many crop producers to be simply a by-product coming from the sale of surplus draft cattle. This means that it is generally only the old and maimed animals that are slaughtered to provide the fresh meat market which, in turn, leads to a variable supply of poor quality beef and it is little wonder that pork and poultry are the preferred meats in south China. However, as more cattle become surplus to crop production with increasing trends in mechanisation, there is an enormous potential to improve the output and quality of beef cattle in south China, provided some of the important production constraints can be overcome and the acceptance of beef can be increased among those in China's emerging middle class.

In general, the lack of feed resources is the most important limitation to developing a specific beef cattle industry in south China (Oldfield 1980). To ensure a continuous supply of high quality forage, particularly on the red soils of the region, it is necessary to utilise both tropical and temperate pasture types as the growth of neither alone provides the quality forage required throughout the year to produce good quality beef (Michalk et al. 1994). A similar situation exists in the subtropical coastal region of New South Wales (Australia) where climatic conditions are similar to those of south China (Horne 1991; Michalk and Huang 1994a). During the 1960s, a feed-year pasture system was developed to provide a continuous forage supply to dairy farms in the north coastal region of NSW (Colman 1966), based on many of the tropical and temperate species tested in the red soil region of China.

Improved transport facilities, expanded government extension services, and credit facilities are additional

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factors needed to stimulate incentives to expand cattle production. Due to changes in government policy coupled with an increasing demand for beef, some of these factors have already started to change over the last decade resulting in a steady increase in beef output. In 1979–81, for example, there was only 3.2 kg of beef produced per head of cattle in the Chinese national inventory, but by 1988–90 productivity had grown to 10.5 kg, and Simpson (1992) predicted that this would at least exceed 25 kg and may increase to 38 kg by 2025, depending on the state of the Chinese economy, local demand for beef and access to export markets. While these changes are encouraging, there is still plenty of scope to increase beef output, particularly in the southern provinces of Guangdong and Hainan where there is already a large non-draft cattle population (2.2 million head in 1990 — Table 1) and where commercial pasture development is well advanced with the area of improved legume-based pasture exceeding 100,000 ha in 1992 (Devendra and Sere 1992).

The aims of this paper are: (1) to highlight the policy changes designed to increase red meat output on grasslands which includes the 40 million ha in south China (Hong 1985); (2) to provide a brief description of the current state of cattle production against the backdrop of the economic and social changes taking in Guangdong and Hainan Provinces; (3) to outline the constraints to development of viable beef production systems, particularly within the grassland areas of these provinces; and (4) to present a whole-farm feed management system based on the growth cycles of adapted pasture and forage species that was developed at Lechang Farm in north Guangdong Province and Gaopoling Farm in western Hainan Island as means to improve beef output.

NEW POLICIES TO INCREASE RED MEAT PRODUCTION

Given the limitations to expansion of crop production and the apparent potential for rapidly increasing red meat production, China's planners have implemented a national program to rapidly expand ruminant production on the nation's untapped rangelands (Zhao 1982). Historically, livestock production in China has been less emphasised than crop production in the priorities of Chinese leaders because the low living standard of the Chinese people was unable to sustain a prime beef industry. However, it is well recognised that the process of economic modernisation stimulates a greatly increased consumption of meat products. This has already occurred in the more industrialised parts of China where the increase in meat consumption is correlated with the increased living standard brought about by the success of the light manufacturing sector of the economy. It is also acknowledged that supplying sufficient red meat to meet such demands can only be accomplished by establishing animal agriculture as a specialised industry rather than a sideline to crops for provision of draft power and manure production (Wiens 1980).

The new direction in livestock policies was launched at the Fourth Session of the Fifth People's Congress in 1981 by Zhao Zi-Yang: "To develop the rural economy, we must, first of all, put all existing arable land to more rational use. At the same time, we must take measures, step by step, to utilise properly and fully China's vast expanses of hilly land, mountainous areas and broad grasslands". The policy had three main platforms: (1) protection and rational use of existing grassland; (2) development of animal husbandry by increasing livestock numbers with the proviso that new developments must produce a high net return on investment; and (3) recognition of science and technology as important keys to improving ruminant production.

The first platform signalled the abolition of former policies that required all pastoral regions to be self-sufficient in grain production. Under this grain self-sufficiency policy the grain targets in most pastoral areas were seldom attained because of the unsuitability of grassland environments to crop production (Ma 1983). Instead, large tracts of valuable grassland were destroyed by the plough (Smil 1983), only to erode away or to be invaded by useless weeds with each successive crop failure.

For the second platform, there are two alternatives to increase livestock output: (1) vacant land can be brought into production using either traditional or improved methods, or (2) the productivity of grassland areas can be increased through the introduction of new pasture species, better grazing methods and improved livestock practices. The most compelling reason for considering the range improvement option relates to research in similar environments that demonstrates that when legumes comprise 20% of intake, livestock performance increases 50% to 100%, particularly in tropical areas where weight loss during the dry season is minimised. The practical impacts of legume-based pastures have been convincingly demonstrated in Hainan Island where marked increases in cattle performance were obtained on *Stylosanthes*-based pastures (Michalk et al. 1995). For pastures remaining productive for 15 years when sown using low-input technologies, internal rates of return ranged from 15% to 40%, depending on input costs and beef prices (Michalk, unpublished data).

The third platform acknowledged that policy alone was not enough to change animal husbandry, but rather effective research and extension programs are needed to achieve the 100% increase in red meat consumption by 2000 from the 1980 level of 12 kg/head. This was consumed mainly as pork with beef accounting for only 0.3 kg/head. Before production goals can be achieved it is necessary to provide appropriate technology and market developments to expedite change from traditional to improved ruminant production. While agricultural planners were aware of the value of new technologies such as pasture legumes, they also recognised that a lack of local expertise in range science posed a serious limitation on progress. To fill this technology void in the short-term, co-operative development programs and technological exchanges were established through bilateral agreements.

Model farms emerged as the standard means used by foreign experts to rapidly transfer range improvement technology to China (Nalson and Ayres 1984). During the 1980s a number of consultants and government agencies were invited to initiate pasture testing and livestock development projects in Hunan (Nan Shan Farm), Guizhou (model farm name unknown), Guangxi (Qian Jian Farm), Hainan (Gaopoling Farm) and Guangdong (Lechang and Maba Farms). These projects were mainly focused on development at the commercial scale, although they included research and "on-the-spot" training components. More recently, ACIAR (Clements et al. 1997) and AusAID have funded research projects directed at solving specific forage-related problems. In the longer-term, training students in overseas universities and upgrading local tertiary courses augurs well for future self-reliance in pasture improvement and ruminant management as graduates return to work in local research and extension programs

The combined effect of these new livestock policies, better management systems and changing markets are reflected in China's livestock statistics. In the 15 years following the introduction of new livestock policy and the responsibility system which changed the ownership arrangements of livestock, cattle and sheep/goat numbers increased by 60 and 69 million head, respectively (Figure 1). Over the same period, beef output rose from 269,000 t in 1980 to 4.15 million t in 1995 while the output of mutton rose by 1.4 million t (Figure 1). Most of this production increase was obtained by increasing livestock numbers on existing grazing land as there was little change in the area (about 1.8 million ha) of grain and forage crops sown specifically for livestock production, or in total area sown to farm crops.

While the production increase has been impressive, it was not long before the increase in livestock numbers started to cause severe overgrazing and degradation on the communal grazing lands. To reduce overgrazing livestock policies were modified to shift the emphasis from livestock number to output, and to move towards private user rights for grazing lands. In 1985, Luo Han-Xian reported that "the former one-sided emphasis on increasing the year-end number of livestock … has been replaced by new stress on raising the ratio of animals ready for slaughter, the amount of meat produced by each animal and the percentage of marketed animals". However, the successful increase in output on a per animal and per area bases will depend largely on providing a

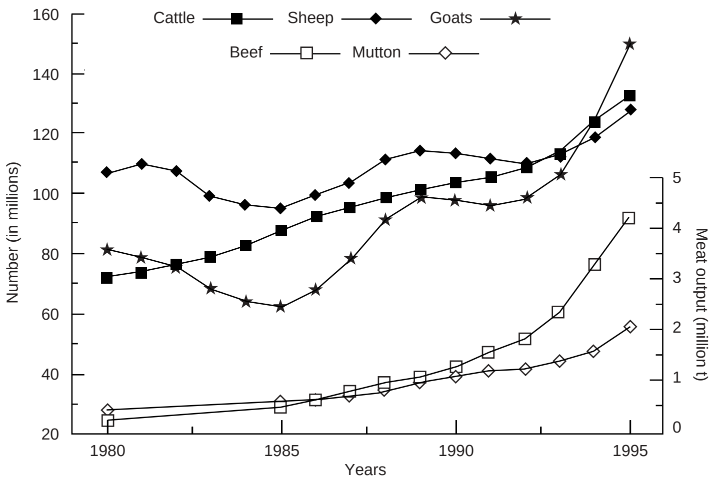

Figure 1. Ruminant statistics for China, 1980 to 1995.

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continuous supply of high quality forage for livestock. At present, even when central to his crop production, farmer inputs to cattle production are minimal and few are likely to cultivate land to establish pastures or use fertiliser since they are unconvinced that forage for livestock will be profitable. Further, it is unlikely that plant introduction and fertiliser strategies will be used to improve the productivity of rangeland areas unless grazing quotas are introduced or the grazing resources are privatised. Policies of this type are being slowly developed throughout China and indeed, the Ninth Five-Year Plan (1996–2000) places considerably greater emphasis on agriculture than previous ones.

GRASSLANDS AND BOVINES IN GUANGDONG AND HAINAN

As part of China's planned expansion in beef output, the Guangdong Provincial Government identified two regions in the province where large areas of wastelands were readily available for improvement for cattle production. These areas included: (1) the subtropical, acid soil area of Shaoguan Prefecture in the northern part of the province (particularly Qujiang and Lechang counties); and (2) the dry tropics of western Hainan Island (particularly Dongfang, Ledong and Yaxian counties). Up until its proclamation as a province in 1988, Hainan Island was part of Guangdong and for this paper the two are considered as one entity. These regions were selected on two counts. First, unlike other parts of Guangdong, the potential for boosting agricultural incomes by increasing food, horticultural, economic and plantation crops is limited by low rainfall (<1000 mm/year), a long dry season (7 months) and infertile sandy soils in the case of Hainan, and acid soil infertility in north Guangdong. Second, these areas have an abundance of bovines.

Grassland resources suitable for cattle production

The area of grazing land that has potential for beef production in these two regions is substantial. In Shaoguan Prefecture published survey data indicate that there are about 2.5 million ha of soil with pH <5.5 (Anon. 1986), much of which is too acid for crop production, and agricultural planners are keen to develop pasture-based cattle production on these infertile soils (Michalk et al. 1988). In the dry tropical region in western Hainan Island there is also a large area not suitable for crop production, of which about 162,000 ha was set aside in 1981 by the government for range improvement (Michalk et al. 1993a). More recently, research on tropical pasture development centered at the Tropical Plant Research Institute in Danxian County has focused on the more humid tropics, which when added to the dry tropical region means that the potential improvable pasture area in Hainan Island exceeds 700,000 ha (He and Jiang 1989).

The original vegetation of the lower hill areas of north Guangdong consisted of evergreen oak and lauraceous forest (Wang 1961), but most was cleared in the 1920s and replaced with pines, bamboo and other secondary vegetation (Fenzel 1929). Where the vegetation has been maintained as open grassland through grazing or cutting as organic mulch for crop land, a community of short-season grasses and a few legumes (mainly *Lespedeza striata*) has developed. Production from these grasslands is low (1.4 to 2.6 t DM/ha), especially in winter when natural pastures are dormant. A similar situation exists in the dry tropics of Hainan where the original forest has been reduced to monsoonal shrubland with tall bunchgrasses (e.g. *Heteropogon contortus*, *Chrysopogon aciculatus*, *Dichanthium* spp.) forming the under storey on better loam soils to degraded grasslands dominated by blady grass (*Imperata cylindrica*) and prostrate, grazing tolerant grasses on sandy soil (Michalk et al. 1993). Forage production ranges from about 1 t DM/ha on degraded grassland to >2 t DM/ha on low density (<5000 shrubs/ha) scrubland (Michalk and Fu, 1988). The legume proportion (mainly *Desmodium* and *Alysicarpus*) is low and the pastures are not very responsive to superphosphate even though the soils are P-deficient (Michalk and Fu, 1988). Growth occurs only during the wet season (May to October) and little herbaceous vegetation remains by the end of the dry season in grazed areas, especially around villages.

This seasonality in production both within and between years in both of these grassland areas is the most important limitation to livestock production, and it is now recognised that improvement to the forage base is needed to sustain a viable beef industry in the two locations. Recent aid programs have identified legumes and grasses suitable for improving both the highly Al-saturated red soils in north Guangdong (Michalk and Huang 1994a, 1994b) and the dry tropics of western Hainan (Michalk et al. 1993a, 1993b). The benefit of using combinations of introduced species is that a year-long supply of high quality forage can be provided as either green growth (in north Guangdong) or as dry stylo residue (in Hainan Island). Not only does this increase the carrying capacity and output per animal, but it also reduces the reliance on supplemental feeds that usually come from arable land and therefore compete with food crops. As in other provinces, these programs have been strongly supported by the central and provincial governments under their policies to increase the ruminant resource, particularly in south China.

Grassland improvement in Guangdong and Hainan

While domesticated local grasses such as *Miscanthus floridulus*, *Sorghum propinquum*, *Hemarthria compressa* and *Pennisetum polystachyon* have been cultivated and utilised for many years in south China (Hong 1985; Hwang et al. 1986), Chinese scientists and managers realised that the introduction of commercially available grasses and legumes (particularly from Australia where a large number of tropical and subtropical pasture cultivars have been commercialised) offered a faster and more efficient means of grassland improvement in south China (Hong 1985). Although the introduction of pasture species such as paspalum to Guangdong Province began in the 1920s (Anon. 1924), it was the development of the model cattle farms at Gaopoling in Hainan Island and Lechang and Maba farms in north Guangdong that resulted in the introduction of more than 100 legumes and 36 grasses.

Improved pasture recommendations

These introductions were tested for their adaptability to the environment and response to fertiliser in the dry tropics of western Hainan and the acid red soils of north Guangdong. Results from these evaluation programs were used to formulate appropriate grass-legume mixtures that would improve soil (Michalk 2004) and beef cattle production systems (Michalk et al. 1993a, 1993b; Michalk et al. 1994). For north Guangdong, a setaria/round-leaf cassia/lotononis sward was recommended as the base improved pasture with white clover pastures and winter forage crops (e.g. oats) providing high quality forage in the February to May period. By integrating the 3 pasture types into a feed-year program it is feasible to provide a continuous supply of forage to meet the needs of a cattle breeding-and-fattening enterprise (Figure 2).

Based on the findings for dry tropical Hainan, a mixture of common stylo and Siratro combined with guinea grass or setaria was recommended for drilling into prepared seedbeds on the more fertile loam soil, while a mixture of shrubby and Caribbean stylos, either broadcast directly into native rangeland or combined with Rhodes grass or brownseed grass on rough disked seedbeds, was recommended for fertilised sandy soil. As is the case in north Guangdong, these tropical pasture types can be managed in a system with Siratro-based pastures providing excellent wet season grazing, while the standing dry forage of stylo-dominated pastures provides ideally grazing over the dry season (Figure 3). A flexible integration of the two provides an optimal grazing system for long-term persistence of the sown species (Figure 3).

Commercial use of improved pastures

Since the introduction of *Stylosanthes* species into Guangdong Province in 1981, there has been a rapid increase in the area oversown with improved legumes, which exceeded 100,000 ha in 1997 (Guoduo et al. 1997). This includes pasture legumes used as an under storey to perennial tree plantations (e.g. mango and rubber), as a monoculture for leaf meal or seed production, and in pastures associated with grasses

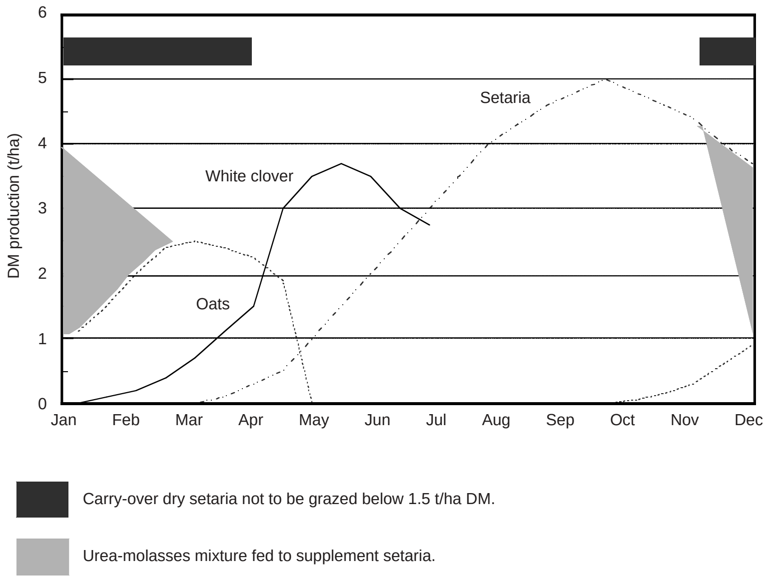

Figure 2. Integrated production curves of different pasture types to provide year round forage in north Guangdong Province (after Michalk et al. 1994).

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(Devendra and Sere 1992). This suggests that a large proportion of the area sown to forages in Guangdong and Hainan may be accounted for by the increase in the area sown with improved legumes, particularly stylos (Figure 4).

Of the Australian stylo cultivars introduced to Guangdong and Hainan, cv. Graham is by far the most widely grown, especially as a understorey crop in citrus orchards, where the area planted mainly to oranges increased from 21,000 ha in 1982 to 177,000 in 1987. Only about 20% of the area sown to Graham stylo is currently used for pastures (Guodao et al. 1997), although a large proportion of the stylo planted by 108,000 farm families in Guangdong Province was used for leaf-meal production (Devendra and Sere 1992), which totalled more than 10,000 t in 1988 (He and Jiang 1988). This small-farm area would include much of the understorey development in citrus where stylo is grown in a pure stand with moderate fertiliser application. However, *S. guianensis* has poor regrowth and persistence particularly when cut at the mature stage for leaf-meal production and other cut-and-carry systems, and the lack of resilience

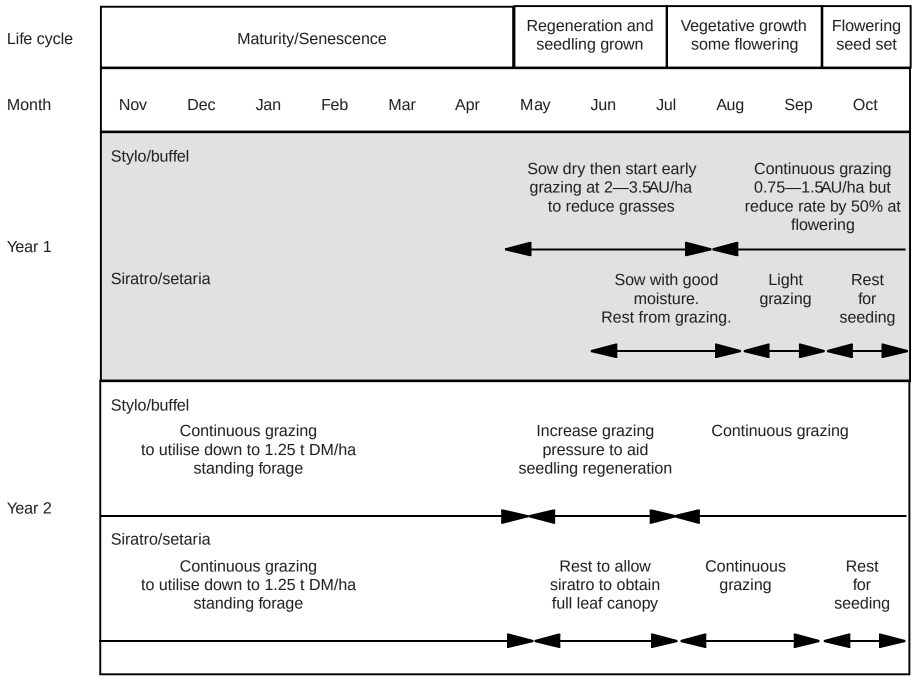

Figure 3. Integrated management of Siratro- and stylo-based pastures at Gaopoling Farm in dry tropical Hainan Island (P.T. Mears and D.L. Michalk, unpublished).

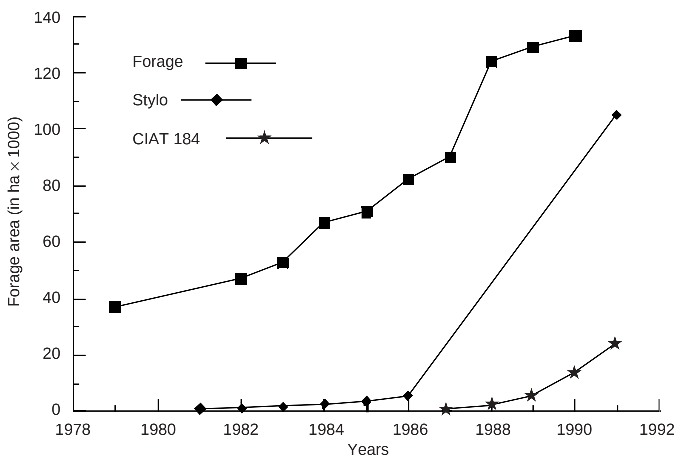

Figure 4. Total of area forage, stylo and CIAT 184 stylo in Guangdong and Hainan (Anon. 1996; Guodao et al. 1997; D.L. Michalk unpublished data).

remains a problem with this species (Guodao et al. 1997). The lack of persistence in grass-legume mixtures is also cited as a reason for the low acceptance of *S. guianensis* as a pasture species by farmers. More persistent stylos such as *S. scabra* (cv. Seca) and *S. hamata* (cv. Verano) are more widely used for pasture production in Guangdong and Hainan (Guodao et al. 1997).

Disease problems associated with the anthracnose fungi *Colletotrichum gloeosporioides* have also limited the production and persistence of many of Australian cultivars of *S. guianensis*. Severe damage was noted first on Schofield in 1982, then on Cook in 1987 and Graham in 1990 (Guodao et al. 1997). Due to persistent damage since 1993, Graham has been replaced by CIAT 1984, which was introduced to China in 1983 and released as the cultivar Reyen II — Zhuhuacao in 1987 (Anon. 1988). Renyen II yields 20% more than Graham, has similar seed production (250–300 kg/ha), but is not damaged by anthracnose (Guodao et al. 1997). Although Wynn cassia was introduced to Guangdong Province in 1986 (Michalk and Huang 1994a) and showed promise as a pasture species for infertile red soils (Michalk 2004), there is no information currently available on the area sown or the impact it may be having on livestock and agricultural systems in north Guangdong Province where frost precludes the use of most stylo species as pasture species and under storey crops.

Cattle resources in Guangdong and Hainan

In 1980, Guangdong and Hainan had a combined bovine herd (which includes draft cattle, dairy cattle and buffaloes) of 3.9 million head (Table 1). By 1990, the bovine herd reached 5.9 million and exceeded 6.2 million in 1995. During the last five years a major part of the bovine increase has taken place in Hainan Island, where between 1990 and 1995 the number of cattle and buffaloes doubled to reach 1.5 million in 1995 (Anon. 1996a). Water buffalo accounted for about 60% of the bovine population, most of which are used to cultivate the 4.1 million ha of paddy rice. Between 1980 and 1990, the non-draft herd, composed mostly of cattle, increased by 78% (or almost 1 million head) and has now stabilised at about 2 million head (Table 1). It is from this cattle herd that further increases in beef output can be obtained if appropriate pasture improvement and better cattle husbandry practices are adopted.

Features of cattle in south China

Referred to as “yellow cattle” (or “Huang Niu”), irrespective of their colour (Epstein 1969), the cattle in south China are of zebu origin (Wang 1985) and are similar to the Kedah-Kelantan cattle of Thailand and Malaysia (Maule 1982) in conformation and adaptability to tropical conditions. Yellow cattle are resistant to tick (Levine 1919) and have acceptable growth rates when provided with adequate quality feed (Michalk et al. 1995). They can withstand heat and humidity, and graze year-round on hard feed conditions. The meat quality is good and the fine-bone structure ensures that the ratio of bone to meat is low (Epstein 1969). However, milk-production of Chinese yellow cattle is limited (Levine 1919), which accounts for poor calf growth rates, particularly when cows are grazed on inadequate poor quality forage. Although they are small in stature, southern yellow cattle have good drafting ability, with a 300 kg steer capable of pulling 80-90% of its body weight.

China does not have special-purpose beef cattle in the southern agricultural zone, all are bred primarily for draft use (Qui et al. 1993). This is partly explained by the fact that crossing these indigenous humped cattle with imported breeds has not proved to be very popular with farmers for the reason that the cross progeny are of little use for draft because the hump against which the yoke fits is very small or not present at all (Levine 1919), even though the cross produces a larger animal with superior beef carcase qualities. However, in central China (e.g. Sichuan, Jiangsu,

Table 1. Selected bovine statistics for Guangdong and Hainan Provinces, 1980 to 1995 (Anon. 1996a).

Parameter	1980	1985	1990	1995
Dairy cattle	17,000	22,000	30,000	26,000
Beef cattle	1,364,000	2,017,000	2,462,000	2,458,000
Water buffaloes	2,568,000	3,171,000	3,498,000	3,686,000
Total bovines	3,949,000	5,210,000	5,990,000	6,170,000
Draft bovines	2,700,000	3,818,000	3,764,000	4,206,000
Non-draft bovines	1,249,000	1,392,000	2,226,000	1,964,000
Bovines slaughtered	113,000	245,000	383,000	na
Total meat output (t)	8,000	21,000	37,000	76,000
Meat output/carcase (kg)	71	86	97	na

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Zhejiang Provinces) where yellow cattle have little zebu blood, cross-breeding to produce a dual-purpose animal for draft and milk production is becoming more popular (Wang and Ding 1996). This is due in part to the demonstrations conducted at 270 cattle improvement stations established in the 1979–1987 period, which produced more than 50,000 cross-bred cattle (Shen 1991).

However, the impact of breeding programs is seldom realised until both the quantity and quality of pastures and supplementary feeds are improved. Protein is short for much of the year whether livestock are grazed, fed on hay, or provided with crop residues. In other words, from the technical side, nutrient content coupled with limited pasture production, and most importantly, winter or dry season feed, are the most serious constraints to expanded beef output (Simpson and Li 1996). “Feed before breed” was used as the banner for Gaopoling Farm to emphasise the need to provide adequate forage first, and only turn to improving the breed characteristics once the nutritional constraints are removed. When given adequate nutrition, the daily gains of southern yellow cattle (0.4 kg/hd/day grazing stylo pastures — Michalk et al. 1995) bring into question the need to upgrade the yellow breed to fill the beef requirements of the local market.

Current management methods and beef output

The majority of cattle in Guangdong and Hainan are still raised using a sedentary pattern of grazing management, where cattle are herded, often by children, on common grazing land (known as wastelands), along roadsides and on field verges during the day and returned to corrals at night for security and to facilitate manure collection (Michalk and Fu 1988). Privately owned cattle are grazed in joint family groups of 20 to 30 head. Little attention is given to animal management practices such as herd segregation, planned breeding to suit the seasonal dynamics of pasture production, or strategic selling of adult animals to reduce stocking pressure during the dry season or winter (depending on location). These same management practices apply irrespective of whether cattle are raised for draft or beef in small numbers by family groups or in large numbers on formerly state-controlled farms.

Sedentary grazing leads to uneven utilisation of the total grazing resource. In general, open grassland areas around settlements, low-lying areas and cropland under fallow are heavily grazed, whereas scrub covered rangeland is avoided whenever possible because of herding difficulties associated with high shrub density. For most of the year cattle consume poor quality forage diets that have a high cell wall content, low nitrogen content and poor digestibility. The metabolisable energy content of these diets is rarely more than 9 MJ ME/kg and the crude protein 90 g/kg of dry matter. Poor utilisation of these low quality forage resources, which is exacerbated by restricted grazing time, leads to low levels of animal production and reproduction. Further, since work animals are normally not used throughout the whole year, farmers do not look after idle animals as carefully as they do when they are providing daily work output (Wang and Ding 1996). During idle periods no attempt is made to nourish the herd to maximise the output of non-draft products (e.g. milk, meat). Rather, animals are often malnourished and neglected during these periods. Silage production is recommended but not widely used in practice.

In Guangdong and Hainan Provinces, Michalk et al. (1985) reported that production from yellow cattle grazing wasteland under sedentary management was low (20 to 30 kg LWG/ha/yr). Low pasture production (<1.5 t DM/ha/yr), poor pasture quality (<0.4 t/ha/yr native legume) and restricted grazing time (<10 hr/day) resulted in low carrying capacity (0.24 AU/ha) and poor cattle growth (<60 kg/steer/yr). Production parameters for yellow cattle grazing unimproved rangeland under traditional management in western Hainan Province are given in Table 2. These results are similar to those for cattle grazing unimproved grassland in South America (Thomas et al. 1984) and north Guangdong Province.

Table 2. Production for yellow cattle grazing native grassland under traditional management in the dry tropics of Hainan Island.

Parameter	Range
Calving rate (%)	55 to 70
Mortality to weaning (%)	5 to 10
Calf age at weaning (months)	9 to 11
Age at first calving (years)	3 to 4
Calving interval (months)	20
Daily LWG birth to maturity (kg/hd)	0.16
Age at adult weight (years)	4 to 5
Annual turn-off rate (%)	5 to 10
Annual beef production (kg/ha)	20 to 30

Overgrazing is the primary cause for these low production levels, as well as for deterioration of forage yield of grassland. The overstocking problem is most severe towards the end of the dry season when animals are in a semi-starved state unless supplementary fed. Animals lose weight quickly during this period, most of which is potentially edible beef. There is some disagreement as to what extent the cattle industry

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in south China relies on grain (including legumes and sweet potatoes) and concentrates, particularly when household supplies of bran, bean cakes and soybean meal are used to sustain work output from draft animals. In recent years, there has been a proliferation of feed mills that produce a range of processed livestock feeds based on forage and grain, some of which are used to supplement draft cattle. However, since little supplementary feed is used for beef production either a reduction in stocking rate or an increase in the forage base, or both, are needed to improve meat output in Guangdong and Hainan.

Despite these relatively low production levels for cattle, beef output is substantial and improving in Guangdong and Hainan. In 1980, for example, the 113,000 bovines slaughtered produced 8000 t beef; but by 1990 the number slaughtered had increased to 383,000, which produced 37,000 t. This means that the average weight per head at slaughter has increased from 70 kg in 1980 to 97 kg in 1990 (Table 1). Beef output doubled again in the five years to 1995. However, to substantially increase beef output to meet the rapidly expanding markets, changes to the current management systems are needed. First, the emphasis must be shifted from raising cattle for draft and manure production to focus entirely on beef production, and second the forage base must be increased to improve the efficiency of the conversion of forage to beef.

Although manure is an important by-product from cattle, which remains the dominant fertiliser for most cropland in China (Smil, 1981), the benefits of manure collection must be weighed against penalties incurred in animal production resulting from inefficiencies in the sedentary grazing system. Michalk et al. (1995) calculated from an analysis of cattle production measured in traditional and fenced systems that the opportunity cost of manure was 15 yuan/t. This was based on the loss in carcase weight of calves (and revenue when liveweight gain was valued at the 1984 price of 3 yuan/kg) incurred under traditional management, where livestock were corralled to collect about 70% of the total manure voided by a cow/calf enterprise. The manure opportunity cost would be even higher if the comparison were made for pastures where the forage base was improved using stylos and managed in a fenced system.

It is fortunate that legume-based pasture systems in Guangdong and Hainan need relatively low inputs of fertiliser (Michalk 2004) and that cattle can convert this herbage cheaply into saleable beef. The tremendous potential to increase red meat production from grazing cattle was demonstrated at both Gaopoling and Lechang model cattle farms where improved pastures were sown. At Gaopoling Farm, Michalk et al. (1995) reported that yellow cattle grazing stylos in fenced paddocks were heavier, in better condition and maintained or increased liveweight over the dry season (Figure 5). Calving and weaning rates were also higher for the improved herd and calf growth rate exceeded 0.4 kg/head/day over the wet season (Table 3). Further, carrying capacity was increased from 0.25 AU to 1 AU/ha where superphosphate was applied and stylos and Siratro were used to augment native grassland. In North Guangdong Province at Lechang Farm weaner cattle grazing setaria-based pastures with an average feed-on-offer of 1.7 t DM/ha produced 3 kg/ha/day LWG when stocked at 3.5 AU/ha over a 119 day grazing period. Based on economic analyses, these results suggest that beef production from well managed sown pastures offers one of the cheapest means of meat production in Guangdong and Hainan.

Table 3. Reproductive performance of cows and calf growth rate for tradition and improved management systems (Michalk et al. 1995).

System	Year	Calving (%)	Calf GR (g/head/day)	Weaning (%)	Weaning wt. (kg)
Traditional	1982	74	222	59	81
	1983	85	288	79	62
Improved	1982	90	458	83	113
	1983	92	378	86	112

Present markets and future potential

In Guangdong and Hainan Provinces, there is a high desire to increase dietary intake of animal products and, as incomes rise, demand can be expected to increase as has been the case in other Asian countries. For example, Japan formerly had dietary and income patterns similar to China, but Japan now has a *per capita* meat consumption of >30 kg (Anon. 1997). Perhaps Japan's development is somewhat indicative of future trends in China (Ward et al. 1986), particularly in Guangdong Province, which is predicted to become the next Asian economic tiger by 2010 (USDA 1998).

The impacts of a booming export trade in consumer goods emanating from Guangdong Province, which accounts for 30% of China's total, coupled with massive foreign investment (40% of China's total foreign investment) are already evident in a rising standard of living and in the demand for meat in Guangdong. At present, local production provides only 50% of current consumption in Guangdong and Hainan, and each year large amounts of pork and beef

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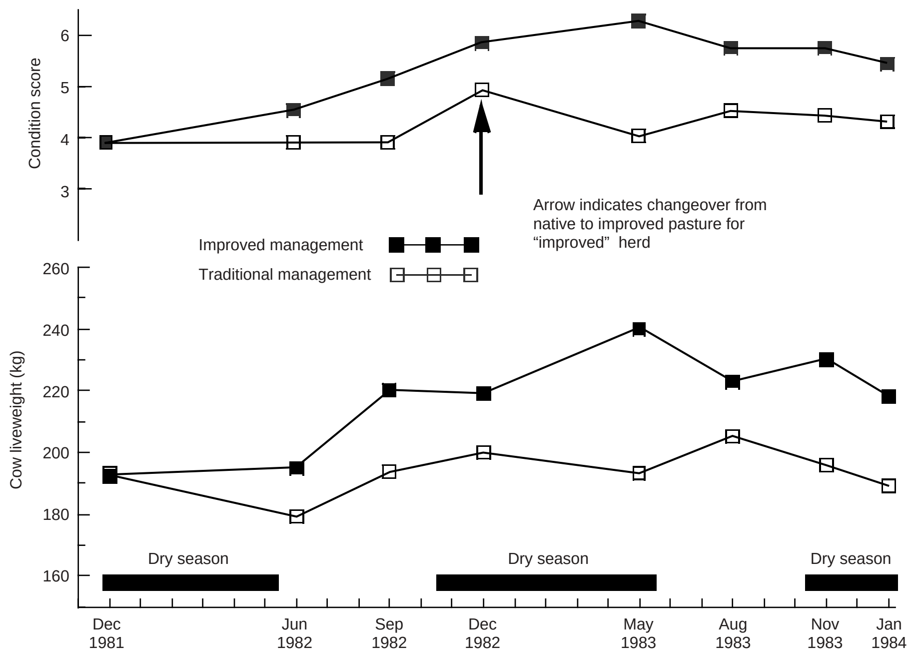

Figure 5. Liveweight and condition of cows grazed using traditional and improved management at Gaopoling Farm (1981–1984). (After Michalk et al. 1995.)

are imported from Sichuan and other provinces to meet increasing demands (Qin et al. 1997). Traditionally, beef has been consumed as a shredded or sliced product in local dishes where price and not quality was the chief purchasing factor. Since breeders have usually received their maximum return by selling their cattle as draught animals to other farmers, there has been little incentive to improve meat quality. However, following the de-regulation of meat markets in 1991 (Longworth and Williamson 1993) the price of beef began to increase to make meat production as lucrative as draft production.

De-regulation has also had an effect on quality. Prior to 1991, there were no standard market requirements specified or demanded by buyers, and cattle were marketed at all ages, weights and level of finish. However, where price incentives have been offered for quality and supermarkets have started to replace the traditional open air markets in Guangdong, the quality of beef and carcase size have steadily improved. Several Hong Kong supermarket chains have expanded into Guangzhou and are popular because of the convenience of the one-stop-shopping they provide. Home refrigerator capacity, which has increased rapidly with more than 50% of urban households now owning at least one small unit, has also enabled consumers to shop for meat, fruit and vegetables less frequently than was the case with buying from 'wet' markets.

As the disposable income levels increase, with more than 250 million affluent Chinese expected to enter the middle class in the next decade (Martin 1995), there is also a rapidly developing market in the fast food industry. McDonald's, for example, has placed a great deal of emphasis on developing markets in China and planned to open 300 outlets by 2000. Many of these will be located in Guangdong Province, where the GDP growth has exceeded 20% *per annum* for several years and the *per capita* income averages upwards of $US1500. Already Guangdong consumers are demanding greater variety, higher quality and more convenience as their disposal income rise as reflected in the increased number of fast food outlets now thriving in Guangzhou. One of the big challenges for these fast food chains is finding farmers willing to supply produce that meet the minimum stringent standards at the right price (Anon. 1996b). Even with other market options, contracting supplies for the burgeoning restaurant chain outlets provides an attractive market for beef in Guangdong and Hainan.

Not all the beef produced or imported from other provinces is consumed in Guangdong as a proportion is exported, mainly to Hong Kong. The current market absorbs approximately 500 to 1000 head per day coming from all over China. Guangdong Province, which adjoins Hong Kong, provides about 50,000 head per year. Exported beef carcases are devoid of external fat and correspond with the cutter or canner grades of the US classification. However, given the growing affluence in Guangdong and Hainan it is unlikely that export markets will be developed for beef produced in south China. Rather, it is more likely that there will be an increasing competition from foreign beef imported from Australia, New Zealand, the United States and Canada initially to continue to supply the tourist hotel trade, but also vying for the local markets as demand and disposable income increase with time.

WHOLE-FARM MANAGEMENT SYSTEM FOR CATTLE PRODUCTION

A major question posed in the 1980s was whether cattle production could be expanded on grasslands by better pasture and livestock management with much less dependence on supplementary feedstuffs that were competitive with human consumption, as is the case with the concentrates needed to support swine and poultry production (Ward et al. 1986). However, many of the model farm development projects have demonstrated that whole-farm systems that combined pasture development with livestock management can be successful in south China. A common basis of all these systems was to first reduce variability in feed supply by combining different pasture species in a feed-year system, and then managing livestock to ensure that periods of peak feed demand coincide with peak pasture production. In Guangdong and Hainan this can best be achieved by strategic mating and selling programs coupled with the use of appropriate pasture species and urea-molasses supplements to improve utilisation of low quality, tropical pastures in autumn and winter (if required).

The most difficult task in integrating various pasture types into a “feed-year” is to decide the area of each pasture type needed to support the particular types of cattle enterprises. Successful integration requires a detailed knowledge of the growth and quality characteristics of each pasture type and the specific nutritional needs of each class of livestock (e.g. breeding cows, replacement heifers, bulls, steers and calves). Based on size, expected production parameters and special nutritional requirements for different livestock classes, Michalk et al. (1994) calculated that for a 100-cow breeding-and-fattening herd, an annual forage supply of 562 t was needed to sustain the 154 AU of the herd, which included cows, replacement heifers, weaners, steers and bulls (Table 4). To avoid the use of supplements, the special nutritional needs of pregnant cows, replacement heifers and weaners (all of which require good quality feed) must be provided by alternative forage sources over the winter-early spring months, when summer growing (tropical) pastures are dormant. For both Guangdong and Hainan Provinces, it was feasible to provide a continuous supply of forage to meet the needs of a breeding-and-fattening enterprise by establishing suitably sized areas of different pasture types and integrating them into a feed-year program.

Table 4. Herd structure for a 100-cow breeding unit. (After Michalk et al. 1994.)

Cattle class	Liveweight mean/ range (kg)	Number	AU equivalent[1]	Total AUs
Cows[2]	210	100	0.80	80
Replacement heifers	140–180	35	0.60	21
Weaners[3]	50–100	76	0.35	27
Steers (>12 months)	100–200	35	0.65	23
Bulls	260	4	0.80	3
Total		250		154

[1] AU = animal unit (equivalent to 400 kg steer).
[2] Suckling calves are included in the AU rating for cows.
[3] Number of weaners based on an 85% calving rate and 10% mortality from birth to weaning.

Pasture budgeting is the process used to decide the area to allocate to each type of pasture (Murtagh and Moore 1987). From the information in Table 4 and Figure 2, Michalk et al. (1994) calculated the area of each pasture type needed to provide adequate feed for a 100 cow breeding herd in the red soil region of north Guangdong Province (Table 5). Based on the pasture budgeting analysis, a ratio of 1:4:8.5 of forage oats, white clover and setaria pastures should be the goal in development of red soil areas of north Guangdong to provide a continuous supply of good quality forage for a breeding-and-fattening enterprise. These pasture types require different levels of management. Setaria-based pastures are the easiest to establish and manage with only moderate grazing pressure required to maintain vegetative growth and palatability for as long as possible and moderate fertiliser inputs (P and K) to maintain yield >5t DM/ha. Due to lower tolerance to acid soil conditions, white clover needs to be grown on limed soil and fertilised with P, K and Mg (Michalk and Huang 1993). Forage oats must be planted early in October on a well prepared seedbed to ensure production in February. However, forage oats can also be oversown into setaria pastures, which provides extra flexibility for filling the February feed gap. This strategy has proved successful in a similar climate in subtropical Australia (Colman 1966) and is a feasible option for north Guangdong Province.

Different pasture types have also been successfully combined to provide a sound forage base for cattle

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production in Hainan Island by providing high quality standing dry pasture over the protracted dry period by integrating Siratro- and stylo-based pastures (Mears 1982; Michalk and Dunn 1984). These pastures have different growth habits, life-cycles and mechanisms for persistence. Although Siratro can live for several years in the dry tropics, severe grazing at the start of the wet season when Siratro is re-sprouting leads to premature death (Jones 1974). This means that conservative stocking rates must be imposed during this period. Apart from lenient management or rest during the June–July period, Siratro-based pastures can be continuously grazed for the remainder of the year (Jones and Jones 1977), especially when sown with setaria as a companion grass on red loam soil in Hainan Island (Mears 1982).

Table 5. Area of each pasture type required to support a 100-cow breeding-and-fattening herd in subtropical Guangdong Province. (After Michalk et al. 1994.)

Pasture type	Yield[1] (t DM/ha)	Area (ha)	Grazing days required	Forage required (t)
Setaria-based	3 to 6	104 to 209	245[2]	434
White clover-based	<2 to 4	45 to 91	92[2]	118
Forage oats	<2 to 3	12 to 18	28	36
Total		161 to 318	365	562

[1] Low yields represent situations where fertilisers are applied at sowing but no maintenance fertiliser applied in subsequent years. These yields will decrease more rapidly as soil fertility declines.

[2] Assumes a utilisation rate of 65% , which is consistent with good management for pasture persistence.

In contrast to Siratro pastures, stylo-based pastures with a strong grass component (whether native or sown) benefit from heavy grazing during the early wet season to reduce competition, particularly from tall bunch grasses as stylos are sensitive to shading when regenerating as well as competition for nutrients and water in the root zone (Tossell et al. 1976). During the early wet season when grasses are growing rapidly and are still nutritious and palatable, cattle select this material in preference to the slower growing stylos (Gardener and Ash 1994). This selective grazing confers a competitive advantage to the stylo by removing the effects of shading. However, to be effective, pasture availability and livestock demands must be balanced because overgrazing at the start of the wet season will be more detrimental than beneficial as cattle consume developing stylos when there is little else available. Further, overgrazing early in the wet season can lead to stylo dominance with the loss of perennial grasses resulting in unstable pastures (Jones et al. 1997) and reduced liveweight gains in the wet season (Winter et al. 1989). Over the dry season, stylo provides good quality standing forage due to its ability to retain leaf material in dry tropical conditions where there is no dry season rainfall to cause spoilage. Gardener (1980) reported, for example, that *S. hamata* (cv. Verano) made a direct contribution to cattle nutrition in the coastal dry tropics of Queensland, Australia, for about the first five months of the dry season. In western Hainan, low rainfall in the December–March period (<45 mm) ensures good carry over feed.

Due to the complementarity between the two pasture types they can be easily integrated to allow stock movement between them as required (Figure 3). This integration can be best achieved by using utilisation levels based on 'correct use' rather than stocking rate recommendations. Observations in commercial paddocks at Gaopoling Farm suggest that for stylo pastures, correct use was achieved when 10% to 25% of the grass component remained at the end of the wet season (but the stylo left unutilised), while stylo can be utilised to a similar level by the end of the dry season but with a residue of about 1.25t DM/ha remaining (Michalk and Dunn 1984). From research undertaken in Thailand, Tudsri et al. (1989) also concluded that grazing stylo pastures (*S. hamata* in this case) at an early stage of growth enhanced stylo performance, especially if grazing intensity was adjusted to leave several residual nodes on the main stem after each grazing. For Siratro pastures, however, recovery from grazing was greatest when 40% of the annual pasture production or 1.25 t DM/ha is left ungrazed at the end of the grazing period.

For most grassland areas in Hainan's dry tropics, a higher proportion of stylo pasture is likely to be included in an integrated feed year system because there is a greater proportion of sandy soil which is not suitable for Siratro production (Michalk et al. 1993a). At Gaopoling Farm, red loam soil accounted for <25% of the farm area and this was the constraint used in Table 6 to calculate the area of stylo and Siratro pastures required to support a 100-cow breeding-and-fattening herd. The real merit of Siratro is to provide high quality wet season grazing for weaners and replacement heifers, that is the area of Siratro needs to be only large enough to provide the requirements for about 48 AUs (Table 4) when deferred-rotationally grazed to ensure persistence of Siratro (Figure 3). Based on these constraints, the best pasture combination would include about 40 ha of Siratro and 140 ha of stylo (i.e. a ratio of 1: 3.5).

Table 6. Area of stylo and Siratro pasture type required to support a 100-cow breeding-and-fattening herd in dry tropical Hainan Island.

Pasture type	Yield[1] (t DM/ha)	AU grazing days required	Forage required (t)	Area needed[3] (ha)
Siratro/setaria	3 to 5	13,054[2]	130	34 to 74
Stylo-based	4 to 6	43,156	432	90 to 157
Total		56,210	562	124 to 231

[1] Low yields for stylo pastures represent situations where no fertiliser has been applied whereas low yields for Siratro/setaria are typical of pastures sown on sandy rather than loam soil.

[2] Based on providing sufficient forage for cows and weaners for four months in the June to December period excluding periods when Siratro is rested (Figure 3).

[3] Based on a utilisation rate down to 1.25 t DM/ha at the end of dry season.

CONCLUSIONS

A major concern of the Chinese government is how meat and other livestock products can be produced more efficiently (Simpson and Li 1996). The central objective of model farms established in Guangdong and Hainan Province was to improve cattle production, especially through the winter-early spring period when cold (north Guangdong) or inadequate soil moisture (Hainan Island) prevails. Research and development over several years (1981 to 1989) demonstrated that the establishment and management of legume-based pastures is the most effective means of improving cattle performance in south China, and there is now good technical information available to enable considerable advances to be made in improving the efficiency and total output of the beef cattle industry in Guangdong and Hainan Provinces.

The combined effect of sowing recommended species, using low-input fertiliser strategies and implementing management systems that effectively integrate appropriate pasture types is to provide a continuous supply of quality forage with potential beef output superior to that possible on unimproved grassland systems. Use of these systems as described for Guangdong and Hainan leads to higher grazing capacity and per head animal performance, which in turn significantly increases beef production per hectare. It is fortunate that legume-based pasture systems demonstrated for both subtropical Guangdong and dry tropical Hainan need relatively low inputs of fertiliser and that cattle can convert herbage cheaply into saleable beef. A similar approach using introduced legumes and grasses is also advocated for livestock improvement in northern China (Sun 1987).

These integrated pasture systems, however, are not designed for use by small subsistence landholders producing beef as a by-product from draft animals, but rather for specialised cattle farms where beef is the focus for production. It is anticipated that such operations will provide the bulk of the beef required to meet the demands of the expanding supermarket trade and fast food outlets in Guangdong and Hainan. The analyses presented indicate that cattle farms of about 200 ha are required to support a specialised 100-cow breeding-and-fattening beef enterprises based on grazed pasture with minimal or no supplemental feed. This type of operation, where the entire beef production process is controlled in a single farm unit, is currently the most attractive option to produce quality beef, while the processing facilities, storage units and retailing outlets are being put in place to accommodate the requirements of the developing markets. Fortunately, much of the “wasteland” areas that offer a great potential for improvement through the introduction of adapted pasture species, fertiliser and management are located in areas where it is still possible to acquire farms of this size. Many of the former county-administered State farms in Hainan, for example, established beef cattle production operations under the responsibility system and have since evolved into commercial ventures.

Once quality beef attracts a premium price, it is likely that a diversified industry will develop where breeding (cow-calf operations), fattening and feedlotting will be undertaken on different farms. Small producers may play an important role of providing feeders in a diversified industry as the dependence on cattle for draft power is eroded by increasing mechanisation, particularly in the double and triple rice systems in Guangdong Province, where the switch to mechanical power sources is most rapid because of the inability of draft animals to cultivate the extra area. A shift to the cow/calf operation at the small producer end of the industry would also free up some rangeland for improvement by reducing stock numbers by moving feeders to specialised farms for finishing. One innovation currently being experimented with at the Beijing Agricultural University to facilitate the movement of cattle from breeding to feeding farms is a contract system in which the cow/calf producers retain complete or partial ownership of calves through the fattening process (Simpson and Li 1996). However, as Simpson and Li (1996) also point out, “there is no one solution to the so-called ‘pastoral problem’ of relatively low offtake rates” in China, and production systems need to be adapted to local conditions. Undoubtedly, a range of beef cattle enterprises will emerge in Guangdong and Hainan as quality beef attracts a price premium.

Irrespective of what system evolves to efficiently produce beef in south China, one message is clear for the future of Guangdong and Hainan Province — their people want a better standard of living which includes better quality food available at retail outlets that are more convenient than the 'open' markets. Given the strength of the economy and the increasing disposable income there is little doubt that the requirements can be met primarily through the development of better quality pastures and cattle management systems. The challenge for researchers and extension officers is to work with producers to continue to develop and modify the technical aspects of beef production to keep pace with the expanding beef consumption.

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ESTABLISHING PASTURE–TREE SYSTEMS TO REHABILTATE ERODED LAND IN FUJIAN

Su Shuijin, Lin Kai Wang, Lin Jielong, Liu Jiancan

Fujian Soil Conservation and River Development, 115 Guping Rd., Fuzhou, Fujian Province, 350003, P. R. China.

Abstract

An experiment to explore the effect of forage establishment on trees (both Masson pine and Longan fruit) to rehabilitate severely eroded sloping land was conducted from 1984 to 1994. It was shown that forage planted under pine and fruit trees can promote the growth of both. The annual height increment of pine trees increased from 21.4 cm/year on severely eroded land (control plots) to 62.2 cm where pine + grass were planted. The weight of pine tree roots and of above ground pine tree biomass where grasses were established were 9.7 and 5.9 times those of the control plots respectively. The total quantity of bacteria in grassland soil was increased 5.5 times that of the control. Soil loss was reduced from 5444 t/km^2/yr for the bare soil control to just 466 t/km^2/yr where grassland was established. There were no negative impacts of the grasses on the fruit trees growing in orchards as the rooting depths of the trees and grasses differed. The grasses did not compete with the fruit trees for soil fertility or moisture; however, they did increase the nutrients and moisture content of the soil. The soil moisture of the grassland in the orchard was increased from 8.8% to 20.7% compared with the topsoil moisture in the orchard land with bare soil because the organic matter was increased, whereas evaporation decreased due to the grass cover.

The soil surface temperature of forage + Longan orchard was 13.3°C lower than that of the bare surface soil of the orchard, where it reached as high as 50°C in August. In the area planted to Masson pine and grasses, the maximum surface soil temperature reached was 4.8°C lower than that of the bare earth control which reached as high as 46.8°C.

The forage + Longan combination also resulted in higher economic benefits than fruit crops alone, grasses, crops, or forage + Masson pine. The forage + Masson pine plantation had a lower cash return from forage in its first 3–5 years after forage planting, but this did not take into account the tree value when the pine was harvested.

The average daily weight of geese fed by a feed mix comprising up to 20% of forage powder was no different to that achieved with normal more costly rations. Thus allowed full use to be made of the meadows and balancing forage supply over the entire year.

Growing day lily mushrooms using forage powder as part of the growing medium resulted in 15% more production than those grown on more conventional sawdust media. In addition, the spent growth media after the mushrooms have been harvested can be used as a useful forage for raising stock and poultry.

Experimental results have shown that grass interplanted with fruit and timber trees is an attractive measure to rehabilitate eroded red soil and bring about more sustainable land management.

INTRODUCTION

FUJIAN is on the southeastern coast of China. It is in the subtropical monsoon climate zone, with a high human population. Because of the development of mountain areas, severe soil erosion had become a major factor limiting local agricultural development. In 1939, soil conservationists in Fujian began to plant grasses as a fuel source on bare hillsides, with some success in reducing soil erosion. However, due to their low economic value, the technologies were not extended widely. On the other hand, some experience had been gained in the development of pasture on sloping land (Zhenju Huan 1984), but because of the rapid growth of wild shrubs, the problems of management and stability of the pasture were not solved. This restricted the area of grasses planted for feeding livestock. Parts of the mountain areas experienced soil erosion that was so severe even the pioneer tree species, Masson pine, which is known as the best drought tolerant species adapted to barren soils, hardly grew there.

The experimental site used in this study was in south Fujian, with its subtropical monsoon climate, and at a latitude of 24°30′N. Annual precipitation is about 1600 mm, of which 52% falls between April and June. The highest temperature is 40.9°C and lowest –2°C. The soil at the site is on sloping land and is a severely eroded red soil weathered from granite rock.

Masson pine (*Pinus massoniana*) had been planted 6.2 years before the experiment commenced. At the start of the experiment, the trees were 50 cm high with a crown width of 42 cm. The tree density was about 320 plants/ha.

A range of forage plants were used including: annual grass species such as *Digitaria sanguinalis*, perennial grasses such as *Paspalum orbiculare*, *Paspalum wettsteinii*, *Sorghum propinquum* and *Setaria sphacelata* and legumes such as *Stylosanthes humilis*, *Lespedeza bicolor*, and *Indigofera* spp.

In the past decade, as development has increased on sloping land, soil erosion has become very serious, especially in new orchards. At the same time, farmers have retained their customary practice of weeding old orchards, which exacerbated the level of serious soil erosion in these orchards. Since the 1960s, some successful technologies for interplanting green manure into orchards have been introduced; however, the low nutritive value of the green manure and lack of suitable perennial species has forced farmers to replant each year resulting in unwillingness by farmers to accept these technologies. In 1985, in an attempt to solve these problems we undertook interplanting of perennial forages in the sparse Masson pine forests and new Longan orchards on sloping land.

EFFECT OF FORAGE ON RED SOIL EROSION AND FERTILITY

Erosion control during pasture establishment

During pasture establishment on the Masson pine land, a seeding combination of annual grass, perennial grass and legume was adopted in order to produce fast cover during the rainy season experienced in spring and summer. Crab grass (*Digitaria sanguinalis)* grows rapidly and covers loose eroded bare red soil. In autumn and in the next year, perennial grasses such as *Paspalum orbiculare* and *P. wettsteinii* replaced the annual crab grass, and legume shrubs such as *Indigofera* spp. and *Lespedeza bicolor* grew vigorously after the second and third year. It was demonstrated that a stable forage + pine system consisting of perennial grasses, legume shrubs and young Masson pine trees had been formed.

Soil on cultivated and eroded bare land was loose following planting and soil erosion occurred readily due to rain in March and April, before the bare soil was covered by grass during the pasture establishment phase (Figure 1). The quantity of eroded soil lost from the sown area of grassland was initially 5.2 times that measured on the bare soil control; however, by the second period (May–August), erosion on the sown area of grassland was only 10% of that which occurred on the control during the late spring to late summer months. Thus, the planted forages dramatically reduced soil erosion.

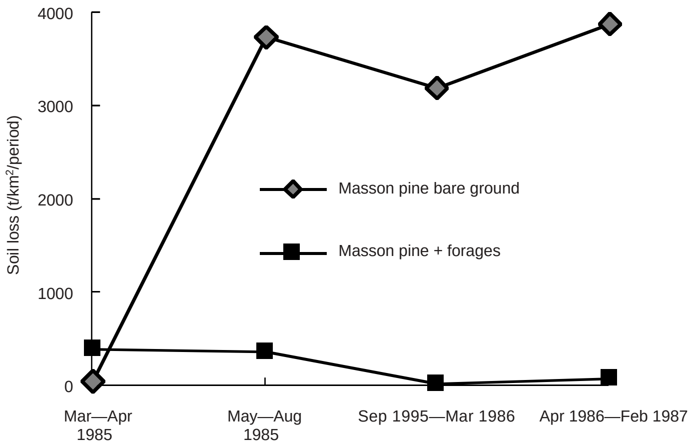

Figure 1. Soil erosion measured during the pasture establishment phase. (Grassland was cultivated by hoe just before seeding in February 1985).

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The effects of grass on soil fertility

Tables 1 and 2 show that the effects were due not only to cultivating and fertilising, but also to the grass growth. Soil fertility was improved by the growth of the forages, especially organic matter, P, K and soil bulk density.

Soil nutrients were increased when forages were planted on bare land in the Longan orchards. The dead leaves and roots of the sown forages decomposed so that the organic matter was increased. Furthermore, the moisture content of the orchard/grassland soil was 8.8% to 20.07% more than that of the control (unfertilized) orchard land, because evaporation was reduced and grass cover also intercepted runoff so that net soil moisture was increased.

INFLUENCE OF FORAGES ON TREE GROWTH

Pasture effect on Masson pine growth

The height of the original Masson pine on severely eroded land increased by only 21.4 cm annually. In contrast, the pine grew 62.24 cm annually for three years on the area with planted forages, which was 290% of the bare pine land cultivated by hoe and fertilised (fertilized control) (Table 3). Pine roots had developed, which increased the capability of the roots to take up soil nutrients and water. The biomass of root, timber and branches was 693%, 1017% and 346% higher than in the CK_1, respectively. Also, the foliage of the pines after planting the grass was greener than that of pine on the original eroded land.

Effect of forages on Longan fruit trees in orchards

Table 4 shows that there was no negative impact of grass on the growth of the fruit trees in the orchard. Tree growth was promoted by the forage planting throughout the measurement period. Because the roots of the sown forages grow mostly within the top 30 cm of the soil and most fruit tree roots grow below that zone, the forages do not compete with the fruit trees for soil fertility or moisture. They also increased soil nutrient content due largely to increased organic matter.

Table 1. Soil improvement by forages planted on severely eroded Masson pine forested land.

Treatment	Organic matter (%)	pH	Total (%)			Available (ppm)			Soil bulk density (g/cm^3)
			N	P	K	NH_3	P_2O_5	K_2O	
Grassland	1.6	5.0	0.05	0.04	3.4	208.3	9.5	75.6	1.4
Control with fertilizer	0.4	5.1	0.03	0.02	3.1	216.4	2.8	53.0	1.5
Control without fertilizer	0.4	4.7	0.02	0.002	1.2	93.6	2.8	52.2	1.6

Note: CK_1 — bare land cultivated and fertilised without forage seeding; determined soil layer is at 0–10 cm depth.

Table 2. Nutrient content in soil of orchards with and without forage cover.

Treatment	Year	pH	Organic matter (%)	Total (%)			Available (ppm)		
				N	P	K	NH_3	P_2O_5	K_2O
Forage cover	1992	4.9	1.71	0.0971	0.103	0.683	77.21	39.20	21.10
	1993	5.2	1.76	0.0993	0.112	0.699	81.21	41.45	25.34
CK_2	1992	4.8	1.47	0.0816	0.091	0.598	86.23	23.83	13.23
	1993	5.2	1.43	0.0767	0.092	0.687	60.63	18.70	25.30

Note: CK_2 — bare land of the orchard, the soil sampled at 0–20 cm depth layer.

Table 3. The effect of forages on Masson pine growth.

Treatment	Annual increase in tree height (cm)	Root weight (kg/tree)	Timber volume (m^3/tree)	Dry weight of tree branches (kg/tree)
Control — fertilized	21.36	0.12	0.00048	0.65
Planted forage	62.64	0.83	0.00488	2.25
Increase (%)	293	693	1017	346

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Table 4. Effect of forage on growth (height, diameter at soil surface and crown diameter) of Longan orchard trees.

Treatment	July 1993			Nov 1994			Increase					
	Height (cm)	Trunk diameter (cm)	Crown diameter (cm)	Height (cm)	Trunk diameter (cm)	Crown diameter (cm)	Height (cm)	(%)	Trunk diameter (cm)	(%)	Crown diameter (cm)	(%)
Fruit trees + forage	134.7	1.90	41.9	181.9	3.77	115.5	47.2	40	1.86	10	73.5	173
Fruit trees + bare soil	136.1	1.97	44.8	181.9	3.61	107.9	45.8	33	1.64	8	63.1	141

EFFECT OF FORAGES ON THE MICROCLIMATE OF ERODED RED SOIL

Activity of microorganisms

After the grassland was established, physical conditions of the soil improved and the bulk density reduced because of the turnover of roots from the sown forages (Table 1). Furthermore, the temperature at the soil surface was also lower than that of eroded bare land, which provided good conditions for microbiological survival and development. Based on the determination of microbiological activity in February 1987, the total quantity of bacteria in the orchard sown with forages was 5.5 times that in the original bare land, and the quantity of ammonia-releasing bacteria 9.3 times that of the control (Table 5).

Table 5. Effect of forage growth on microorganisms numbers assessed in February 1987.

Treatment	Total bacteria	Fungi in soil	Ammonia-releasing bacteria
	(number/g soil)		
Grassland	99.5×10^6	65.1×10^4	202.0×10^3
Control	18.0×10^6	7.0×10^4	11.8×10^3
Percent increase over control	453%	830%	1612%

Temperature changes due to forages

Daily measurements made at 1.00 p.m. in August 1993 showed that the soil surface temperature under forages was lower than that of bare land in the orchard. The soil surface temperature in the orchard reached 50°C, which is 13.3°C higher than that under the planted forage. The forage cover had a great effect on soil temperature within the top 30 cm layer of soil. Temperatures above 37°C in soil have a negative impact on the root development of fruit trees (Li Lairong 1983).

GRASS–TREE ECONOMIC BENEFIT

Geese-raising using composted forages

In this test, 150 head of 30-day-old geese were selected, and divided randomly into three groups (two treatment groups and one control group) with an insignificant difference in initial weight ($P > 0.05$).

The forage formula used was based largely on ingredients recommended by the NRC Standard of USA, the Geese Breeding Standard of the former USSR, and the local geese-breeding forage formula. Forage powder was added to this ration at either 0%, 15% or 20% by weight and was fed for 30 days. The composition of the forage formulations fed to the geese and its cost is shown in Table 6 below.

Table 6. Forage formula and cost.

	Forage composition		
	Control (no forage)	15% forage content	20% forage content
Grass forage powder (%)	0	15	20
Maize (%)	54	54	54
Wheat bran (%)	12	7	2
Bean powder (%)	14	14	14
Fish powder (%)	7	7	7
Rice bran (%)	10	0	0
Shell powder (%)	1.6	1.6	1.6
$CaH_2P_2O_5$ (%)	1	1	1
Mineral elements (%)	0.2	0.2	0.2
Medicines (%)	0.2	0.2	0.2
Vitamins (%)	10	10	10
Cost (RMB)/100 kg forage	197.2	186.4	182.4

Table 7 shows there was no significant difference among the three groups, with almost the same feed conversion from forage to meat. This confirmed that forage powder could be substituted for bran ingredients at up to 20% of the ration with no loss of nutritional value for the birds.

Analysis of economic benefits

Table 8 shows that there was no significant difference among the three groups in feed consumption or weight gain, but the cost of forage was reduced by adding forage powder.

Raising geese with the compound forages can make full use of meadows, balance the forage supply in the off- and peak seasons, and guarantee the supply of high-quality forage powder in the off-season.

The culture of edible mushrooms using forages in the growing medium

Forage powders were produced from a range of forage species including: *Indigofera* spp., *Sorghum propinquum*, *Zea* spp., *Setaria sphacelata*; and *Paspalum wettsteinii*. This forage powder was used to formulate culture media for the growth of day lily mushrooms.

Of the various formulations tested, that which included *Paspalum wettsteinii* was found to significantly improve mushroom growth by up to 15%.

DISCUSSION AND CONCLUSION

Grass in the grass–tree system plays an important role in rehabilitating red soil on severely eroded sloping land. It has positive effects on erosion control and soil improvement, and is superior to pure stands of trees, in bringing about sustainable land use.

Experiments have shown that the following management practices should be adopted:

1. The grass should be cut both for high quality fodder and to keep the area under the tree crown clean to prevent excessive grass competition.
2. Grass types with short roots and of medium height should be selected.
3. Perennial grasses and legumes give good cover and high quality pasture.

Through the variety comparison experiment the Bahia grass (*Paspalum notatum*), *Paspalum wettsteinii* and *Stylosanthes* legume were found to be the best varieties of forage for establishing with fruit trees in the orchards on the southeast coast of China.

In general, grasses resulted in greater soil improvement on severely eroded land as they have extensive and fibrous root systems and grow rapidly. Several desirable species have been identified.

Raising geese with the compound forage of grass powder demonstrated that up to 20% of the feed could be made up with forage powder with no loss of nutritional value and yet resulting in reduced forage costs. Raising geese with formulated feed comprising some grass powder made fuller use of pasture areas, balanced the forage grass supply over the seasons, and guaranteed a supply of high-quality grass powder for forage in the off-season.

The culture of day lily mushrooms was also found to be successful when using grass powder in the growing media. This resulted in cost savings of up to 30,000

Table 7. Effect on weight increment and feed conversion efficiency of including forage in geese feed.

Group	Average starting weight (kg)	Average finishing weight (kg)	Average weight increase (g/day)	Feed conversion efficiency (kg feed/kg meat)
Control (no forage)	2.2	4.24	69.6	3.04:1
15% forage content	2.2	4.25	68.0	3.01:1
20% forage content	2.2	4.24	70.3	3.00:1

Table 8. Comparison of economic benefits of adding forage to geese feed.

Group	Amount of forage consumed (kg)	Cost of forage (RMB)	Weight gain (kg)	Output value of weight increase (RMB)	Gross profit (RMB)
Control (no forage)	310	612	102	938	326
15% forage content	310	578	103	948	369
20% forage content	311	567	104	952	385

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yuan/ha and the spent material can still be used for feeding livestock and for poultry.

Pasture establishment must provide economic benefits from increased animal products or edible fungus products through its use of grass. Therefore grass utilisation is an important factor in the grass–tree system and its economic benefit. The key is to motivate farmer interest in participating in soil conservation activities aimed at providing sustainable land use in red soil degradation areas.

The results have shown that planting forages can promote the growth of Masson pine, control soil erosion and improve the micro-ecological environment. Interplanting the forages in the orchards did not harm the Longan fruit trees; meanwhile it improved the soil fertility and the land productivity per unit area for economic and environmental benefits. It was a successful demonstration for the development of eroded sloping land that has been extended to large rural areas.

REPORT OF WORKSHOP DISCUSSION ON 'FORAGES FOR RED SOILS — FROM RESEARCH TO PRACTICE'

I.R. Willett and Liu Chungchu

AFTER the presentation of the papers collected in these proceedings, the workshop participants held a two-hour discussion period. The participants formed four groups to discuss:

(a) soils, climate and biological constraints to the introduction of forages in the 'red soils' areas of China;

(b) animal production systems for forage utilisation;

(c) socioeconomic factors; and

(d) constraints to extension and adoption of new technologies.

The four groups came together at the end of their discussion periods for a joint discussion. This report briefly summarises the outcomes of these workshop discussions. The theme of 'Forages for red soils — from research to practice' was kept prominent. The discussions included elements of taking stock of the research results that have been achieved and could be put into practice in the short term, as well as identification of constraints that may require further research.

The group considering extension matters provided a valuable stocktake of what has been achieved by the considerable research effort supported by ACIAR and other agencies. They concluded that pasture species have been successfully identified for a wide range of soil and site conditions. These range from hardy plants suitable for low input systems in highly degraded areas, to more productive species for favourable conditions such as fertilised understoreys in citrus orchards in Fujian. The group considered that there is already enough information available on the fertiliser requirements of introduced forage species. In addition, they were satisfied that the techniques to reliably establish forage species for a range of soil stabilisation and pasture production systems have been developed by the research projects.

The group concerned with extension also noted that practical techniques involving forages for soil stabilisation and control of soil erosion by water have been well established. They considered that there is a reasonable amount of information known about the benefits for animal production of the temperate forage species and some of the tropical species.

So, with such promising research results, what are the problems for the extension and adoption of new forage-based systems in the red soils region? The group identified the following factors:

- an inadequate knowledge base in the farming community to adopt new technologies into their farming system;
- difficulties have been experienced in convincing farmers of the need for change, or of the benefits of new forage-based technologies;
- new technologies have often been produced as single item improvements and these have been difficult to introduce into complex farming systems;
- the relative complexity of the new technologies, particularly if they include the introduction of ruminants, makes transfer and adoption difficult;
- there is still uncertainty of the financial returns of the new technology to farmers; and
- research centres have not been effective in demonstrating the technologies or their financial returns in a practical or clear way.

The means of introducing changes in the region were discussed. In particular it was considered that the large development projects, such as those supported by the World Bank, may be too ambitious in rapidly introducing large changes. While large development projects, and reliance on government support are essential for infrastructural development such as electric power, processing plants and transport, it was thought that a more 'local model' may be successful in introducing new forage-based systems. This model envisages direct linkages between researchers, extensionists and farmers, and would involve incremental changes rather than large interventions as often promoted by major development projects.

The group that discussed socioeconomic aspects of the introduction of forage-based systems recognised several constraints to the adoption of the new technological results. It was recognised that opportunities for forage production must fit in with competing alternatives, that rice production in well-watered areas will have priority, and that opportunities in non-agricultural activities have increased labour

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costs, particularly in the coastal provinces of China. It appears farmers are not accustomed to investing in forages, and expect it to be available at very low, or no cost to themselves, in the form of crop residues or common grazing lands. In comparison with some other agricultural investments, forage production requires high initial establishment costs for weed control, seedbed preparation, fertilisation and liming, and seed. There was a perception that the return on forage establishment would be long term. In some commercial enterprises, concentrates are being used for animal feeding, and these appear to discourage interest in forage development.

The opportunities for improved forage production, where they may contribute to farmers' incomes and reduce soil degradation in the 'red soils' area, are as follows:

(a) *Forages as short-term winter crops grown after rice in well-watered areas.* It is envisaged that high quality forage, perhaps triticale, could be produced for feeding animals in the late winter and early spring when fodder supplies are critically low. Such materials could also be used for silage and fed at other times. In some areas, winter forage crops would be in direct competition with canola (oilseed rape) and in others could contribute to difficulties in raising two rice crops during the spring and summer. Farms in these areas are generally very small (<1 ha) and the introduction of only one or two large ruminants may be too risky for many farmers.

(b) *Forages as dual purpose soil stabilisers and fodder producers under orchards, particularly in Fujian.* There is abundant evidence of the benefits of low-growing forages such as *Lotononis* or *Arachis pintoi*, effectively stabilising hill slopes or rough terraces used for fruit production, and the legumes may contribute nitrogen. Soil improvements intended for the fruit trees, such as the application of manures and fertilisers, may improve the soil so that forage productivity is raised. However, ruminants cannot freely graze in orchards, and cut-and-carry systems would be necessary, and then only for the first few years until the trees cast too much shade for fodder production, or impede access for the harvesters.

(c) *Forages for degraded 'wastelands' and upland areas that are currently very unproductive.* Lower input systems, with minimal fertiliser phosphorus and lime, and perennial forage species are suggested for these purposes. *Chamaecrista* species may have a role if varieties that regenerate in spring are identified. Larger grazing enterprises could be established in such areas, but this may require resolution of land ownership where it is ambiguous.

In all systems, the labour cost of forage establishment is the largest part of the investment. It appears that mechanised cultivation and sowing will be required to reduce these costs, particularly in Fujian where labour costs are higher than in inland provinces.

In addition to the difficulties for each of the above situations, there are constraints that apply to the production of sheep or goat meat, and milk or beef in southern and central China in general. There is little traditional production of these animals in the red soils regions, where rice has always had priority. The researchers do not seem to know the desires of the farmers on whose behalf the research is being done. In addition, there are doubts about the acceptance of beef on the local markets because of its reputation for poor quality, and the processing and markets for meat products are either not there, or are ill-defined. Experience with excess orange production and associated plummeting prices will probably add to the difficulty of introducing changes — it can be speculated that widespread adoption of the results could lead to over-production of beef and the collapse of prices.

The group that discussed animal production systems recognised several constraints to forage utilisation. The key factor identified was the need for forage conservation and the need to increase the reliability of the feed supply so that production could be spread throughout the seasons and years. There were also concerns regarding the nutritional quality of some of the tropical forages, which can be low in protein and digestibility.

The utilisation of forages produced in orchards presents some difficulties and cut-and-carry systems need more evaluation, or systems for grazing orchards need to be reconsidered. Forage production systems must also be developed for other situations, including both smallholder and large production systems.
The use of high quality forages should be further considered for smallholder farming systems. Cattle were considered to be more profitable in the long term but goats may produce better returns in the short term. It was considered that goats would not cause environmental problems so long as forage production was adequate and there was good management of stocking rates. Forage utilisation by monogastrics should also be reconsidered. It was noted that Chinese Government policy was for 'grass-eating animal' meat production rather than ruminant production. Consideration of other animals may well accord with the desires of the local farmers. It was also noted that

organic matter and manure management will be essential for long term productivity and profitability.

The group that discussed soil, climate and biological constraints to forage production and its adoption considered resource constraints as well as some of those identified by the other groups. Low soil fertility and optimum utilisation of soil moisture were considered inherent constraints to forage production, as was the need to replace poor quality native grasses with nutritious forages. A change of attitude toward acceptance of fertiliser inputs to forages is required. Mixed pastures would offer advantages in reducing vulnerability to rodent damage, insect pests and disease. Adequate climatic indices are required to identify temperature and moisture stress periods and account for the variation expected over the large area of the red soils region.

In terms of problems of utilisation of forages it was concluded that animal production systems and the matching of animal production to the seasonal variation in forage supply during the year — the management decisions of when to breed or sell the animals — was an underdeveloped area. This aspect is closely related to the need for forage conservation identified by the animal production systems group. The animal production system would also need to take account of the cost of labour, and its availability throughout the year associated with existing farming practices.

This group also recognised the difficulties of productive utilisation of forages produced in orchards caused by limited access, and how development of ‘wasteland’ should be staged (large developments or by increments). Marketing for beef was also debated. On the one hand there is a limited local market associated with the lack of tradition of eating beef, and on the other an expectation that rising living standards in China will raise the demand for quality beef. Caution was expressed about the feasibility of developing a beef industry based on export marketing without first developing a local market.

The group recommended further research to match forage production with demand, while maintaining surface cover to prevent soil erosion, further searching for adapted perennial legumes, finding a means of staging the development of wastelands, and further work on overcoming low soil fertility.

CONCLUDING COMMENTS

Research has shown that there are productive forage species for a range of situations in the red soils regions of Hunan and Fujian. Forage production during winter in rotation with rice in productive lowlands can provide high quality fodder for feeding in late winter or early spring, or may be conserved by ensiling, as practised elsewhere in China. Nutritious forage can also be produced under orchards and offers several advantages in stabilising the soil against erosion by water, and by providing income before the trees start bearing fruit. In the uplands and degraded wastelands, lower input systems appear feasible, with dual benefits of halting soil erosion and increasing fodder production. One of the most promising species, *Chameacrista rotundifolia*, has some questions regarding its ability to regrow each spring from seed and to provide adequate protection of the soil in spring and early summer, and research is continuing to explore this genus for these characteristics.

It is clear that widespread adoption of forages in the red soils region will not occur for soil stabilisation purposes alone. The costs of soil loss, which may be largely external, cannot be expected to motivate farmers to grow forages. Rather, farmers need direct financial incentives, which can come only from effective utilisation of the forage by animal production. Our research has taken us as far as selecting, establishing, and managing a range of forages, and has demonstrated their effectiveness in reducing soil erosion. The challenge now is to convert the forages into financial returns to the farmers, which, in turn, should lead to adoption with benefits of soil conservation for the farmers and the whole community.

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Edited by J.M. Scott, D.A. MacLeod, Minggang Xu and A.J. Casanova
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