An Agroecological Approach to Management of SAT Alfisols

R.L. McCown[1]

Abstract

Crop production in the semi-arid tropics (SAT) is predominantly on Alfisols and without irrigation. Crop yields are low, and soils are being degraded rapidly due to a complex of climatic, edaphic, and management factors. Green Revolution technology does not alleviate the serious problems of managing the soil surface; it calls additionally for capital and energy requirements that are incompatible with economic circumstances of farmers in this environment. Certain approaches to land use that are in sympathy with the limitations of both the climate and soils may offer better prospects of improved production systems. Research that provides a first approximation of the suitability of such systems as (a) no-tillage/mulch farming, (b) legume alley farming, and (c) legume-ley farming for various physical and socioeconomic conditions in the SAT is urgently needed. Preliminary results of a no-tillage legume-ley strategy at an Australian SAT location show substantial benefits of the legume to both crop and animal production and of no-tillage/mulch to improved soil environment and crop yields. The need for a research approach in developing countries that evaluates such strategies in a relevant cost/benefit framework, and the problems of capital availability as a constraint to adoption, are discussed.

Introduction

Alfisols are agriculturally important soils throughout much of the SAT, in spite of serious chemical and physical limitations. The diversity within the group and the lack of a simple, agriculturally meaningful classification greatly hinders interregional communication pertaining to their management. Nevertheless, such communication is urgently needed to facilitate sharing of any new progress and coordination of new research effort. In general, agriculture on these soils suffers from nutrient impoverishment, soil erosion, and unfavorable surface physical conditions that result in reduced infiltration and poor crop establishment (Jones and Wild 1975, Lal 1979). In Africa and India, opportunities for using traditional practices of land rotation, or bush fallow, to counter these forms of degradation have declined rapidly with increase in human population. Replacement of fallow with land-saving technologies is rare because of the general scarcity of farmer capital. A promising approach to improved agriculture on these soils is the use of agricultural practices that capture many of the benefits of natural and traditional agricultural systems and require less capital than Green Revolution technology.

This paper examines the problems of Alfisols and the management requirements for improved systems, the agroecological concept (and an example of a research program that has been testing the feasibility of one strategy), and discusses the prospects for success of this approach in the developing countries of the SAT.

The Problems of Alfisols as a Resource for Crop Production

The problems of agriculture on Alfisols in the SAT are numerous and their causes complex. The main

1. Tropical Crops and Pastures, CSIRO, PMB P.O. Aitkenvale, Queensland 4814, Australia.

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problems are set out hierarchically at the top of Figure 1, and direct contributions to these problems by various climatic, edaphic, and management factors are indicated. Multiple entries in "problem" columns show the complexity of causes, often involving all three main factors.

Good crop establishment is jeopardized by a high risk of rapid surface soil drying because of erratic rainfall and very high radiation in the early wet season. On light-textured soils, high temperature of this dry zone causes injury to emerging seedlings (McCown et al. 1980); on heavy-textured Alfisols, mechanical impedance of this dry zone to emerging seedlings is the main problem (Arndt 1965).

The effects of unreliability of rainfall, especially early in the wet season, are exacerbated by the low moisture-storage capacity of Alfisols. Reliability of water supply for growth is reduced by impaired infiltration, in turn caused by lowered conductivity of pore systems when cover is not present to dissipate raindrop energy (Bridge et al. 1983). Cultivation increases infiltration initially, but, in the longer term, porosity and infiltration rates are usually lower than in untilled soil with mulch cover (Osuji and Babalola 1982).

These soils are very poor in supplying nitrogen and phosphorus (Nye and Greenland 1960, Jones and Wild 1975, Jones et al. in press)—deficiencies that have probably dominated management systems more than other problems. The total amount of P in Alfisols is generally very low, and, while they do not "fix" or absorb large amounts of P (Mokwunge 1977, Probert 1978), they are not well buffered against removals of P from the system. Inherently low concentrations of organic matter and rapid leaching act to keep N supply low. While long periods of bush fallow tended to replenish nutrients, increased cropping intensity has resulted in widespread "mining" of nutrients on these soils, with drastic loss of productivity (Ruthenberg 1980).

In the long term, the most serious problem in Alfisols is soil erosion (Sanchez 1976, Lal 1977). Under the natural vegetation, erosion on SAT Alfisols is very low (Roose 1977, Kowal 1970). But, when these soils are denuded, and especially if they are cultivated, high rainfall intensities cause particle detachment and degeneration of infiltration capacity. This results in high runoff and soil loss.

Alfisols in the SAT are frequently described as structureless or massive, with the implication that hydraulic conductivity is low. These soils are more correctly described as "apedal" and, when undisturbed and well vegetated, they behave hydraulically as "well structured" (Wilkinson and Aina 1976). This state is fragile, however, and destroyed by tillage and/or denudation. Its maintenance depends strongly on macrofaunal activity, which in turn is dependent on amelioration of a hostile water and temperature environment by organic mulch (Lal 1975).

In general these soils are especially sensitive to mismanagement, i.e., by denudation, cultivation, and nutrient mining (Fig. 1). Historically, low population pressures and long fallow periods with vegetative growth have together diluted the deleterious effect of man's activities on these soils. In present demographic circumstances there is an urgent need for technologies that are more sympathetic to the ecological tolerances of Alfisols in SAT farming systems.

Improvement of Alfisol Management

The prospects for applying high-input Green Revolution technology to solve these problems are poor. Few small farmers have the capital required, or access to credit (Greenland 1975). There are, however, a number of strategies that are conceptually appealing both ecologically and economically and whose performances have yet to be adequately tested in the SAT.

How can innovative strategies worthy of high research priority be identified? In 1973, Janzen called attention to the degree of misconception and distortion of the reasons for the lack of contemporary sustained-yield tropical agroecosystems. In recent years, considerable progress has been made in elucidating the ecology of existing systems and quantifying various constraints. At the same time there has been a growing tendency to look to natural ecosystems and traditional agricultural ecosystems as a source of concepts for improved agricultural systems. The aim is to mimic strategies that confer yield stability, and efficient use of energy and nonrenewable resources, and result in minimum ecosystem degradation (Altieri 1983). Although it is inescapable that innovative systems that substantially increase land productivity will require greater capital inputs than either traditional systems or current involutionary ones (Ruthenberg 1980), modest capital and energy demands are important criteria in selecting prospective technology.

What agroecological concepts are available that might contribute to improved Alfisol management

Factors contributing to problems / Heirarchy of problems of cultivated SAT Alfisols		Poor crop stands		Poor crop growth					Declining land productivity	
		Poor emergence		Unreliable soil water supply			Low soil fertility		Accelerated erosion	
		High soil temper-atures	High mech-anical imped-ance	Drought spells	Low infilt-ration	Low water storage	Inade-quate nutrient supply	Rapid leach-ing	High runoff	Ready particle detachment
CLIMATIC	Unreliable rainfall	X	X	X						
	High-intensity, high-energy rainfall		X		X				X	X
	High radiation, E_o, in early rainy season	X	X	X						
	Rainfall excess for days or weeks							X	X	
EDAPHIC	Structurally unstable surface soil		X		X				X	X
	Narrow available water range	X		X		X		X		
	Low rates of mineral supply						X			
	Low organic matter		X		X		X			X
MANAGEMENT	Denudation	X	X		X				X	X
	Cultivation		X		X				X	X
	Net nutrient removal						X			

Figure 1. Summary of problems in agriculture on Alfisols in the semi-arid tropics.

in the SAT? There are a number of key concepts that are sufficiently well understood to point the way in research for the development of feasible technologies.

The enormous importance of vegetative cover in the management of soils in the tropics is well documented. The main problems are how to get enough of it at the right time, and at an acceptable cost. Increase in crop canopy density (Hudson 1971), additional interrow vegetation, e.g., intercrops or "live mulch" (Akobundu 1982), and dead mulch all benefit soil physical properties and soil and water conservation. The retention of organic residues and replacement of tillage with the chemical killing of weeds at, or just prior to, planting has been shown to be a practical way of providing mulch in the humid tropics (Lal 1975) and providing it at the time when the crop canopy is least effective (Wilkinson 1975a and b). Although less research has been conducted in the SAT, results indicate that benefits from mulch here are similar with respect to soil conservation (Roose 1977) and are even greater with regard to crop establishment (McCown et al. in press).

Rotating tropical legumes with nitrophilous crops is an effective means of supplying N to the crop (Henzell and Vallis 1977). Although in Africa and India grain and oilseed legumes have traditionally been grown in rotation with cereals and as intercrops, recent developments in forage legume technology for the SAT have opened up prospects for enhancement of this N-supply strategy. Pasture and browse legumes that produce high yields of N are now available (Vallis and Gardener in press) and knowledge on their ecology is growing. There has, however, been virtually no evaluation of these legumes in cropping systems.

The concept of mixtures of crops possessing different morphological and agronomic attributes is well established as a means of more fully utilizing scarce resources both above and below ground. This is one of the advantages of the traditional practice of intercropping (Willey 1979). Recently, there has been increased interest in mixing annual crops with perennial species, a strategy that maximizes differences in utilization of both above- and below-ground resources in space and time (Willey et al. 1987). Agroforestry (King 1979) and alley cropping (Kang et al. 1981), both of which capitalize on these principles, deserve comprehensive evaluation in the SAT.

The benefits of integration of livestock and cropping are well established and widely appreciated. Of the several types of possible linkages, the one that holds the most unexplored promise is that of enhanced production of legume fodder in the cropping enterprise (McCown et al. 1979). The future contribution of improved integration of livestock and cropping in this zone is controlled largely by nontechnical factors, e.g., the effects of cultural traditions of crop and livestock husbandry on current farmer attitudes and skills. Where the likelihood of integration under one ownership is low, but where herders and cultivators co-exist, there is the possibility of greater market transaction of legume fodders produced in the crop lands. Although integration of livestock with cropping does not directly benefit soil management, and at times is detrimental (Bayer and Otchere 1984), it is crucial to the economics of increased use of legumes to provide increased soil N. Forage legumes in cropping systems are profitable only when additional substantial benefits to an animal enterprise can be realized (McCown et al. 1979).

While there are promising ways of substituting N-fixing plants for N fertilizer, there appears to be no escaping the purchase of other nutrients, most commonly P. Deficiencies of nutrients other than N will limit both the growth and fixation of N by the legume and the growth of the succeeding nitrophilous crop. To capitalize on a biological supply of N, relief of these nutrient deficiencies is necessary. Substantial progress has been made in recent years in understanding the complexities of phosphate fertilizer-soil-water-plant relationships. This has enabled the development of models for predicting responses to applied phosphate (Barrow and Carter 1978). This has potential for improving the management tools for determining optimum use of P fertilizer on the SAT Alfisols.

What sort of research is needed? In general, the priority need is to examine the economic feasibility of practices that are promising conceptually. Analyses need to be conducted for a range of cost-price-capital availability scenarios that include, but extend well beyond, those which farmers now face. To do this will require a large biotechnical research effort, but it must be orientated toward this economic goal. Table 1 provides an example of such a research framework for no-tillage/mulch farming. In spite of the fact that, (a) research by R. Lal in the humid tropics in the early 1970's showed enormous benefits, and (b) benefits should theoretically be greater in the SAT, very little research on no-tillage/mulch farming has been conducted. It is often argued that mulching with crop residues is not practical in the SAT because they are utilized for

Table 1. Research on the economic feasibility of no-tillage/mulch farming.

Information needs	Research activities
Costs	
Opportunity costs of using plant materials suitable for: Fodder; Building materials; Fuel (instead of mulch)	Documentation of: a. existing system and b. innovative systems with increased production of mulch and/or timber
Herbicides and application equipment	Verification of optimum application methods and rates of "best-bet" herbicides
Benefits	
Effects on crop yields via: Soil water; Soil temperature; Soil surface seal impedance	Quantification of the effect of different types and amounts of mulch on: a. seedbed environment, crop establishment, and yield b. soil hydraulic properties, infiltration, soil-water regime, and crop yield c. soil detachment, runoff, and sediment transport
Effects on water and soil conservation: Infiltration/runoff; Soil erosion	
Effects on labor economy: Reduction of plowing labor and time; Reduction in weeding labor and time	Documentation of existing and alternative systems
Effects on farm draft requirements of reduction in tillage	Documentation of fodder requirements of system and effects on herd size and structure

fodder, fuel, or as building materials. But, considering the rate at which land degradation is taking place, there are good grounds for asking the question: can the farmer (or society) afford not to leave residues for mulch? Answering the question would call for quantitative understanding of the performance of innovative farming systems. If the farmer had greater on-farm production of timber and fuel wood, he could well afford to leave residues for mulch. If he brought down N and P deficiencies, increases in yields might allow him to remove the usual amount of residues and leave a substantial amount.

This example illustrates a second attribute of the kind of research that is needed, i.e., a production system scope. One of the lessons of past research is that innovations need to be evaluated in the context of the larger system or subsystem. As Figure 1 indicates, the problems form a matrix of complex interactions. Evaluation in too narrow a biotechnical field risks missing other crucial biotechnical implications. For example, the finding that grass leys can greatly improve aggregate stability upon cultivation is viewed very differently when the strong yield-depressing effects due to nitrogen immobilization are considered as well (Fig. 2). Similarly, tied ridges have been shown to effectively reduce runoff in the SAT, but maximum yield benefits will not be realized where high soil temperatures are a problem, since this is exacerbated by ridging (Lal 1973).

Too exclusive a biotechnical approach to soil management risks missing opportunities for addressing those economic issues on which success or failure of this technology most depends. Improved soil management involves costs, and, in general, the farm system has to bear them. Although improved soil management is the key to technically improved farming systems, improved soil management is sustainable only within economically improved farming systems.

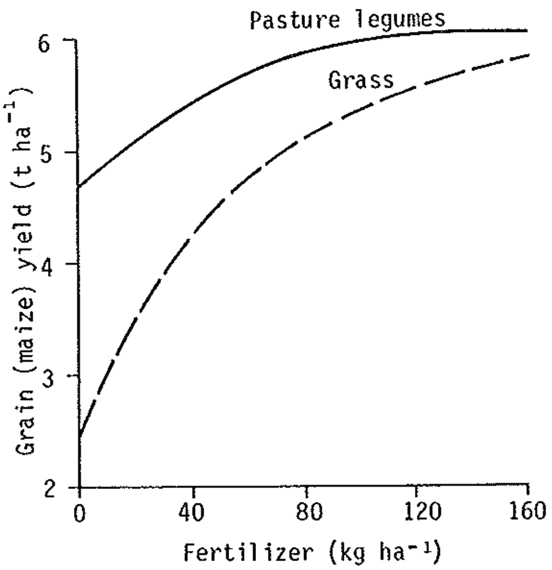

Figure 2. Maize grain yield responses to nitrogen fertilizer in the first crop following 1 year of legume or grass-leys on a loamy Alfisol.

An Innovative Agroecological Strategy for the SAT

Problems of Australian SAT agriculture

The Australian SAT is used almost exclusively for cattle and sheep grazing. Periodic attempts have been made to establish dryland cropping industries, but all have failed due in part to high costs of production and use of inappropriate technology. A feature of this area is that land that is potentially arable tends not to occur in large, contiguous areas, but is rather interspersed with large areas of land suitable only for grazing. One possible means of more efficient utilization of these land resources is the integration of livestock grazing and cropping. The concept of legume-ley farming, so important in the integration of wheat and wool production in Australia's Mediterranean and warm climates, has been suggested as a promising model for West African savanna zones (Jones and Wild 1975), but to date there has been no substantial evaluation of the strategy anywhere in the SAT.

Past research has set the stage for this test. The technology for growing leguminous pastures is well-developed for the Australian SAT, but has not proved economic because of the high costs of improvement relative to beef prices, as well as serious marketing uncertainties. Crop research on the Alfisols has shown the need for high inputs of both nitrogen and phosphorus (Jones et al. in press) and revealed other problems (Fig. 1) associated with conventional tillage practices.

The research strategy

The strategy is expressed as a hypothetical farming system that combines the concepts of legume-ley farming and no-tillage with the existing system of grazed native pastures. The key feature (Table 2) is the rotation of a self-regenerating legume pasture and a maize or sorghum crop, where the legume supplies all or most of the N fertilizer required by the crop.

The second feature (Table 2) concerns the integration of cropping with the existing system in which cattle graze on native pastures. In areas with long dry seasons, the strategy of having cattle on native grass pastures during the green season, when they are at their best, and on sown leguminous pastures in the dry season, is attractive (Norman 1968). However, the test of this strategy in the late 1960s and early 1970s failed because of the inability of the legume, Townsville stylo, to compete satisfactorily with annual grasses and, ultimately, to its susceptibility to the fungal disease anthracnose. The availability of several "new" legumes with superior competitive ability and resistance to anthracnose makes a new attempt at implementing this strategy feasible. (The growing of a nitrophilous crop every 1-3 years should further contribute to maintaining legume dominance by regularly depleting soil N.)

The third feature of this system (Table 2) is the retention of surface mulch by use of no-tillage planting technology. In this system, the main source of mulch is killed pasture vegetation rather than crop residues.

Table 2. Features of a hypothetical farming system.

1. Self-regenerating legume-ley pasture of 1-3 years duration are grown in rotation with maize or sorghum.
2. Cattle graze native-grass pasture in the green season and leguminous pastures and crop residues in the dry season.
3. Crops are planted directly into the pasture that is chemically killed at, or shortly before, sowing.
4. The legume sward, which volunteers from hard seed after the pasture is killed, is allowed to form an understory (live mulch) in the main crop.

The fourth feature of our hypothetical system concerns a form of intercropping (Table 2). The herbaceous pasture legumes that are well adapted to this climate invariably produce a proportion of seed that is still "hard" when the re-established pasture is killed with herbicide and a crop planted early in the next rainy season. However, newly germinable seed from the "hard-seed" pool produces a new stand of legume of the same age as the sown crop. [This is an important difference from the "live mulch" situation in which the legume sward is never killed (Akobundu 1982)]. Although re-establishment can be prevented by use of a pre-emergent herbicide, this legume intercrop offers several potential benefits: it does not cost anything to establish; it provides a more long-lasting protective cover for the soil than the dead mulch; it provides high-protein forage to complement the low-protein stover available for grazing in the following dry season; and it provides an additional source of seed for pasture re-establishment in the following season. The main potential detriment is that the understory of pasture legume may depress the yield of the grain crop. In this particular version of intercropping, this would be a very undesirable outcome because the grain crop has a much higher monetary value than the forage intercrop and, therefore, only small reductions in grain yield can be tolerated. Although recent results from the humid tropics of West Africa have shown that yields of crops sown into legume swards killed only on the row zones can compare favorably with those of crops grown without this live mulch (Akobundu 1982), the degree to which competition for water or nutrients during the growing season jeopardizes the success of this forage intercropping strategy in the SAT is unknown.

Research Progress

Subsystem 1: Effect of legume-ley/crop rotation on crop production

In studying this subsystem, the prime objectives are to quantify the N contribution to the following grain crops by leys of various legumes grown for between 1 and 4 years. Objectives of a lower order are quantification of the amount of N fixed by various legumes and elucidation of the relative importance of losses from litter, urine, and dung. It is to be expected that soil type will strongly influence N transfer processes, so studies of this subsystem are being conducted on two Paleustalfs—one heavy-textured (Tippera clay loam) and the second very sandy (Blain sand).

A direct experimental approach is used to estimate the N contribution by legumes, whereby a crop of maize or sorghum is used in a bioassay. Rates of fertilizer N are superimposed on the crop so that its responses to N, additional to that supplied by the preceding legume or grass (control) swards, can be measured and compared. Supporting information includes soil N prior to cropping, and N yield of both the ley and the crop.

Salient results from six experiments—most of which are still in progress—include the following.

1. On the loamy soil, maize grain yield with no N fertilizer, following 1-year leys of various pasture legumes, was equivalent to that on plots receiving at least 50 kg ha^{-1} N following 1 year of grass. (Fig. 2 shows data from one experiment). Legume leys of longer duration had greater effects in the first crop and a greater residual effect on the second crop.
2. For a given level of dry-matter production by a short ley of Caribbean stylo (*Stylosanthes hamata* cv Verano), the apparent N contribution to the following crop is much less on the sandy soil than on the loamy one.
3. Legume species do not differ greatly in N contribution after 1-year leys, but large differences occur following 4-year leys.

Subsystem 2: Effect of no-tillage technology on crop production

The first objective here was to quantify the advantages/disadvantages of sowing crops with no tillage in relation to conventional tillage. The reason for focusing on this practice is that, wherever comparisons have been made throughout the world, the inherent benefit of no-tillage/mulch retention in conserving soil has been demonstrated. The pressing questions were those of the effects of this technology on yields and of comparative costs.

On both light-textured and heavy-textured Alfisols, stands were better and yields higher under the no-tillage system. On the sandy soil, mulch retention resulted in an average increase in maize yields of 33% (from 1.8 to 2.4 t ha^{-1}) in two crops. This was on account of the soil temperature reduction by the mulch (McCown et al. 1980). On loamy soil, injurious soil temperatures are less frequent than on the sandy one, but, without mulch, they are still too high for optimum seedling growth. This soil poses an additional problem: on drying, it forms a strong surface crust that impedes seedling emergence (Arndt 1965). Mulch reduces this problem by protecting the soil surface from raindrop impact and slowing the drying of the soil. In four crops, mulch retention resulted in an average yield advantage of 20% (from 4.8 to 5.8 t ha^{-1}) in maize.

Having confirmed that mulch retention and no-tillage had beneficial effects on establishment and yields, we turned our attention to the following questions: what constitutes a minimum effective mulch? How do we get an effective mulch economically? How do we plant into such a mulch efficiently? (In most years, the pasture mulch at planting time consists of a mixture of dead pasture residue—mainly stems—from the previous growing season and recently-killed regrowth and seedlings resulting from rainfall received early in the current wet season. The relative proportions of these components varies with the intensity of grazing during the dry season and with the amount and distribution of rainfall in the early part of the wet season.)

Work to date has been on the loamy soil only and we can make the following observations:

a. As little as 700 kg ha^{-1} of mulch—in this case standing Caribbean stylo which had been killed with herbicide—reduces soil temperatures enough to dramatically improve emergence.
b. Analysis of the radiation balance has shown that mulch retards the rise in soil temperature and soil strength by retarding drying. This is due primarily to the interception of radiation by mulch.
c. Pasture mulch is quite efficient in radiation interception; 1900 kg ha^{-1} of dead standing Caribbean stylo intercepted 80%, and 700 kg ha^{-1} 55%, of direct beam radiation.
d. Tropical grasses and weeds, in general, are killed by dosages of the herbicide glyphosate similar to those used in temperate regions (1.5 to 2 t ha^{-1}).
e. The most successful planter has been a narrow tyne preceded by a rolling coulter to cut surface mulch, and followed by a narrow in-furrow press wheel.

Research has recently commenced on planting on the sandy soil where there appear to be fewer technical problems than on the loamy soil.

Considering the overall results of the various studies in this subsystems, our tentative conclusion is that no-tillage technology for this farming system is feasible in all major aspects, and that further progress will most likely be made in on-farm research and development that is now under way.

Subsystem 3: The effects of competition from pasture/legume intercropping on crop production

Two early studies were conducted to assess the effect of Caribbean stylo, *Alysicarpus vaginalis*, and *Centrosema pascuorum* intercrops on maize yield. In one, intercropped maize yielded 15% more than sole maize, but in the other it yielded 30% less. Data on yield, chemical composition, and weather only were collected, and these are inadequate to explain the results. Work at present is focused on the competition between the crop and the pasture/legume intercrop for the two resources most likely to be deficient in this system: water and nitrogen.

Preliminary results indicate the following.

a. With an ample supply of water and N, maize yields are high (>5 t ha^{-1}) and little reduced by the legume intercrop, despite a yield of dry matter up to 4 t ha^{-1}.
b. At low nitrogen levels, a legume understory reduced yields 10-50%, depending on the species of the legume.
c. When water deficits occurred, a legume understory exacerbated the stress effect on maize yield, but the effects were moderate and dependent on the timing of the stress.
d. In a year of very high rainfall and low radiation, legume yields were low.

The question of whether it is economically desirable to have a legume understory at a given location has a weather-related probabilistic answer. The only feasible way to answer this question is by numerical simulation of the effects of the legume for a long period of weather records.

Subsystem 4: The effect of cattle-ley rotations on animal and crop production

Study of this subsystem is being conducted within one "whole-system" experiment. Its objectives are the following.

a. To quantify the N contribution to a succeeding crop by various legumes under realistic dry-season grazing management.
b. To compare liveweight performance in the legume-ley system with that on continuously grazed native pastures and on improved pastures.
c. To document the ecological stability of pastures of Caribbean stylo, *A. vaginalis*, and *C. pascuorum*, particularly in relation to re-establishment and the ability to resist invasion by annual grasses.

d. To document the trends in weed abundance in the crop and the pasture and to identify possible weed-management strategies.
e. To quantify costs of production and yields of maize under realistic operational conditions with respect to planting and harvesting.

The cropland component of this study consists of three paddocks in which the legume-ley is Caribbean stylo, *A. vaginalis* or *C. pascuorum*. Within each paddock there are three areas of equal size. This allows a 1-year maize: 2-year legume-ley rotation, with a maize crop every year. Adjacent is a large area of unimproved native pasture under eucalypt woodland.

The native pasture area is stocked during the green season at an appropriate density (0.2 beasts per ha) with equal numbers of weaners and yearling steers. After crop harvest, three groups of four cattle (2 weaners + 2 yearlings) are moved into the cropland paddocks; an equal number remain on the native pasture. At the end of the dry season, yearlings are turned off and weaners return to native pasture; the latter return in the following year to their respective legume paddocks for finishing.

Maize is planted by no-tillage after spraying the regenerating pasture with glyphosate. In half of the crop area, the legume understory is allowed to develop; in the other half this is prevented by the application of a pre-emergent herbicide. A range of N rates is superimposed on parts of the maize to assess response to N above that contributed by the 2-year leys.

Botanical composition of ley pastures is measured annually near the end of the green season. Pasture on offer, and the proportions and chemical composition of leaf, stem, and seed are measured periodically through the dry season in conjunction with diet sampling with oesophageal-fistulated cattle.

This experiment was sown only in January 1982, so time trends in pasture production and ecology, as influenced by crop-pasture rotation, are not yet available. Animal production, however, is not as dependent on crop-ley sequences, and results from the first two dry seasons should be as informative as those to come. In 1982 the liveweight gain on legume ley/stover, averaged over legume species, was 75 kg per head greater than on native pasture for the 4-month period mid-July to mid-November. In the cropland, during the first 7 weeks, 10–20% of time spent grazing was in the stover and, after that, virtually all grazing was on legume. There was virtually no effect of legume species on liveweight performance.

Discussion

From an agroecological standpoint, a no-tillage legume-ley system appears promising for SAT Alfisols in northern Australia. Of the problems in Figure 1, all those involving a management factor are alleviated, i.e., high soil temperatures, surface crusting seals, low infiltration, high erosion, and poor nutrient supply. Although there are still numerous technical questions to be answered, the most pressing questions concern the economics of the system. At this preliminary stage there are at least some indicators. On the positive side, there are high grain yields, savings in fertilizer, only modest herbicide demands, (and willingness of the government to subsidize a fledgling industry if the technology is appropriate). On the negative side, there are unfavorable trends in Australia's export markets for coarse grains and beef. In response to the latter, particularly, our research scope is expanding to include systems that allow continuous cropping and which use high-value grain legumes in addition to pursuing further research on the ley system.

There is ample evidence of a general nature to indicate that a no-tillage legume-ley system can contribute to improved management of Alfisols in other SAT regions. The main questions concern adaptation to economic and sociocultural environments; the issues of land and capital availability are especially pertinent.

In the evolution of agricultural systems in the SAT (Ruthenberg 1980), grass fallow systems occur when pressure on land increases to a level at which insufficient time is allowed in the fallow period for woody vegetation to regenerate. The substitution of sown legumes for naturally-regenerated native grass in fallows is a possible means of increasing the effectiveness of this phase of the rotation in terms of both animal and crop production. Thus land requirements for a legume-ley system can be satisfied where fallow systems are used, and substitution of pasture legumes provides a potential means of maintaining production as shorter fallows are forced. Under circumstances where land must be used even more intensively, other agroecological options become relatively more attractive. No-tillage/mulch farming combined with alley cropping or with a living mulch system offer possibilities of retaining benefits of legumes to soil, crop, and animals, while cropping continuously.

Ruthenberg (1980) argued that implementation of a ley system, although less capital-intensive than modern permanent cultivation, still requires considerable investment in clearing, livestock, fences, implements, carts, tracks, and buildings. He viewed these costs as prohibitively high. I suggest that a no-tillage legume-ley system, in contrast to Ruthenberg's traditional European model, requires an initial investment only in pasture legume seed and annual capital inputs of phosphate fertilizer and herbicide. Vis-à-vis Ruthernberg's model, this system offers (a) greater N fertilizer-saving and animal production benefits as a result of recently-domesticated legumes better suited to the SAT, and (b) capital and labor reductions associated with no-tillage. Substitution of chemical land preparation for mechanical preparation eliminates or reduces the need for stump clearing, traction, and implements. Realization of the latter requires a low-cost herbicide with the broad-spectrum, nonresidual, and low-mammalian-toxicity properties of glyphosate (Roundup®). With the expiry of the original patent of this product in many countries in 1987, substantial price reductions are expected as other producers enter the market. The simple nature of the compound and its inherently low cost of production offer prospects of much reduced prices in the longer term. The demonstration of technological and ecological successes of no-tillage/mulch farming by small farmers in the SAT could favorably influence the future cost and supply aspects of a suitable chemical.

Even assuming a much cheaper herbicide, the capital requirements of the most ecologically sound and capital-conserving farming strategies are still too high for most farmers working on Alfisols in the SAT, who have a largely subsistence economy. However, it is most important that these potential innovations are not dismissed as inappropriate on these grounds. If a given strategy can be shown to have large ecological and economic advantages over that currently used in a given environment, governments have the means to alter the farmer's economic environment to favor adoption by changing policies that affect markets, the cost of inputs, product prices credit, etc.

In the African SAT, deficits in urban food supply and expenditure of foreign exchange on food imports have been increasing at alarming rates. These problems of great political and economic urgency may provide the needed incentives for national food production reforms. If so, the urgency extends to the research evaluation of innovations that offer the best promise of stable, profitable agriculture.

It cannot be assumed that it is economically feasible to check the degradation of SAT Alfisols and the accompanying impoverishment of those who subsist on them. Fyfe et al. (1983) suggest that no form of improved management using conventional technology is cost-effective on such soils. It remains to be seen if management strategies designed for maximum ecological and economic efficiencies greatly alter this conclusion.

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