Management of Acid Soils

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Management of Acid Soils in the Humid Tropics of Asia

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Foreword

THE publication of this Monograph as a joint ACIAR/IBSRAM book demonstrates the close working relationship both organisations have enjoyed since the creation of IBSRAM and the role ACIAR played as executing agency during the establishment phase.

A brief report of the workshop held in Kuala Lumpur in early 1989 was published by IBSRAM in May 1989. This Monograph contains the research and country status papers presented at the workshop. The papers review the state of the art in research on the management of the acid infertile soils which dominate the humid tropics of Asia. In addition to reviewing the problem, the papers describe some of the technological solutions emerging from the research. The major outcome from the meeting was the decision by participants to establish ASIALAND–Management of Acid Soils Network which IBSRAM will coordinate.

Both ACIAR and IBSRAM welcome the creation of this network which will foster a more cohesive and effective approach to the solution of the complex problems facing smallholders in Asia. We wish to thank the Rubber Research Institute of Malaysia, Universiti Pertanian Malaysia and the University of Queensland for their collaboration in the organisation of the workshop.

Thanks are also due to the International Development Research Centre for supporting the meeting.

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Preface

Research on Acid Soils Management: Present Status and Future Needs

Eric T. Craswell*

THE logical starting point for any consideration of upland soil management in the region is the natural rain forest vegetation, which covers large areas of Oxisols and Ultisols in Asia and is discussed in the von Uexküll and Bosshart paper. They point out that, although these soils are generally acid and infertile, the tropical forest thrives because a dynamic equilibrium of nutrient cycling between the vegetation and the soil has been set up. Improper clearing of the forest, particularly with heavy machinery, disturbs this equilibrium and can lead to ecological disaster: examples are extensive soil erosion, which not only degrades the soil on site but also leads to serious off-site effects on fisheries, reefs and agriculture in lowland production areas, and the invasion of acid soil areas by pernicious weeds like *Imperata cylindrica*. It is important to remind ourselves of the responsibility we have not only to maintain, but also to improve, the quality of our soils, for our own good and that of future generations.

Many of the Country Reports (Section 2) on the state and utilisation of acid soils in the region illustrate that we have not been very successful at husbanding our soil resources. The Liu Gengling paper highlights the problem of soil erosion and structural degradation in the vast areas of red soils in hilly areas of tropical and subtropical China. Reports from Indonesia, the Philippines, Thailand and Vietnam suggest that, because of the shortage of land in these countries, large areas of acid soils in upland areas have been cleared for crop cultivation and have become eroded physically and chemically. This degradation contrasts with the productivity of acid soil areas which have been developed for plantation crop production in a number of countries in the region, as reported in the Malaysian Country Report.

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The key problem addressed at the workshop is the management of acid soils for sustainable food crop production. In this regard, Sharifuddin's paper relates recent research in Malaysia on food crop production on Oxisols and Ultisols, and considers crops grown alone and as intercrops under rubber. Large crop yield responses to ground magnesium limestone and fertilisers have been recorded, and the agronomy of profitable corn and peanut production is being sorted out successfully. Of particular note is the finding that intercropping of food crops with rubber may advance tapping by as much as 12 months, which should be a very attractive proposition to the smallholder at whom this technology is targetted.

A number of other technologies and principles for food crop production on acid soils are described in the von Uexküll and Bosshart paper. Of particular interest is a mechanised approach to the rehabilitation of *Imperata* land in Indonesia using heavy doses of phosphate fertilisers. However, the economics of this technology relies on the availability of a cheap source of phosphorus fertiliser which is not necessarily widespread. The importance of economics and of the farmer's attitude to technology is stressed in the Spaargaren paper, which covers the management of acid soils in Africa. His paper shows that there are many interesting and valuable lessons to be learnt from African farmers, and I am sure that Africans can learn much from the Asian experience. The discussion at the workshop showed that IBSRAM has a vital role to play in facilitating the international exchange of information on soil management. The emphasis by African farmers on organic mulching is particularly interesting, considering that most of them do not have access to fertiliser supplies.

The importance of the management of organic matter and manures was repeatedly emphasised during the workshop. The paper by Yu Tian Ren covers the Chinese experience in this area. Given that organic litter is so important in the recycling of nutrients in the forest, perhaps we *are* learning from nature. Another way we are learning from nature is in the inclusion of trees in our sustainable technologies developed for acid soils; examples include plantation crop systems and alley cropping. As in the tropical forest, trees in these systems stabilise the soil, recycle nutrients from the subsoil and provide leaf litter to protect the soil surface. Legume trees and shrubs also provide valuable inputs of nitrogen, so the selection of these plants for acid soils tolerance is important, and is reported on in the paper by Palmer and his colleagues.

It is important to know just what is meant by the term 'acid soil.' The Edwards and Bell paper on Australian acid soils shows that a much clearer picture is beginning to emerge. For example they have found that monomeric aluminium in the soil solution appears to be the specific culprit causing aluminium toxicity to plants growing in acid soils, and they have developed methods for measuring it. Furthermore, the dynamic nature of the chemistry of acid soils has been demonstrated by the finding that the application of fertilisers may increase the ionic strength of the soil solution, and induce aluminium toxicity in soils which initially may not have high levels of exchangeable aluminium. Some of the new techniques developed in this research should be applied more widely through the mechanism of the IBSRAM network.

Acid soil management research work, both in the field and greenhouse, at the Rubber Research Institute of Malaysia and the Universiti Pertanian Malaysia was inspected by the workshop participants. The Segamat trial showed the beneficial effects of the application of ground magnesium limestone (GML) and fertilisers on the growth of corn as an intercrop with rubber. The Chembong trial also demonstrated responses to GML. One of the striking features of the field experiments is the importance of water availability in determining yield. In humid tropical areas one does not expect drought in the wet season but a number of the RRIM and UPM field trials have been affected, some to the point of crop failure. Much more effort is needed to develop technologies which improve soil physical conditions and reduce erosion. Minimum tillage with mulching of crop residues is an example of such a technology. Furthermore, means must be found for increasing rooting depth, possibly by adding with the GML small amounts of soluble calcium, such as gypsum which will leach into the subsoil. These are refinements which we must continue to develop to supplement our basic food production technologies.

Experimental sites should be carefully chosen and managed to minimise variability. Field plots should be laid out using designs which have been developed to help overcome variability. IBSRAM has put a great deal of effort into developing methodologies for this purpose, and these were refined through discussions at the workshop. They should be considered carefully in future work.

The key to a successful network is commonality of purpose in research and validation activities. In this regard, most of the country proposals for the IBSRAM Network were concerned with acid tropical soils and with rainfed uplands. The range of crops was quite diverse but most country proposals included food crops. The conclusion was that there was sufficient commonality to form a network and that participants could consider including maize as a common crop in all experiments. The need to consider low input systems utilising legumes, mulching and intercropping was stressed.

The Network Coordination Committee reviewed the country project proposals and found that most of them included a core experiment which compared farmer practice, low input technology and high input technologies. This work will form the basis for membership in the network, although it will not be the only activity because many of the countries also plan satellite trials on aspects of lime materials and management, phosphorus fertilisation, etc.

The workshop successfully defined the work needed in each country to validate various technologies for the management of acid soils for sustainable food production. The country project proposals describing these activities will be finalised by IBSRAM and submitted to donors for consideration. Following a positive response, IBSRAM will appoint a network coordinator, the country programs will start and the Network on the Management of Acid Soils in Humid Tropical Asia will be well and truly underway. Hopefully this new initiative will speed up the adoption by farmers of sustainable technologies which will boost their income while maintaining, and even improving, the quality of the acid soils of this region.

Section 1

Management of Acid Soils

Management of Acid Upland Soils in Asia

H.R. von Uexküll and R.P. Bosshart*

Abstract

The fact that to the present day most acid upland soils are not used for agriculture is an indication that it is very difficult to practice sustainable agriculture on them. Before the introduction of chemical fertilisers and high yielding crop varieties, many acid soils were considered unsuitable for arable crops. However, tree crops have been grown on them successfully for many decades because trees represent a rather natural succession to the rain forest, the natural cover of those soils.

Acid upland soils (Ultisols and Oxisols) of tropical Asia are, in general, inherently infertile and Al or Mn toxic. Their shallow topsoils, the Ultisols particularly, are highly susceptible to erosion. The organic matter can be easily degraded and lost by conventional land-clearing practices, including burning and direct exposure to sun and rain. If not managed properly after clearing, these soils can rapidly lose much of their original fertility and beneficial physical properties.

To sustain production on these soils requires inputs far exceeding the means of poor farmers. Unfortunately, there is no such thing as a 'low input' technology for the poor acid soils of the tropics. If poorly managed with no or low input to replace nutrients removed by cropping or erosion, these soils will within a few years be incapable of producing a decent crop and will be invaded by *Imperata cylindrica*. Eventually they may become barren if the degradation is not stopped.

At present most acid soils are still covered by primary or secondary forest. Before any forested area is to be opened up for agricultural use, short as well as long term costs and benefits and possible damage to the environment should be considered. In the long run, we may need the acid soils more as a source of timber and a sink for carbon dioxide than for food production.

Introduction

Once soils have lost their fertile surface layer, they cannot, even with the best management, be returned to their former productivity in less than 10 years, if ever. Furthermore, the present-day management of agricultural soils must protect them against erosion and leaching losses, if their productivity, even at high input, is to be sustained. Much technology to make acid infertile upland soils productive and profitable on a long-term sustainable basis is already known, but it needs to be adapted and applied locally. To get farmers to apply it will take much more research and extension education than we have at present.

Although we would like to offer some hope to smallholder Asian farmers, we firmly believe that long-term proper and profitable management of acid upland soils will require a lot of knowledge and money not presently available to them. There are no cheap and easy alternatives to preserving existing soils while still earning a good living at present or in the future from these soils. By 'earning a good living' we're talking about profitable sustainable agriculture, which means crop yields and fertiliser inputs above present national

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averages. Low-yield agriculture is not profitable nor sustainable, because it leads to soil degradation and abandonment of the land.

Fertile well drained soils, the area of which is very small in the humid tropics, may be able to sustain agriculture at least initially for a number of years with little or no input. Our concern, however, is with acid infertile soils, many of which have poor physical as well as chemical properties. At least 38% of the land area in Southeast Asia has acidic upland soils (Ultisols, Oxisols); in Malaysia 72% of the area is acidic upland soils (IBSRAM 1985).

Most of these soils would probably be best left under forest. Unfortunately, this view, regardless of its ecological merits, has not been and likely will not be recognised and accepted by government policymakers as being more important than the short-term income derived from logging and developing for agriculture. As populations increase and economic development inevitably occurs, calls will occasionally be heard by politicians to allow development of most lands, even those protected by law.

Rates of deforestation in selected Southeast Asian countries are shown in Table 1. In terms of area deforested, Indonesia is the leader, followed by Malaysia and Thailand. Clearing of the forest is usually done to plant oil palm or rubber and for transmigration.

Political leaders in Asian countries have occasionally and rightfully pointed out that little or no forethought or surveying was done before the forests of Europe and North America were cleared. So why should countries in the tropics retard their economic development to please doomsayers in temperate regions? Floods and environmental degradation have occurred in temperate regions due to land clearing as well.

Table 1. Deforestation in selected countries of Southeast Asia and Brazil (Scott 1989).

	Annual rate 1981–85 (%)	Annual area 1981–85 ($\times10^3$ha)
Indonesia	0.5	600
Malaysia	1.2	255
Thailand	2.6	244
Burma	0.3	102
Laos	1.2	100
Philippines	1.0	91
Vietnam	0.7	60
Brazil	0.4	1 360

All of this is true generally, but many people do not realise that major differences exist between the temperate and tropical situations:

(a) the climates and soils of the temperate and tropical regions are very different;

(b) the scale of flooding and environmental degradation has been far greater in the tropics than the temperate regions;

(c) the distribution of organic carbon is about equally divided between soil and above-ground biomass in a temperate forest ecosystem, but is concentrated almost entirely in the biomass (over 85%) with very little in the soil in a tropical forest ecosystem (Fig. 1); and

(d) the level of knowledge we have now is much greater than it was when virgin temperate forests were cleared.

We would like this knowledge applied as soon as possible, so it benefits people, especially farmers, in the humid tropics. Without full use of this knowledge, the rural development of tropical countries has already been and will continue to be delayed by inappropriate land clearing and post-clearing soil management practices.

Climate

Year-round high temperatures (day and night, except at high elevations), rainfall, and humidity are unique to the humid tropics. Sunlight can also be intense. All of these can be advantageous, allowing continuous crop production if rainfall is uniform or irrigation is available to balance water input by evapotranspiration.

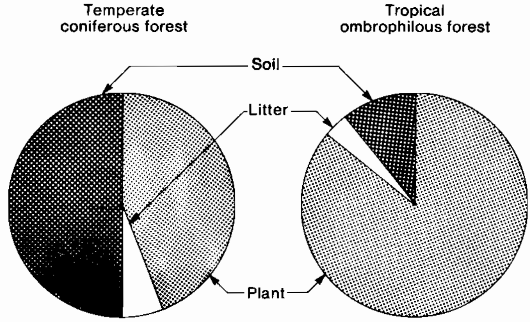

Fig. 1. Distribution of organic carbon in a temperate and tropical forest ecosystem (Kira and Shidei 1967).

The disadvantages, most of which are attributable to high rainfall and temperatures, include:

- high rates of weathering of soils;
- high rates of leaching of nutrients from soils;
- very rapid destruction of a usually shallow topsoil, especially its organic matter and structure;
- quick and severe erosion of the topsoil;
- acute drought stress after less than one week without rain.

Only exposed soils, which have lost their protective cover of vegetation or leaf litter during land clearing and burning, are susceptible to these disadvantages. Under forest cover neither leaching, topsoil destruction, erosion, nor drought stress is significant (Goodland and Irwin 1975).

Winds, which can erode exposed soils, are common to the subtropics but not the humid tropics. Also, the prolonged dry season of the subtropics, which can accelerate wind erosion of uncovered soils, is actually more beneficial to permanent agriculture than the year-round rainfall of the tropics because it breaks pest life cycles and permits seasonal use of tillage equipment (Goodland and Irwin 1975).

Vegetation

Three major types of vegetation cover concern us in this paper: forest, anthropic savanna, and barren hillsides. Excluded are paddy rice lands with their protective water cover and flat surfaces and perennial tree crops like rubber, oil palm, coffee, and cocoa. Both are stable and sustainable agricultural systems.

Asian populations have historically concentrated in areas suitable for wetland rice because of their stability, even at low input. These areas were specifically developed by Asian farmers to overcome the climatic constraints of high rainfall and erosion of hillsides. Rice is the only cereal adapted to high rainfall and to flooded soils. The capacity of wetlands to meet the ever-increasing needs for rice and other food crops will soon reach its limit. Thus, the need exists to expand food crop production to upland soils.

Perennial tree crops, which are raised for cash and not food, have been profitably grown on acid upland soils for many decades. With the possible exception of rubber, most tree crops can be grown profitably only with relatively heavy fertiliser use. Nevertheless, with year-round soil cover, perennials are the best crops for sustained production in the humid tropics, because they most nearly duplicate conditions under natural forest.

Forest

Forest is the natural climax vegetation in the humid tropics. The luxuriance and high biomass of tropical forests cannot usually be attributed to high soil fertility because almost all nutrients and organic carbon (Fig. 1) are in the biomass or organic litter on the soil surface and not in the soil itself (Herrera et al. 1978, 1981). Saving these nutrients (Table 2) must be a major objective of persons clearing forest land for agriculture as will be explained below.

According to Herrera et al. (1978), the mechanisms by which tropical forests conserve nutrients include:

- building a dense root mat on the soil surface with a high nutrient retention capacity;
- direct nutrient cycling from litter to roots via mycorrhizal fungi;
- nutrient conservation by plants: (1) synthesis of secondary metabolites toxic to plant-eating animals, thereby minimising their populations, and (2) nutrient recovery before leaf shedding;

Table 2. Estimated biomass and nutrients in a tropical rain forest on an Ultisol in Kalimantan, Indonesia (von Uexküll 1982), and an Oxisol near Manaus, Brazil (Toledo and Navas 1986).

Component	Dry matter (t/ha)	Nutrient content (kg/ha) N	P	K	Ca	Mg
Kalimantan						
Leaves and twigs	26	468	31	312	130	65
Litter	6	72	1	18	60	9
Dead wood	18	16	2	9	26	11
Live wood	285	513	71	712	855	132
Roots	50	150	22	150	223	33
Total	385	1 219	127	1 201	1 294	250
Manaus						
Total biomass	504	3300	69	504	528	275

- physiological adaptation of trees to low Ca/high Al acid soils and to flooding (anaerobiosis);
- unique arrangement of fallen leaves on the forest floor, which reduces residence time of water on them and minimises leaching of nutrients;
- the multilayered structure of the forest which filters and extracts nutrients from through-fall rain. Some epiphytes on leaves and branches may fix N from the air.

Unlike most temperate forests, tropical forests are very diverse in species composition. Trees with commercial value are often far apart, meaning that tropical forests may be logged without removing all tall trees or most vegetation. Nevertheless, even selective logging upsets the nutrient cycles and damages soils because of the road construction and heavy equipment used in modern logging operations.

Natural regeneration of commercial tree species is often not a concern because all commercial trees are usually removed by loggers; rarely are any left to reseed logged areas.

Even if 20–30 years between logging operations were allowed, few of the highest value species would be able to regrow through the dense canopy or reach commercial size in such a short time.

Unless tropical forests are carefully and selectively logged the first time and managed thereafter, they are most unlikely to have the same value when logged the second time. To maintain the economic well-being of the indigenous people, as well as those people and businesses imported by or because of the logging operation, eventually the remaining forest will be cleared for agriculture.

According to Dowdle and von Uexküll (1988), clearing a tropical forest will:

- eliminate the protective leaf canopy cover;
- interrupt the deposition of plant biomass on and in the soil and, if burned, eliminate most of the organic carbon from the ecosystem;
- increase the amount of rainfall and the force of raindrops hitting the ground directly;
- increase erosion of the topsoil;
- rapidly decrease the small amount of organic matter in the topsoil (with *or* without burning);
- decrease plant root and microbial activity in the soil;
- decrease water infiltration into the soil, especially if heavy machines have compacted the soil;
- decrease soil water-holding capacity;
- increase surface water runoff (and soil erosion);
- increase markedly the soil surface temperature maxima;
- increase the variation in soil moisture at and just below the soil surface, ranging from excess to severe drought stress in short time periods;
- increase nutrient losses by leaching and erosion;
- decrease nutrient availability in soils;
- decrease plant growth (biomass), and thereby decrease the protective leaf canopy cover provided by spontaneous regrowth or subsequently planted crops.

Over time this series of degrading events will be repeated until, depending on the severity, the forest becomes savanna and/or barren land.

Not included in the above nor usually recognised is the downstream damage caused by the erosion-induced flooding and soil removal (Fig. 2). When roads and bridges are washed out, people may or may not attribute the cause to deforestation. Of course, the cause of the recent floods in southern Thailand was

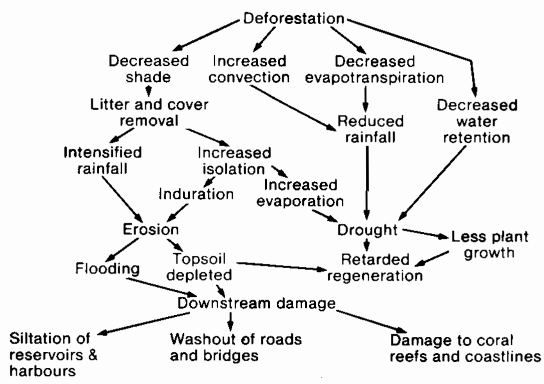

Fig. 2. Environmental changes and damage caused by deforestation in the humid tropics (modified from Goodland and Irwin 1975).

never in doubt. Less well recognised environmental degradation of immense economic importance includes the siltation of water reservoirs and harbours and damage to coral reefs and coastlines. Destruction of coral reefs breaks the food cycle of coastal marine life and can be economically devastating to fishermen and coastal villages dependent on seafood.

The amount of eroded soil annually transported to the sea in rivers of Southeast Asia far exceeds the soil losses from the Amazon Basin of South America (Milliman and Meade 1983). The economic impact of this destruction has not yet been recognised.

Anthropic Savanna

Savanna in the humid tropics is always anthropic. In tropical Asia the dominant grass species is *Imperata cylindrica* which invades cleared areas of characteristically high Al and Mn and low nutrient status, especially low P. Most nutrients from the previous forest have already been lost by leaching, runoff, or soil erosion. Like other grasses, *I. cylindrica* is shallow-rooted and compared to the forest forms a thin soil cover. Thus, nutrients are not brought from the topsoil to and concentrated at the soil surface. Because *Imperata* goes into dormancy during dry weather, its dried leaves can be a serious fire hazard, which usually leads to another round of leaching and topsoil erosion when rains fall again. This degradation process may result in the soil becoming barren and unable to support any vegetation.

An example of a degraded soil under savanna is Sitiung, West Sumatra (Table 3). Note the near absence of exchangeable bases and high Al and their concentration in the shallow topsoil. Olsen ($NaHCO_3$) extractable P was less than 5 ppm in the topsoil.

Barren Land

Barren land or wasteland covers large areas of southern China, Thailand, Laos, and Vietnam, especially on the upper slopes of hillsides (Dowdle and von Uexküll 1988). These lands are unable to support the growth of any vegetation without some fertiliser.

Properties of a barren hilltop soil in southern China are shown in Table 4. Note the very low organic carbon content, which indicates complete removal of topsoil, and the very low concentrations of bases, especially K, and of P.

Originally, this soil when under forest was much more fertile than now. Over centuries it was used by chance or design to fertilise the neighbouring lowlands, first with ash from the burnt forest and later by erosion of the topsoil

Table 3. Properties of a Typic Paleudult under savanna vegetation, Sitiung IV–D, West Sumatra (Wade et al. 1988).

Property (%)								Exchangeable (cmol/l)					
Depth (cm)	Clay	Silt	Sand	Org C	Free Fe	Bulk density	pH H_2O	Ca	Mg	K	Al	ECEC[a]	Al sat. %
0–5	64	14	22	4.6	3.6	–	4.1	0.6	0.2	0.1	4.3	5.2	83
5–20	70	13	17	1.5	4.4	1.18	4.9	0.1	t	t	3.3	3.4	97
20–48	74	12	14	1.1	4.8	1.12	5.0	t	t	t	2.8	2.8	100
48–102	77	10	13	0.6	4.7	1.07	4.9	t	t	t	2.4	2.4	100

[a] ECEC = effective cation exchange capacity.

Table 4. Properties of a barren hilltop soil in Xinyi County, Jiangsu Province, China (Dowdle and von Uexküll 1988).

Depth cm	Texture	Organic C %	pH H_2O	Exchangeable Ca (meq/100g)	Mg	K	Al	Available P (Olsen) (ppm)
0–15	silt loam	0.6	5.9	1.75	0.35	0.08	2.0	0.2

down the slope. Grasslands, which succeeded the forest, were used as fodder and fuel or were burned during the winter dry season. The first spring rains then further eroded the topsoil and continued the transfer of nutrients to the lowlands, resulting in the present-day countryside with barren dry hillsides surrounding fertile wetlands (Dowdle and von Uexküll 1988).

Soil Classification

Most acid upland soils are classified as Ultisols, Oxisols, and perhaps a few Alfisols. Combined they occupy over 50% of the area in the tropics. Eswaran (1987) proposed specific criteria for characterising acid mineral soils, including exchangeable Ca and Al concentrations and Al saturation. Soil moisture and temperature regimes, texture, activity of clay, amount of organic matter, soil depth, and slope can influence the effects of soil acidity and therefore must be well defined. An acid soil selected for an IBSRAM network experiment must be thoroughly characterised according to Soil Taxonomy (Soil Survey Staff 1975) and the Fertility Capability Classification (Sanchez et al. 1982) to assure transferability of technology to similar sites elsewhere.

Ultisols

Ultisols, which cover more than 50% of the acid upland soil area in tropical Asia, have an argillic or kandic horizon in which clay has accumulated. In other words, clay content increases with depth.

Clay minerals are predominately kaolinitic and are generally less weathered than those found in Oxisols. Thus, shrinking and swelling clays may be present to give Ultisols poor physical properties, including instability and susceptibility to erosion. They are also sensitive to compaction by heavy machinery. Water infiltration through the argillic horizon may be slow. During high rainfall periods, this may cause temporary waterlogging and anaerobiosis within the profile, even though water may or may not be on the soil surface.

As noted in Table 3, Ultisols are poor in nutrients, especially P. Base saturation is less than 35%, especially below the A horizon.

Oxisols

Although Oxisols cover vast areas in South America and Africa, they are less common in Asia. Their clay mineralogy is dominated by kaolinite and oxides of Fe and Al. Because weatherable shrinking and swelling minerals, e.g. montmorillonite, are virtually absent, Oxisols have excellent physical properties even at high clay content. They are stable, i.e. minimal shrinking and swelling, have rapid water infiltration rates, good drainage, and a relatively low erosion hazard (compared with Ultisols). They may dry quickly and be drought prone. They can tolerate the use of heavy machinery except when wet and will compact less easily than Ultisols.

Oxisols are poor in nutrients, especially Ca, Mg, K, and P. P fixation is generally more severe in Oxisols than Ultisols. The CEC is less than 16 meq/100 g of clay, of which less than 10 meq may be due to permanent charge.

Topsoils of both Ultisols and Oxisols may be relatively fertile but are usually shallow, which means that erosion of the surface layer of soil will increase the dependence of crops on the subsoil for water and nutrients. The subsoils, on the other hand, are extremely poor in nutrients and may have potentially toxic concentrations of Al or Mn, which may inhibit root growth of sensitive crops. The Ultisols with their poorly permeable argillic horizons may pose physical barriers to root growth as well.

Major Soil Constraints to Crop Production

Most acid upland soils may have one or more of the problems in the incomplete list below. The number and severity of problems increases rapidly if a soil has been left without cover, been eroded, been burned, or been compacted by machinery. They may include:

- low pH
- high exchangeable Al concentration
- high Al saturation percentage
- high available Mn concentration
- low concentrations of exchangeable Ca, Mg, and K
- low base saturation percentage
- low available P and high P fixation capacity

- low and pH-dependent CEC
- low organic matter and absence of OM–clay mineral complexes
- low microbial activity
- sensitivity to erosion
- low water-holding capacity
- low permeability to air, water, and roots (high soil strength)
- slow water infiltration rate
- sensitivity to compaction by heavy machinery.

Several major constraints to arable crop production on acid upland soils will be considered.

Acidity in the Topsoil and Subsoil

Low soil pH (below 5.0) brings with it many potential associated problems, including H, Al, and Mn toxicity, Ca deficiency, low CEC, P fixation, and low microbial activity (nitrification, N fixation). Liming to pH 5–6 helps to reverse these adverse effects, but overliming can bring with it a new set of ills such as trace element deficiency and cation imbalances (deficiencies). Usually, the major objective of liming is to reduce Al saturation (Fig. 3).

Tolerant Species and Cultivars

How to manage acidity-related soil problems is a very important matter to be decided by each farmer. If allowed a choice, farmers should seriously consider at least initially planting crops which do not require liming and tolerate acid soils, such as upland rice, cowpeas, rubber, or oil palm. Until they can afford to apply lime, farmers need to be advised of this option. Upland rice and cowpeas have the highest tolerance of percent Al saturation compared to maize, peanut, soybean, and mungbean, as shown in Fig. 4.

Liming Requirements

Once the crops and their sequence have been decided, liming decisions should be based on crop requirement as well as those of the soil. Soil analysis is a valuable tool in determining lime requirements. A soil pH determination alone is not the best means, but depending on the soil, crop, and lime supply, buffer capacity or exchangeable Al determinations are usually recommended. These are described and compared in excellent reviews on the liming of tropical soils by Kamprath (1984) and Pearson (1975).

Liming Materials and Particle Size

Although calcium carbonate is the most widely used liming material, consideration should be given to others such as calcium magnesium

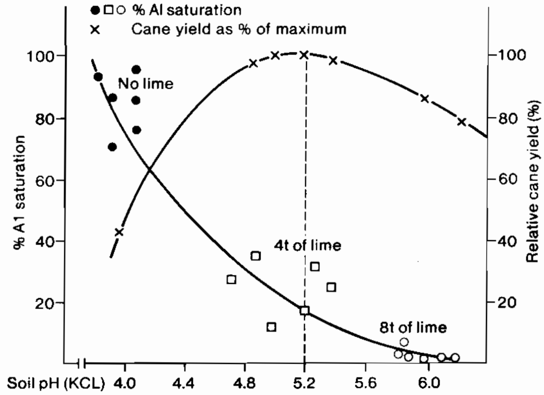

Fig. 3. Relationship between rates of lime, pH, Al saturation, and yield of sugarcane on an Ultisol in Indonesia (von Uexküll 1986).

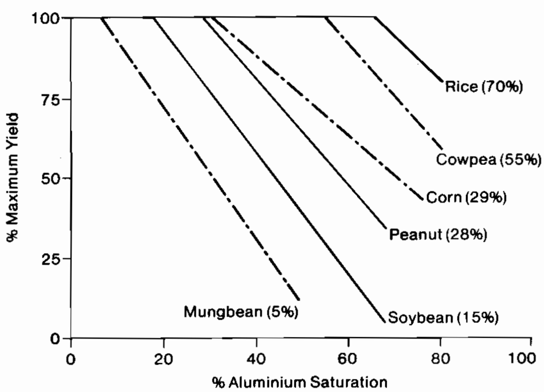

Fig. 4. Tolerance of several food crops to percent aluminium saturation, Sitiung, West Sumatra (Wade et al. 1988). Values in parentheses are the critical levels.

carbonate (dolomite or dolomitic limestone), calcium oxide, calcium hydroxide, or calcium metasilicate depending on their availability, price, and crop requirements. Ca and Mg content and reactivity must be assessed because all are not the same in quality.

Particle size can strongly affect reactivity of liming materials. If short-term effects are needed, fine materials are best.

Liming materials and their properties are discussed in most textbooks on soils or fertilisers, including Tisdale et al. (1985).

Placement

Lime placement is important in determining reactivity and movement into the subsoil. Broadcast application is almost always recommended and, where possible, the lime should be incorporated in the soil as deeply as possible by a plough or disc harrow. Lime left on the soil surface may, depending on a soil's buffer capacity and amount of pH-dependent charge, react only with the surface layer (1–2 cm) of soil and not release Ca to move down the profile.

Surface (0–5 cm) and subsoil pH should be monitored, especially where lime is broadcast on the soil surface and not incorporated. Otherwise, subsequent applications may be doing nothing to raise pH below the top few centimetres.

An example of successful subsoil amelioration 1 year after incorporation to about 15 cm at three rates of lime applied to a Haplorthox in Sitiung, West Sumatra, is shown in Fig. 5.

Subsoil Amelioration with Gypsum

The reason for subsoil amelioration is to improve rooting depth by increasing subsoil permeability and to minimise drought stress by reducing toxic concentrations of Al and Mn. To try to overcome the sometimes slow reactivity and downward movement of liming materials, especially where they cannot be incorporated, some researchers have successfully used high rates of surface-applied gypsum (calcium sulfate) to get Ca into the subsoil to displace Al from the negative charges (Farina and Channon 1988; Pavan et al. 1987; Ritchey et al. 1980). Leaching rains are necessary to move Ca into the profile and remove the displaced Al from the root zone. As the Al is removed, soil pH will be raised only slightly, because gypsum is not a liming material.

Loss of Organic Matter and the Importance of Soil Cover

The roles of organic matter in the productivity of mineral soils are 'still grossly underestimated and neglected in most tropical areas' except China (von Uexküll 1986). Greenland and Dart (1972) listed nine major benefits of organic matter, the most important being increased available nutrient supply and CEC, reduced surface temperature, improved water relations (conservation, infiltration), and reduced soil erosion and surface water runoff. These benefits and management practices for retaining and building soil organic matter content were reviewed by Greenland (1988) and von Uexküll (1986). Because of the small percentage of organic carbon in the soil of a tropical forest ecosystem (Fig. 1), every effort should be made during land clearing to save as much of the carbon in the above-ground biomass as possible. This can best be accomplished by maintaining a cover on the soil at all times. The beneficial effects of different covers at reducing soil losses are clearly shown in Fig. 6.

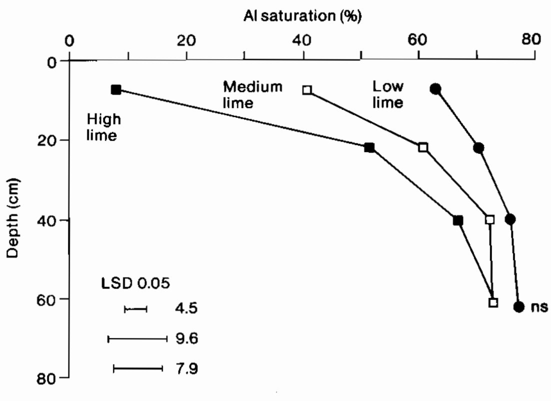

Fig. 5. Percentage of Al saturation of a Typic Haplorthox one year after application of three lime rates: low (0.375 t/ha), medium (2.25 t/ha), and high (5 t/ha), Sitiung, West Sumatra (Wade et al. 1988).

Organic matter additions as crop residues and/or green manure crops in rotation or as intercrops (alleys) must be key components of crop management systems for acid upland soils planted to food crops. They should be left on the soil surface as a mulch, incorporated into the soil, or, ideally, used both ways.

Nitrogen

By conserving or adding organic matter, one also helps to conserve or add N. Preserving the topsoil by keeping it covered and not burning crop residues will minimise soil erosion and oxidation of organic matter and N. This must be a major objective of proper land clearing in order to minimise N fertiliser costs (if any) for the first few crops.

Because soil N supply decreases rapidly after cultivation begins, the fertiliser N requirement will have to increase if yields are to be maintained. The rate of increase can be minimised by including green manure or mulches in the management system. These can provide much of the N required by low- to moderate-yielding crops.

N fertiliser requirements are usually based on estimated crop yield and N removal: anticipated losses (20–80%) depending on the source and application methods: and soil concentrations of N or organic matter, or the N-fixing capacity of the legume being grown if any. For high-yielding grass crops (maize, rice), the soil N concentrations in the humid tropics are often considered negligible because, even if significant, they are very difficult to measure by soil analysis and the losses (native soil N and fertiliser N) are hard to estimate.

The pros and cons of different N fertiliser sources and application methods are explained by Randall (1984) and Tisdale et al. (1985).

Phosphorus

The fixation and immobility of P in acid soils of the tropics can be either major problems or blessings in disguise, depending on how soils and P fertilisers are managed.

Phosphorus fixation is often high in Oxisols and Ultisols because they are most likely to have P-fixing clay minerals (amorphous and crystalline hydrous oxides of Fe and Al), high Fe and Al, and low pH, all of which are conducive to P fixation (Fox et al. 1971; Fox 1988). The magnitude of difference in P-fixation capacity of an Ultisol and Oxisol at Sitiung, West Sumatra, is compared indirectly in Fig. 7. To achieve an Olsen's soil test P value of 10 ppm (0–15 cm depth) required only about

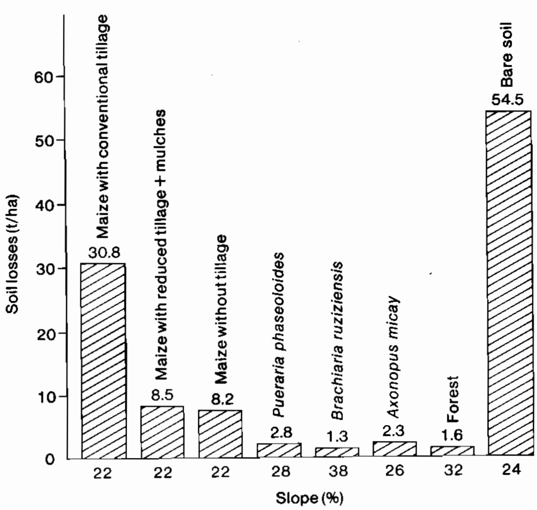

Fig. 6. Soil losses from different crop soil management systems over 32 months (Navas 1982 as cited by Toledo and Navas 1986).

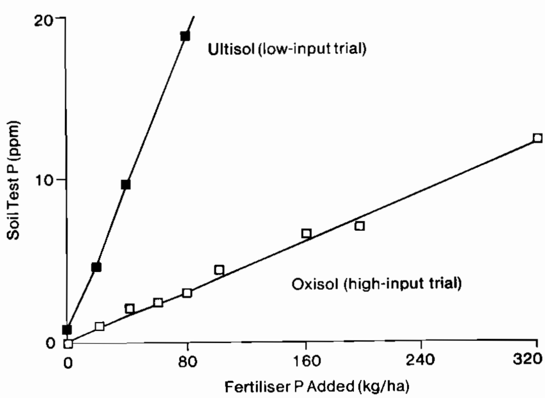

Fig. 7. Differences in P fertiliser applied versus soil test P (modified Olsen) between an Ultisol planted to a low-input experiment and an Oxisol planted to a high-input corn–soybean trial, Sitiung, West Sumatra (Wade et al. 1989).

40 kg P/ha for the Ultisol but more than 260 kg P/ha (more than six times as much) for the Oxisol.

If amounts of P fertiliser have been applied over several years to satisfy both actual crop demand (crop uptake of P is usually much lower than that of N and K) and a soil's fixation capacity, many tropical soils are now known to be able to return this 'capital' investment by releasing the P which was fixed in past years for use of present-day or future crops (Fox 1988).

The relative immobility of P makes it extremely difficult to increase the P fertility of subsoils. Because it stays where it is placed on or near the soil surface, it can be easily lost by sheet erosion. On the other hand, P cannot usually be leached. If one can afford to deep-place P manually or with machinery, or to add it to deep planting holes of the tree crops (ideally as rock phosphate), subsoil amelioration is possible and loss by sheet erosion will not occur.

Application Methods

P should ideally be applied either broadcast and incorporated or placed in a diffuse or mixed (not concentrated) band below the soil surface. Surface-applied P will be available to plants only when the soil surface is moist enough to permit both (a) root growth and interception of P and (b) P solubility. Fox et al. (1989) pointed out that when soil P concentration exceeds a certain level, P uptake by crops will actually be inhibited. Thus, highly concentrated bands of P fertiliser should be avoided.

Soil Analysis Methods for Determining P Requirements

None of the various methods of analysing soils for available P is accurate, reliable, and quick and easy. Each has its disadvantages (Landon 1984). Acid extractants may be less effective than Olsen's $NaHCO_3$ method for determining available P in acid soils high in sesquioxides or those previously fertilised with rock phosphate. P sorption isotherms (Fox and Kamprath 1970) may not always provide reliable results (Wade et al. 1988).

Even if a method of P determination were 100% acceptable, climatic and soil variability makes critical level determination difficult. Sumner (1987) pointed out that this problem exists with all nutrients, not just P (Fig. 8a). It would likely be solved by using the boundary line technique (Fig. 8b) involving hundreds of data points from experiments and/or farmers'

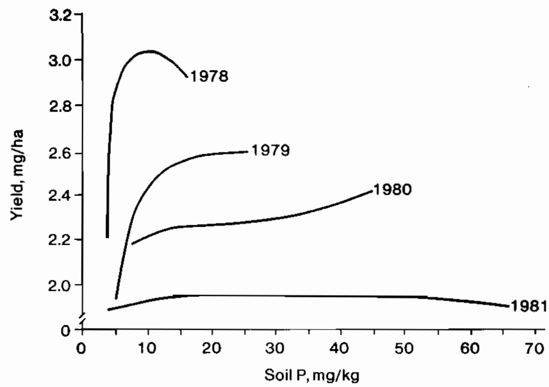

Fig. 8a. Effect of season on relationship between soil tests P and soybean yield (Sumner 1987 taken from Hargrove et al. 1984).

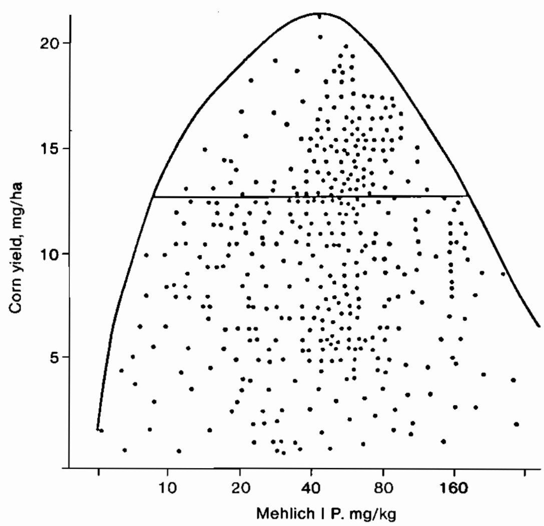

Fig. 8b. Scatter diagram with boundary line for relationship between soil test P and corn yield on Coastal Plain soils in the southeastern USA (Sumner 1987).

fields, where both yield and soil P data are known.

Soil Sampling for P

The method of P fertiliser application — surface broadcast, incorporated, or banded — must be considered in sampling soils for P. For unirrigated crops subsoil P status is especially important during dry periods when P in the fertilised topsoil is not available. A standard 0–15 cm depth soil sample may not be adequate to assess soil P status if P fertiliser is applied to the surface (not incorporated or banded below surface) or if the subsoil is P deficient.

P Sources

The advantages and disadvantages of different P fertilisers are discussed in fertiliser textbooks (Tisdale et al. 198 5).

Because of strong interest in rock phosphates for direct application to tree crops in Southeast Asia, one must know that rock phosphates differ significantly in their reactivity (Fig. 9). Because of their low cost, high Ca content, and residual effects, rock phosphates are especially well suited for amendment of acid soils poor in P and Ca (Dowdle and von Uexküll 1988).

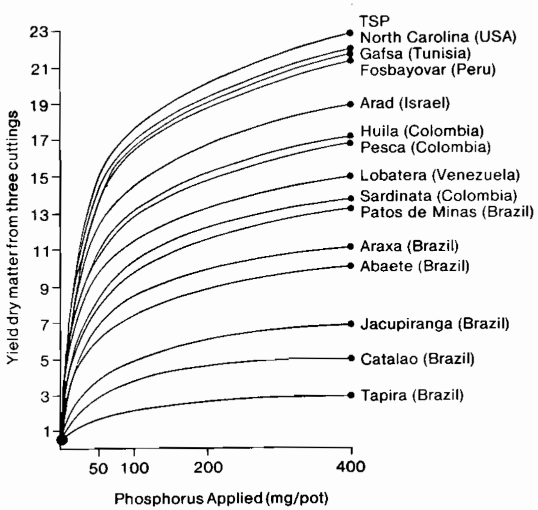

Fig. 9. The effects of different rock phosphates on the dry matter yield of *Brachiaria decumbens* (Hammond and Diamond 1987).

Drought and Poor Subsoil Fertility and Permeability

Because of the high temperatures and solar radiation common to the tropics, crops grown on upland soils are often subject to drought stress. Most Oxisols and many Ultisols can dry quickly to 30 cm in less than 1 week, especially if they are exposed to direct sunlight. To conserve soil moisture for the crop, keeping the soil surface shaded at all times (mulches, rapid canopy close-in) should be a high priority.

Most researchers and farmers in humid regions rely only on subjective visual observations to assess drought stress effects on their crops. The soil water balance in the root zone is rarely, if ever, determined. If actual water balance determinations, including root zone depth, were made, one would probably find that rainfall is often adequate but that the rooting depth of many crops is restricted by adverse conditions in the subsoil, including: (a) toxic levels of Al and/or Mn; (b) deficiencies of P, K, Ca, and Mg; and (c) for many Ultisols, high strength soil with poor permeability to air, water, and roots (i.e. naturally compacted). If any of these conditions prevails in subsoils, what farmers and researchers perceive to be drought stress effects on their crops may actually be due to toxicities or deficiencies. If there are any doubts, soil profiles should be dug to assess the depth of the active roots during dry periods and to sample the subsoil for fertility evaluation.

Potassium

Yield Responses to K

Some crops planted to recently cleared virgin soils may not respond to K fertiliser application. However, if crop residues are removed and lime and other fertilisers have been applied to obtain high yields, most crops planted on upland acid soils will show a yield response to K. The yield responses of upland rice to K and maize to K and lime in West Sumatra are shown in Fig. 10.

Residue Management

Because most K is stored in the stems and leaves, fertiliser K use efficiency is strongly influenced by what is done with crop residues

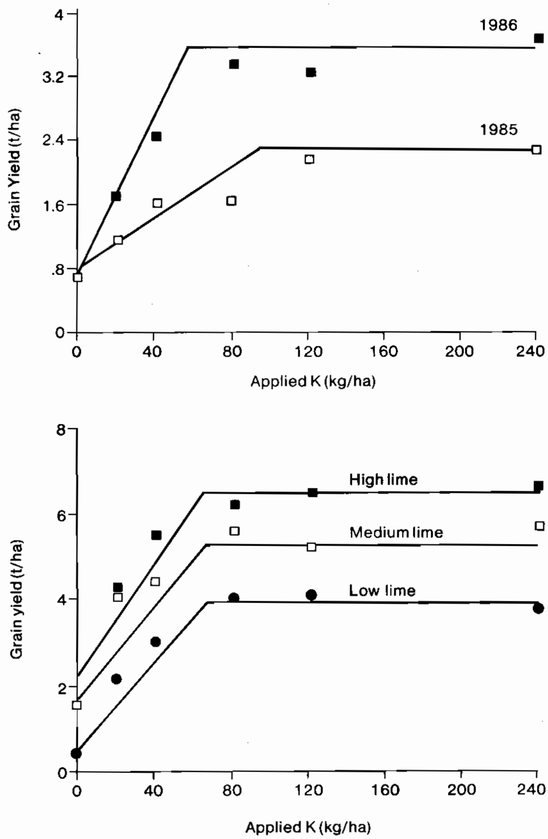

Fig. 10. Yield responses of upland rice and maize to applied KCl at Sitiung, West Sumatra (Wade et al. 1988).

after harvest. If they are removed for fuel, fodder, or other uses, the K fertiliser requirement is much higher than if residues are returned to the soil.

Potassium and Liming Interactions

As shown in Fig. 10 for maize, liming can significantly increase the yield response to KCl. Raising soil pH can increase CEC and reduce leaching of K but, unless K is increased with lime, sorption of K may be increased and availability decreased. Other negative interactions of lime with K, which may decrease K availability and uptake, are discussed by von Uexküll (1986).

Potassium and Plant Health

Potassium nutrition is important in determining plant health, especially in reducing damage due to various diseases (Table 5) and insects (von Uexküll 1987a). Adequate K nutrition also helps reduce drought damage (Darst and Wallingford 1985).

K Fertiliser Requirements

Potassium fertiliser requirements of upland crops in tropical Asia are often underestimated because they may have been based on either the K fertiliser needs of paddy rice or on fertiliser trials which produced low yields or were done many years ago. If K fertiliser trial data are not available, K rates should be based on (a) estimated crop yield and K removal and (b) soil analysis. A table of suggested critical values for ammonium acetate extractable exchangeable K was presented by von Uexküll (1986) along with a discussion of current methods of analysis. By sampling the subsoil over time, one can assess whether K rates applied were adequate to meet crop needs and to raise subsoil K concentration to a level to meet crop demand during dry weather when roots may not be able to absorb K in the topsoil.

As for other nutrients, daily demand for K depends on growth stage. For grasses like maize, over 80% of the K is absorbed during 2 weeks before tasselling (Fig. 11). To avoid temporary (or longer) K deficiencies, farmers and researchers must assure that enough K is available in the soil to meet crop demand at such peak periods.

Application Methods

Because most Ultisols and Oxisols have clay minerals which do not fix much K and because

Table 5. Rice blast (*Pyricularia oryzae*) incidence rating for upland rice grown in 1985 in Sitiung, West Sumatra, at different rates of K (Wade et al. 1988).

Treatment (kg K/ha)	Blast rating[a]
0	4.9
20	2.9
40	2.2
80	2.1
120	1.8
240	2.0

[a] 0 = no blast; 10 = all plants killed.

effective CECs are low, K use efficiency can be optimised and leaching minimised by broadcast application of K fertiliser. Banding is not recommended.

K Sources

Except for chloride-sensitive crops like tobacco and pineapple, for which potassium sulfate and potassium magnesium sulfate are recommended, potassium chloride (KCl) is suitable for most crops.

Magnesium

Because Al toxicity can induce Mg deficiency (Grimme 1983), liming may be beneficial by raising pH and reducing exchangeable Al concentrations. Dolomitic limestone would be the best liming material if Mg deficiencies are suspected. If dolomitic limestone cannot be used because the soil pH is above 5.5 or if it cannot be incorporated into the soil, either magnesium oxide or magnesium sulfate may be applied to correct Mg deficiencies. MgO requires a soil pH less than 6.0 to be readily solubilised, whereas $MgSO_4$ or potassium magnesium sulfate are soluble in water and can be used in all soils.

Because the Mg in soluble sources is relatively mobile in soils, particularly those with low CEC, soluble Mg fertilisers may be leached into the profile to displace Al from the negative charges in the subsoil. To be effective, however, application rates would have to exceed crop requirement.

Crop species differ widely in their Mg requirements, their sensitivities to deficiency, and their capacities to absorb soil and fertiliser Mg (von Uexküll 1986).

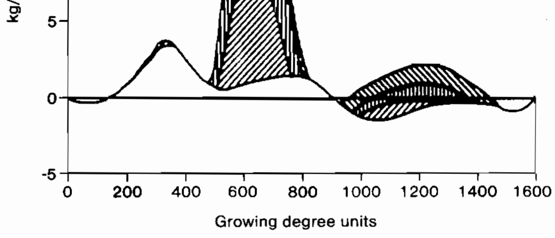

Fig. 11. Daily accumulation rate and partitioning of K versus growing degree units (time) for a high yielding maize crop (Karlen et al. 1988). Growth stage versus GDUs: 8 leaves (422), 12 leaves (571), and tassel (753) each fully emerged and silks emerging (909).

Sulfur and Trace Elements

Increasing usage of relatively pure, sulfur-free fertilisers, e.g. urea, TSP, ammonium phosphates, will lead to increasing S and trace element deficiencies as high crop yields increase removal. Where organic matter has been lost due to burning or topsoil erosion, S and/or trace element deficiencies may occur, but they are rarely primary constraints to crop yield. In Southeast Asia zinc and boron are the most commonly deficient trace elements. If organic matter is conserved and liming is not excessive, trace element deficiencies are not likely to occur.

Soil Management Practices

Sound soil management for agriculture must aim to:

(a) protect the best of what is already present, including organic matter and topsoil; and

(b) improve soil physical properties and build and maintain fertility, especially in the subsoil, so profitable yields can be sustained far into the future.

Because of the many problems with acid soils in tropical Asia, these objectives cannot be met without some 'capital' investments in soil conservation, lime, and phosphate fertilisers.

These investments will provide returns for many years. Fox et al. (1971) illustrated the long-term benefits (residual effects) of a single heavy application of P to pastures grown on a Gibbsihumox in Hawaii and recently Fox et al. (1989) compared the P fertiliser consumption by Hawaii's sugar industry with P export in sugarcane from 1923 to the present (Fig. 12).

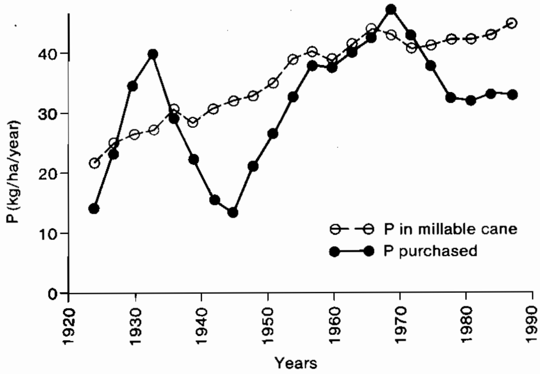

Fig. 12. P fertiliser consumption and P export in sugarcane, Hawaii (Fox et al. 1989).

The return on P fertiliser investment might be maximised if crop species and cultivars can be carefully selected for the P-supplying potential of their mycorrhiza–root associations. For example, the P-supplying power of the mycorrhiza–root association of pineapple is much greater than that of sugarcane (Fox et al. 1989). Thus, cultivars and species need to be screened not only for their tolerance to acidity and high Al but also for the strength of their mycorrhiza–root associations. The aim should be to provide farmers with information about the largest number of species which they can choose to grow under various soil and market conditions, which, of course, will always change with time.

Essential to profitable farming is knowledge of the soil, climate, and crops and their management and site-specific assessments of yield-limiting factors. Developing and extending that knowledge is one of IBSRAM's as well as our Institutes' objectives. University lecturers, extension educators, and farmers should ideally have that knowledge *before* as well as after farming begins.

Although we already have much knowledge about growing low-input and high-input crops on poor tropical soils, it needs to be extended to farmers. Indonesia's extension service has done an outstanding job training farmers how to grow high-yield paddy rice. Also, Malaysia and Thailand have very effective extension services for rubber smallholders. Unfortunately, extension services for other crops are understaffed, poorly trained, or nonexistent.

Development of Forested Land

As mentioned above, a series of degrading events occurs when a forest is cleared without regard for protecting the soil, especially the organic matter in the topsoil. Most countries have recognised these problems and to varying degrees have established officially approved methods for clearing land for government projects. Bulldozing and root raking are generally discouraged; only *manual* underbrushing and felling of large trees is now acceptable. The extremely adverse effects of bulldozing on water infiltration rates of an Oxisol and an Ultisol are shown in Fig. 13.

In spite of the progress made to discourage the use of heavy machinery in clearing, burning the underbush and felled trees is still normal practice in all countries. Indonesia has gone one step further to require government contractors

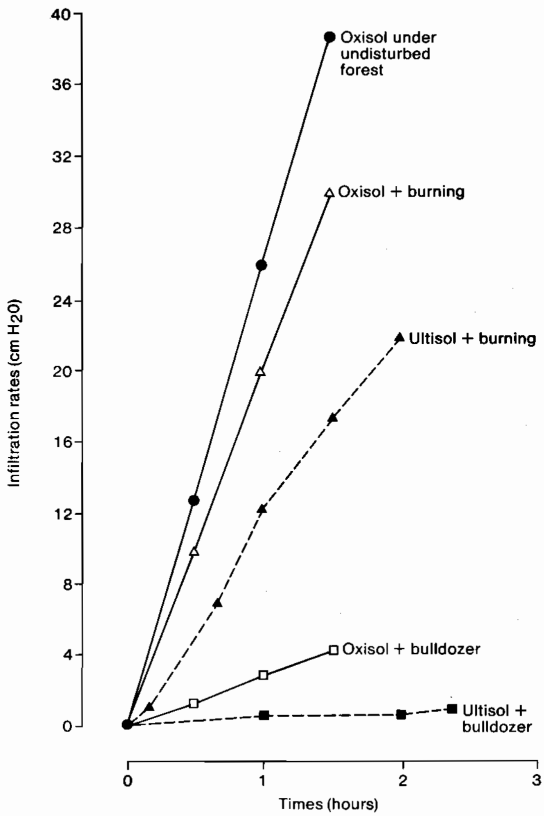

Fig. 13. The effects of land clearing method on the water infiltration rates of an Oxisol and an Ultisol (Toledo and Navas 1986).

to plant legume cover crops on burned land which is not to be planted by farmers immediately (Wade et al. 1988). Steep slopes must be left forested.

Zero-burn techniques, as recommended by von Uexküll (1984, 1986, 1987b) and Dowdle and von Uexküll (1988) have been recognised (Wade et al. 1988; Lal 1987) but not yet tested or implemented in toto. They are repeated here, quoted from von Uexküll (1986) for the benefit of those not familiar with the practice:

(a) Cut the underbush at the start of the rainy season, so that it remains moist.

(b) Stack the cut underbush to allow access to the land.

(c) Plant cover crops while the large trees are still standing. Large seeded legumes such as *Mucuna utilis* or *Phosphocarpus palustris* are most suitable, but cuttings of *Pueraria triloba* or *Calopogonium caeruleum* can also give good results. The winged bean (*Psophocarpus teragonolobus*) is a good cover crop which also provides food.

(d) Spread 100–200 kg/ha of rock phosphate along the rows where the cover crop is being planted or sown.

(e) Ring-bark (girdle) and poison the large trees. Poisoning traps the moisture in the tree trunks and thus promotes rapid decomposition. The herbicide 2,4,5-T has been widely used as an arboricide in the past, but Triclopyr (DOWCO 233) is now considered safer. Note: different tree species may require different types and dosages of arboricides so they die at the same time.

(f) Fell the trees when the canopy starts to die without waiting too long. If the trees are left standing, the dead branches rapidly become very brittle and whole trees may collapse and endanger workers.

(g) Before the large trees are poisoned and felled, the cover crop must be well established so that it rapidly covers the felled tree trunks and branches.

After about 2 years under the cover crop, all wood except the trunks of some hardwood trees will have decayed, and the soil will be covered by a thick layer of organic mulch. The cover crop planted before the large trees are removed takes over the following fertility-maintaining functions of the rain forest:

(a) shading the soil and keeping it cool and protected;

(b) fixing up to 350 kg/ha/year of atmospheric N, which is needed for rapid microbial decomposition of the dead wood; zero-burning works best when the cover crop is vigorous and productive;

(c) covering the logs and thereby preventing them from becoming a breeding ground for black beetles (*Oryctes* spp.);

(d) preventing weed infestation, especially by grasses such as *Imperata cylindrica*;

(e) stimulating the activity of various soil organisms including earthworms, thereby improving the chemical and physical properties of the subsoil;

(f) helping to maintain soil CEC and reduce leaching losses of nutrients.

Zero-burning is highly recommended for Ultisols (Acrisols). Oxisols (Ferralsols) and Andosols have excellent physical properties and the conservation of organic matter is less essential than in Ultisols. Nevertheless, zero-burning is still the preferred technique for all forested lands.

Development of Anthropic Savanna and Barren Land

In tropical Asia anthropic savanna is dominated by the grass *Imperata cylindrica*, which is well adapted to low-P soils. The land area under anthropic savanna is expanding rapidly, especially in Indonesia where lands have been cleared for transmigration. Improper soil management has resulted in abandonment of the land by the migrants and invasion by *Imperata*.

Reclamation of anthropic savanna and barren lands, which have reached the ultimate stage of degradation, requires immediate replenishment of some of the organic matter and nutrients lost during clearing, burning and subsequent erosion and leaching, before agricultural crops can be grown. At least 200 kg P/ha and 1000 kg Ca/ha or 1 tonne of rock phosphate/ha should be incorporated as deeply as possible into the soil by ploughing (Dowdle and von Uexküll 1988). Legume cover crops, such as those recommended for establishment on forested land (see above), should be planted immediately to control erosion and weeds, including *Imperata*. These treatments are recommended without soil analyses, which, if available, might indicate needs for more lime and/or other nutrients. Dowdle and von Uexküll (1988) described what has been done by P.T. Gunning Madu Plantations, Lampung, Sumatra, Indonesia, to reclaim 20 000 ha of Ultisols under anthropic savanna for sugarcane production and make it the highest yielding and most profitable sugar plantation in Indonesia.

Crop Management Systems

Because of their infertility, acid upland soils require regular fertiliser nutrient additions in excess of the amounts removed by the crops. These are required for low-yielding (national average) or high-yielding crops, if continuous crop production is required. The soils themselves are capable of supplying only a small percentage of the total nutrient requirement.

Newly cleared Ultisols and Oxisols may be able to support crop production for several years without fertilisers, much as they do for shifting cultivators. But shifting cultivation, when done properly, involves small, not large cleared areas. It is suitable only for areas with low population pressure and for people who subsist on it and do not expect to improve their standard of living.

Transitional Low Fertiliser Input Systems

Von Uexküll (1984, 1986) suggested several low-input cropping systems for regenerating degraded soils and for maintaining a cover on the soil surface, the importance of which is illustrated in Fig. 6. These are:

(a) rotations between cover and food crops;

(b) avenue cropping with avenues of food crops planted between strips of legume covers; and

(c) alley cropping with food crops planted between single or double rows of fast growing leguminous trees such as *Leucaena leucocephala* and *Gliricidia maculata*.

These systems can supply much of the N needs of food crops. Depending on the yields obtained or required, additional N and other fertiliser nutrients, especially P and Ca, will be necessary particularly for the legumes. After several years other nutrients (K, Mg) will likely be needed.

Bandy and Sanchez (1986) and Sanchez et al. (1987) listed several steps farmers might follow after clearing a forest to minimise inputs (i.e. no lime) but still obtain modest crop yields for several years:

(a) plant acid-tolerant species and cultivars, particularly upland rice and cowpeas in rotation (see Fig. 4);

(b) no or minimum tillage;

(c) apply the above-ground portion of a green manure crop (*Pueraria*) from a nearby field;

(d) apply crop residues or compost;

(e) return all above-ground crop residues without burning to the soil in which they were produced; and

(f) alternate 1 year of continuous cropping with 1 year of managed fallow with a leguminous cover crop like *Pueraria*, which may be necessary to control serious weed problems.

Until more is known about how to manage low-input systems, particularly fertiliser management and subsoil amelioration without tillage, the above low-input practices should be regarded as *transitional* at best. Eventually, after several years, farmers must go to high input systems to prevent yield decline due to net export of nutrients and declining fertility. The encouraging aspect of these practices is that they may give poor farmers time to produce above-average yields and build some financial resources for the time when they must make 'capital' investments in lime, rock phosphate, and fertilisers in amounts exceeding crop requirements so as to build up soil fertility and a sustainable system.

Sustainable Medium to High Fertiliser Input Systems

Sustainable medium to high yields (at least double national averages) of most crops are possible in Southeast Asia with good crop husbandry. They should be managed as follows:

(a) amended with lime to correct high H, Al, and Mn and low Ca;

(b) fertilised with amounts of N, P, K, Mg, and other nutrients sufficient to meet crop removal as well as to raise topsoil and subsoil concentrations to above 'critical'; and

(c) protected from direct exposure to sun, rain, and wind, and from topsoil erosion and loss of organic matter by the use of sound soil conservation practices and by keeping a cover on the soil surface.

The success of these methods has been demonstrated in enough locations in the tropics — Manaus, Yurimaguas, West Sumatra, Lampung, to name a few — to prove their value, provided that there are no other unusual physical or chemical limiting factors (e.g. salinity in Northeast Thailand).

Without question the greater the effort expended to preserve the topsoil and the organic carbon and nutrients in the forest biomass, the higher will be not only the initial but long-term yields. Even soils which have been severely degraded can be reclaimed, although 10 years or more of intensive high input management may be required to restore them to their original post-clearing productive potential.

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Acid Soil Infertility in Australian Tropical Soils

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Abstract

A review of knowledge on limitations to plant growth in acid soils of tropical Australia indicates that calcium deficiency and molybdenum deficiency are more common than aluminium toxicity or manganese toxicity. However, many acid soils have the potential to become aluminium toxic when soluble fertilisers are added. The soil test procedures used to assess the nutrient status of acid soils in Queensland have been detailed; no satisfactory soil test exists for molybdenum. Soil acidity management in tropical Australia rests upon the use of lime to alleviate acid soil infertility constraints to the growth of agriculturally important plant species.

Introduction

In Australia, acid tropical soils are found in the wet tropics of northeast Queensland in areas where the rainfall is high (>1500 mm p.a.) and there is a short dry season. The region is largely one of narrow coastal plains bounded on the inland side by mountains up to 1600 m. Similar soils are also found in the subtropics in southeast Queensland and northeast New South Wales as far south as latitude 30°S. In this region, the rainfall is generally lower, evaporation is only about 60% of northern values, rainfall seasonality is less pronounced, and minimum temperatures are considerably lower than those in northeast Queensland. Latitude 30°S indicates the southern limit to the dominant use of rainfed summer crops, including sugarcane, and pastures.

The area dominated by Oxisols and Ultisols in tropical Australia has been estimated at 8×10^6 ha, which represents only 3.6% of the total land area (Sanchez and Salinas 1981). The proportion of the Australian tropics dominated by Oxisols and Ultisols is thus very much lower than in tropical America, tropical Africa or tropical Asia. In Australia, the area of Ultisols greatly exceeds that of Oxisols; a similar picture exists in tropical Asia, but not in tropical America or tropical Africa (Sanchez 1987).

The major agricultural crop in the Australian wet tropics is sugarcane production, which occupies about 126 000 ha, and is mainly confined to the coastal lowlands. Other agricultural cropping includes maize, peanuts and potatoes on the elevated Atherton Tableland. Horticultural crops are locally important, particularly bananas in the Tully-Babinda area. Tea has long been grown commercially near Innisfail. Grazing of beef cattle on improved pastures and dairying are also of importance. Plantation forestry based on Caribbean pine (*Pinus caribbea*) and hoop pine (*Aravcaria cunninghamii)* is of some importance. Selective logging of rainforest species for structural and cabinet timber has long been an important industry in the extensive areas of state forests and timber reserves. However, this activity ceased in the northern rainforest areas at the end of 1987 following an application for World Heritage listing. The pattern of land use on the acid soils in southeast Queensland and northeast New South Wales is likewise diverse.

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Sugarcane is a crop which is highly tolerant of soil acidity (Hetherington et al. 1988) and has a long history of high fertiliser inputs. Its dependence on low labour and high horsepower inputs highlights a major difference between the Australian tropics and many other tropical regions.

It might be noted also that the coastal lowlands of north Queensland are well suited to sugarcane, because the seasonality of the climate permits reasonable yields; this contrasts with more equatorial climates where radiation levels can be inadequate because of continuous cloud cover.

In terms of overseas land use comparisons, the wet tropics of north Queensland are almost unique in the lack of any farming system remotely resembling shifting cultivation, in the lack of rainfed paddy rice production, and in the virtual absence of plantation crops such as rubber, oil palm, coconuts and cacao (Isbell and Edwards 1988). Population pressure in southeast Asian countries is leading to increasing needs for production of food crops; this is being addressed by the increased use of land for multiple cropping and by intercropping of food crops in young plantation crops such as rubber and oil palm following replanting. This latter issue is being addressed currently in the ACIAR research program 'The Management of Soil Acidity for Sustained Crop Production'. In contrast to Southeast Asia, land use pressures in north Queensland are resulting in the setting aside of increased areas for recreational activities associated with a burgeoning tourist industry.

Causes of Acid Soil Infertility

The major growth-limiting factors that have been associated with acid soil infertility include toxicities of aluminium and manganese, low pH per se, and deficiencies or low availability of certain essential elements including calcium, magnesium, phosphorus and molybdenum (Foy 1984). These factors may directly restrict plant growth or indirectly restrict plant growth through interference in the development and functioning of symbiotic associations with rhizobia, mycorrhizas and actinomycetes. A further constraint to plant growth in highly acid soils may arise from water stress which results from the restriction of root growth into acid subsurface horizons (Adams 1984).

The importance of aluminium toxicity, manganese toxicity, calcium deficiency, and molybdenum deficiency in limiting plant growth in acid soils of the Australian tropics and subtropics will now be examined.

Aluminium Toxicity

Despite reports of acidification of sugar-growing soils over the past 10–15 years (Chapman et al. 1981; Wood 1985), no field evidence has been obtained that aluminium toxicity restricts growth of sugarcane (Haysom et al. 1986). sugarcane is a crop tolerant to high aluminium (Pearson 1975; Hetherington et al. 1986), and problems are more likely to appear in other more susceptible crops such as navybean, soybean or maize (Hetherington et al. 1988) when grown in rotation with sugarcane or as replacement crops in areas which previously grew sugarcane.

Teitzel and Bruce (1972b, 1973a, 1973b) first suggested that lime responses by pasture species on soils from the wet tropics of Queensland involved the alleviation of aluminium toxicity. Subsequently, Carvalho et al. (1980) concluded that the growth of six *Stylosanthes* species in three acid soils from southeast Queensland was limited, at least in part, by the presence of toxic aluminium concentrations in the soil solutions. More recently, Bruce et al. (1989a,b) have reported an intensive study of soil and soil solution attributes of a wide range of surface and subsoil horizons of 48 acid soils from Queensland. Ionic strengths and activities of monomeric aluminium species in the soil solutions were calculated. Higher activities of monomeric aluminium species in the soil solutions of surface soils than those of subsoils were attributed to an overestimation of monomeric aluminium in the former, probably through inclusion of some soluble organic matter - aluminium complexes (Bruce et al. 1989a). In subsoils, the activity of Al^{3+} in soil solution was dependent on ionic strength (I_{ss}) and aluminium saturation and was described by the following equation:

$$\ln (Al^{3+}) = -6.97 + 1.96 \ln I_{ss} + 0.077 \text{ Al sat \%}$$

($R^2 = 0.947$).

Thus the activity of Al^{3+} can be predicted simply, knowing the ionic strength (or electrical conductivity) of the soil solution and the aluminium saturation. Following detailed studies with 21 acid soils (four surface soils and 17 subsoils) from southeast Queensland which were amended with liming materials and soluble calcium salts, Bruce et al. (1988) concluded that exchangeable aluminium and aluminium saturation were poor indicators of aluminium toxicity limitations on root growth of soybean, whereas the activity of Al^{3+} in the soil solution was a good indicator. The critical activity of Al^{3+} associated with a 10% reduction in root elongation was 4 µM. Aluminium toxicity was not a common problem in the unamended soils from southeast Queensland because the low ionic strengths of the soil solutions more than offset the high aluminium saturations; however, aluminium toxicity is a potential problem when these soils are amended with soluble fertilisers. On the basis of the determined critical activity of Al^{3+} (4 µM), Isbell and Edwards (1988) predicted aluminium toxicity would limit root elongation of soybean in only one of 18 subsoils, and possibly in seven of 18 surface soils from the wet tropics of northeast Queensland for which soil solution analyses were available.

Suthipradit (1988) reported a pot experiment in which cowpea, soybean, peanut and green gram were grown in the surface horizon of three acid soils amended by acidification or liming to cover the pH (0.01 M $CaCl_2$) range from 3.5 to 6.5. Acidification treatments markedly increased ionic strength and monomeric aluminium in extracted soils solutions. An attempt was made to employ aluminium in the soil solution measured by the method of Blamey et al. (1983) to predict aluminium toxicity. This procedure, which works successfully in solution cultures, failed to discriminate between monomeric aluminium and organically complexed aluminium present in soil solutions. This latter form is not phytotoxic. Subsequently, Suthipradit (1988) used the procedure developed by Kerven et al. (1989), which utilises differences in the reaction rate of monomeric and organically complexed aluminium with pyrocatechol violet, to explain the relative effects of monomeric aluminium in limiting growth in the three unamended acid soils.

Nutrient solutions offer some considerable advantages over acid soils in detailed studies of the effects of aluminium on nodulation and growth of plants. Much of the solution culture work conducted at the University of Queensland was reviewed at a previous IBSRAM Meeting (Bell and Edwards 1987) and will not be repeated here. However, Fig. 1 provides a schematic representation of the development of our understanding of aluminium toxicity limitations to plant growth as approached by soil chemists and plant nutritionists. Solution culture studies on aluminium toxicity at the University of Queensland have developed along the pathway outlined, and at all times we have been aware of the ultimate need to be able to understand the effects of aluminium toxicity in acid soils. Unfortunately, much of the solution culture work still being conducted today remains at the point of simply calculating nominal aluminium concentrations on the basis of the amount of added aluminium.

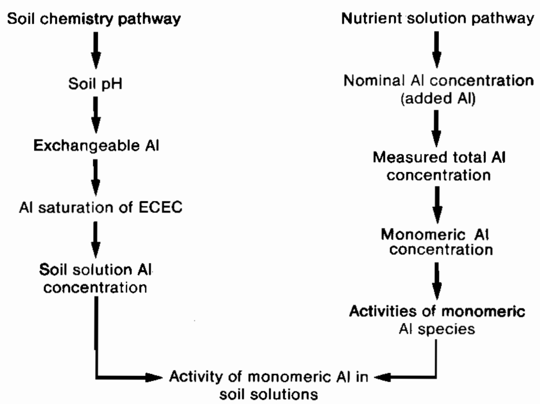

Fig.1. Development of an understanding of aluminium toxicity.

Current solution culture studies at the University of Queensland are directed towards understanding the effects of aluminium on nodulation, growth and nutrient status of soybean and peanut, the food crop legumes under study in the ACIAR-supported field program in Malaysia. Nodulation of soybean cv. Fitzroy has been shown to be inhibited by very low activities of monomeric aluminium, and these effects occur prior to effects on host plant growth. The aluminium-sensitive stage of the infection/nodule initiation process occurs within 12 hours of inoculation with *Bradyrhizobium japonicum* CB1809. The mechanism of inhibition appears to be impaired root hair growth and thus a reduction in the potential number of sites for infection. Electron microscope studies have shown effects of aluminium on root hair development and on the structures of root epidermal and cortical cells. Nodulation of peanut cv. Red Spanish has also been shown to be more sensitive than plant growth to aluminium (Suthipradit 1988; D.J. Brady pers. comm.). Root hairs present in the axils of the lateral roots have been shown to play no role in nodulation of peanut; they are not present in plants grown at activities of monomeric aluminium as low as 6 μM, while nodules are formed at activities of 6, 12 and even 25 μM.

Calcium Deficiency

Calcium deficiencies have been reported in pasture legumes in acid soils of southeast Queensland (Andrew and Bryan 1955; Andrew and Norris 1961; Lee and Wilson 1972; Jones 1982), on solodic soils of southern Queensland (Russell 1966) and on a yellow earth of north Queensland (Probert 1980). In addition, in the late 1970s, calcium and magnesium deficiency symptoms were first observed in the sugarcane cultivar Q90 grown in the wet tropics of Queensland. These observations were made some years after the sugar industry changed to high analysis fertilisers, thereby eliminating the small inputs of calcium which occurred previously in the annual applications of superphosphate. Responses in sugarcane yield to lime occur when exchangeable calcium is <0.65 cmol(+)/kg (Ridge 1984). Although much lower exchangeable calcium values than the above have been reported for some surface soils and for subsoils in Queensland, there are insufficient local correlations with plant response to enable sound interpretations to be made (Bruce et al. 1989a).

Bruce et al. (1989a) determined the concentration of calcium in soil solutions extracted from surface and subsoil horizons of 48 acid soils from Queensland. Soil solution calcium concentrations were not well correlated with exchangeable calcium or calcium saturation of the effective cation exchange capacity (Bruce et al. 1989b). Additionally, Bruce et al. (1988) determined the effects of calcium in the soil solution of 21 acid soils from southeast Queensland, amended with liming materials or soluble calcium salts, on root elongation of soybean. They showed that the calcium activity ratio (defined as the ratio of the activity of calcium to the sum of the activities of calcium, magnesium, sodium and potassium) and calcium saturation were superior predictors of calcium limitations to root elongation than calcium concentration and activity in the soil solution and the amount of exchangeable calcium. The critical values associated with a 10% reduction in root elongation were 0.05 for the calcium activity ratio and 11% for calcium saturation. Using the calcium activity ratio of 0.05 and an Al^{3+} activity of 4 μM as diagnostic indices, Bruce et al. (1988) concluded that none of the 20 acid soils from southeast Queensland used in two experiments were toxic in aluminium, while 13 (all subsoils) were deficient in calcium. On the basis of the critical calcium activity ratio of 0.05, Isbell and Edwards (1988) predicted calcium deficiency would limit root elongation of soybean in two of 18 surface soils and six of 18 subsoils from the wet tropics of northeast Queensland for which soil solution analyses were available. Using the critical calcium saturation index of 11%, four of the 18 surface soils and eight of the 18 subsoils were predicted to be calcium-deficient. In a recent study of 58 acid soils from Queensland and northern New South Wales, 19 and 48% of the surface and subsoils respectively were considered to be calcium deficient, based on the critical exchangeable calcium saturation index of 11% (N. Menzies, pers. comm.). Thus, it would appear that the primary limitation to root growth in unfertilised acid tropical soils of Australia is calcium deficiency rather than aluminium toxicity, in spite of the relatively low pH and high aluminium saturation of these soils. Addition of fertilisers which increase the ionic strength of the soil solution, however, can increase the activity of soluble aluminium species to toxic levels (Bruce et al. 1989b).

Suthipradit (1988) observed poor growth and calcium deficiency symptoms in soybean cv. Fitzroy grown to the commencement of flowering in two out of three acid soils from southeast Queensland, viz. a gilgaied acid clay with 5.2% calcium saturation and Wallum sand

Table 1. Properties of three acid soils from southeast Queensland and the relative shoot yield of groundnut, cowpea, soybean and green gram grown on these soils (Suthipradit 1988).

Parameter or crop	Soil type		
	Wallum sand	Yellow podzolic soil	Gilgaied acid clay
		Soil properties	
Soil pH (0.01M $CaCl_2$)	3.95	4.21	3.85
Exch.Ca (cmol(+)/kg)	0.30	1.47	0.42
Ca saturation (%)	24.0	30.0	5.2
Ca concn in soil solution (µM)	476	2 260	246
Ca activity in soil solution (µM)	296	1 347	163
Ca activity ratio	0.12	0.14	0.038
		Relative shoot yield (%)	
Peanut	100	66	88
Cowpea	86	28	55
Soybean	52	72	26
Green gram	51	28	10

with 24% calcium saturation (Table 1). Using the critical calcium activity ratio of 0.05 (Bruce et al. 1988), calcium deficiency was predicted on the gilgaied acid clay only. Development of a strong calcium limitation on growth of soybean in the Wallum sand raises the question whether other cations including the various monomeric aluminium species and ammonium should be included in the denominator in calculating the calcium activity ratio. Green gram cv. Berken also grew very poorly in the gilgaied acid clay (Table 1), even though it did not exhibit any identifiable calcium deficiency symptoms. In contrast, peanut cv. Red Spanish grew well in both the gilgaied acid clay and the Wallum sand, suggesting that the critical calcium activity ratio may well vary with plant species.

Manganese Toxicity

Few reports exist of manganese toxicity limitations to plant growth in acid soils of northern Australia. Fergus (1954) reported manganese toxicity in French bean grown in a krasnozem of pH 4.4 (1:2.5, soil:water) in the Mary River valley, near Gympie, southeast Queensland. The initial pH of the surface horizon of the virgin soil was 6.0, and the problem arose in part from heavy applications of ammonium sulfate to pineapples which were previously grown on this soil. This study demonstrated the need to measure various pools of manganese in soil by using different extractants when attempting to correlate plant responses and soil tests. Lovett and Johnson (1969) reported manganese toxicity in tobacco and beans grown on acid soils of the Mareeba–Dimbulah area in north Queensland, while Siman et al. (1971) reported that manganese toxicity is a common limitation to growth of French beans on krasnozems in northeast New South Wales. Recently, manganese toxicity has been identified in barley grown on acidified red-brown earths in the Oakey district of southeast Queensland (P.M. Bloesch, pers. comm.).

Although reports of manganese toxicity in the field are few, there is no doubt that soil acidification will lead to an increase in the incidence of manganese toxicity in the future. For example, acidification of a yellow podzolic soil from southeast Queensland, in which soil pH (1:5, soil:water) was decreased from 4.60 to 4.13, resulted in the development of severe manganese toxicity symptoms, greatly increased manganese concentrations in leaves, and strongly depressed growth of soybean (Suthipradit 1988). Growth of peanut was not depressed by this treatment, although manganese concentrations in leaves were greatly increased.

Molybdenum Deficiency

Molybdenum deficiency appears to be relatively widespread in acid soils of tropical and subtropical Australia (Bruce and Crack 1978; Kerridge 1978; Rayment 1978). There have been many reports of responses to molybdenum by tropical pasture legumes growing on acid soils of Queensland. These reports embrace a wide range of soils including deep sands (Jones 1973; Teitzel and Bruce 1973b, krasnozems (Kerridge et al. 1972; Teitzel and Bruce 1972a), euchrozems (Kerridge et al. 1972; Teitzel and Bruce 1972b), xanthozems (Kerridge and Everett 1975; Johansen et al. 1977), solodic soils (Truong et al. 1967; Jones and Crack 1970), and red and yellow podzolic soils, a solodised solonetz and a prairie soil (Johansen et al. 1977). In general, responses to molybdenum have been greater on the acid soils of volcanic origin (krasnozems) than on soils developed on granite. The above list of soils embraces the Orders Entisols, Oxisols, Utisols, Alfisols and Inceptisols of the U.S. Soil Taxonomy.

Molybdenum deficiency may be masked in soils of high available nitrogen status and by lime application which increases the availability of molybdenum (Kerridge 1978). Kerridge et al. (1972) showed that the deficiency of molybdenum was so severe on some krasnozems (Oxisols) that responses to the element occurred even in the presence of added lime.

Identification of Nutrient Limitations to Plant Growth in Acid Soils

Soil chemical analysis has been widely used to provide information in advance of crop establishment on whether or not a nutrient may be growth-limiting to a particular crop. Usually, soil testing is based on the use of a selective extractant which removes only a fraction of the total nutrient which is present in the soil. Most of the widely used soil testing procedures are empirical in nature, and the extraction procedure must be standardised to enable reproducible results to be obtained.

The soil test procedures currently used in assessing the nutrient status of acid soils in Queensland are listed in Tables 2 and 3. Other determinations, of particular interest in the identification of aluminium toxicity limitations to plant growth in acid soils, are presented in Table 4. The procedures identified cover those that are routinely used by the Agricultural Chemistry Branch of the Queensland Department of Primary Industries and by the Bureau of Sugar Experiment Stations.

Most of the procedures for macronutrients (Table 2) and micronutrients (Table 3) are based on determination of the amount of nutrient which is potentially available for uptake; this includes the amount of absorbed nutrient which is capable of being desorbed into the soil solution in a given period, the amount

Table 2. Soil tests for macronutrients on acid soils of Queensland.

Element	Soil test	Reference
Nitrogen	NO_3–N in soil profile	1
Phosphorus	BSES-extractable P (0.005M H_2SO_4, 1:200, 16 hours)	1,2
	$CaCl_2$-extractable P (0.005M $CaCl_2$, 1:5, 16 hours)	1
Potassium	Exchangeable K (1M NH_4Cl, pH 7.0, 1:20, 1 hour)	1
	Exchangeable K (0.02M HCl, 1:10, 16 hours)	2
	$CaCl_2$-extractable K (0.005M $CaCl_2$, 1:5, 16 hours)	1
Calcium	Exchangeable Ca (1M NH_4Cl, pH 7.0, 1:20, 1 hour)	1
	Exchangeable Ca (0.02M HCl, 1:10, 16 hours)	2
Magnesium	Exchangeable Mg (1M NH_4Cl, pH 7.0, 1:20, 1 hour)	1
	Exchangeable Mg (0.02M HCl, 1:10, 16 hours)	2
Sulfur	Phosphate-extractable SO_4 (0.01M Ca $(H_2PO_4)_2$, pH 4.0, 1:5, 16 hours)	1,2

1. Moody and Bruce (1988).
2. Chapman et al. (1981).

Table 3. Soil tests for micronutrients on acid soils of Queensland.

Element	Soil test	Reference
Manganese	Exchangeable Mn (1M NH_4OAc, pH 7.0)	1
	Easily reducible Mn (1M NH_4OAc, 0.2% hydroquinone)	1,2
	DTPA-extractable Mn (0.005M DTPA, 0.01M $CaCl_2$, 0.1M triethanolamine, pH 7.3, 1:2, 2 h)	1,3
	$CaCl_2$- extractable Mn (0.01M $CaCl_2$, 1:10, 16 hours)	1,4
Copper	DTPA-extractable Cu (see Mn above)	2,3,4
Zinc	DTPA-extractable Zn (see Mn above)	2,3,4
	0.02M HCl (1:2, 16 hours)	5
Iron	DTPA-extractable Fe (see Mn above)	2,4
Boron	Hot water-soluble B (1:2, 5 min boiling of suspension)	3
	Hot $CaCl_2$- extractable B (0.01M $CaCl_2$, 1:2, refluxed for 10 min)	2,6
Molybdenum	–	

1. Bruce (1988).
2. Moody and Bruce (1988).
3. Bruce and Rayment (1982).
4. Chapman et al. (1981).
5. Haysom (1982).

released by dissolution of solid phases, the amount released by mineralisation of organic matter and the amount actually present in the soil solution (Moody and Bruce 1988). Only those based on the use of 0.01M $CaCl_2$ as an extractant (phosphorus, potassium, and manganese) are primarily concerned with estimating the intensity or nutrient concentration in the soil solution. Although some of these tests have been used for a considerable length of time, few have been adequately calibrated against plant yield response or fertiliser requirement (Moody and Bruce 1988).

In assessing the likely occurrence and severity of aluminium toxicity, the present focus is on the identification and measurement of the phytotoxic monomeric aluminium present in the soil solution (Fig. 1). However, measurement of the amount of exchangeable aluminium (Table 4) and calculation of the aluminium saturation of the effective cation exchange capacity will continue as routine procedures in the chemical characterisation of acid soils and in the assessment of lime responses on individual soils. The Bureau of Sugar Experiment Stations has been using 0.01M $CaCl_2$ as an extractant for aluminium for several years (Chapman et al. 1981); this procedure shows the potential of the soils to release soluble aluminium as its pH declines or as ionic strength of its soil solution increases rather than the immediate aluminium toxicity status of the soil for plants (Bruce et al. 1988). Bromfield (1987) reported a rapid field test for aluminium, based on 0.01M $CaCl_2$ as the extractant and colour development with pyrocatechol violet in ammonium acetate.

Moody and Bruce (1988) reported that little calibration work had been carried out on calcium (or magnesium), apart from the establishment of a critical exchangeable calcium level (1.4 cmol (+)/kg) for peanut in north Queensland (Armour et al. 1985). However, Moody and Bruce (1988) suggested that calcium saturation of the effective cation exchange capacity might be a more useful index than absolute level of exchangeable calcium, because of its relationship to the calcium activity ratio in the soil solution. The utility of the calcium activity ratio in the soil solution (Bruce et al. 1988) needs to be evaluated over a much wider range of acid soils, for plant species other than soybean, and for nodulation and growth of plants.

A range of soil tests for manganese is used in the prediction of toxicity in Queensland soils (Table 3). The chemistry of manganese in soils is complex, being controlled by oxidation–reduction reactions, and separate tests may be necessary to distinguish current toxicity from potential toxicity (Bruce 1988). Bromfield (1987) reported a simple field test for determination of manganese in 0.01M $CaCl_2$ extracts

Table 4. Other analytical methods used on acid soils of Queensland.

Attribute	Method	Reference
Soil pH	Deionised water (1:5, shake 1 hour at 25°C, measure after standing for 1 hour)	1,2
	$CaCl_2$ (0.01M $CaCl_2$, 1:2, shake 30 min, measure in next 15 min)	2
Electrical conductivity	Deionised water (as for soil pH)	1,2
Aluminium	Exchangeable Al (1M KCl, 1:10, 1 hour)	1
	Exchangeable Al (1M KCl, 1:5, 30 min)	4
	$CaCl_2$-extractable Al (0.01M $CaCl_2$, 1:10, 22°C, 16 hours)	2
Exchange acidity	As for exchangeable Al	1,4
Effective	Sum of exchange acidity and exchangeable cations (Ca, Mg, K, Na)	1
CEC	Saturation with 0.1M $BaCl_2$, equilibration with 0.0015M $MgSO_4$ (exchange procedure)	3,4

1. Bruce and Rayment (1982).
2. Chapman et al. (1981).
3. Gillman (1979).
4. Chapman and Haysom (1984).

based on a colour reaction with alkaline formaldoxime.

Although molybdenum deficiency is comparatively common in acid soils of Queensland, there is no recommended soil test procedure in routine use (Table 3).

Management of Acid Soil Infertility

The procedures used to ameliorate soil acidity in the subtropical and tropical regions of Australia vary depending on soil, crop and rainfall factors. The type and rate of ameliorant are dictated by both soil and crop factors, while the frequency of application is influenced by the intensity of leaching by rainfall and the capacity of soil to inactivate the ameliorant. For convenience, the nature and rate of ameliorants and their frequency of addition will be considered in terms of the major crops grown in this area (Table 5).

Sugarcane

Cane is grown on a diverse range of soils on the coastal lowlands, but many of these soils have low effective cation exchange capacities and low exchangeable base status. As indicated previously, sugarcane is very tolerant of high aluminium, and there is no evidence to suggest that this element has limited production to date. The high rainfall in many areas, together with the low cation exchange capacity of the soils and the use of high analysis fertilisers which contain little calcium and magnesium, has led to development of deficiencies in these elements.

Deficiency of calcium is commonly corrected with application of 2.5-5.0 t/ha of limestone broadcast and incorporated prior to planting; cement at 4.2 t/ha has also been used, but it is more costly per unit weight of calcium (Ridge 1984). The longevity of the liming effect is dependent on the cation exchange capacity of the soil, rainfall, permeability of the profile, rate of nitrogen fertiliser, and the rate, fineness and depth of incorporation of the limestone (Reghenzani 1987). It is recommended that limestones have a neutralising value of not less than 90 and contain 60% fine (<0.25 mm) material. Reghenzani (1987) indicates that for the cane soils in north Queensland, reapplication of limestone in the range of 1.25–2.5 t/ha is required in deficient soils about every 5 years.

With soils containing <0.1 cmol (+)/kg of exchangeable magnesium, a response of cane to application of the element is likely. On such soils, magnesium oxide at 0.3 t/ha or dolomite at 5.2 t/ha is recommended (Table 5).

High rates of potassium are added to sugarcane in Queensland (80–100 kg/ha at planting and 100–120 kg/ha on ratoon cane); these rates are primarily related to the large amount of potassium in the harvested crop

Table 5. Amelioration of acid soil infertility in the wet tropics of Queensland.

Crop	Limiting factor	Ameliorant	Rate	Reference
Sugar cane	Ca deficiency	Limestone ($CaCO_3$)	5.0 t/ha (<0.65 cmol (+) kg)	1
			2.5 t/ha (0.65–1.5 cmol (+)/kg)	
		Cement	4.2 t/ha (<0.65 cmol (+)/kg)	
	Mg deficiency	MgO	0.30 t/ha (<0.1 cmol (+)/kg)	1
			0.15 t/ha (0.1–0.3 cmol (+)/kg)	
		Dolomite ($CaMg(CO_3)_2$)	5.2 t/ha (<0.1 cmol (+)/kg)	
Groundnuts	Ca deficiency	Limestone	0.69 t/ha (<1.4 cmol (+)/kg)	2
		Gypsum	0.61 t/ha (1.4 cmol (+)/kg)	
Bananas	Al toxicity/ Ca deficiency	Limestone	2.0 t/ha	3
Pastures				
Tropical	Al toxicity/ Ca deficiency	Limestone	0.6 t/ha	4
	Mo deficiency	Mo (MoO_3)	0.05–0.2 kg/ha	4
Temperate	Al toxicity/ Ca deficiency	Limestone	2.5–5.0 t/ha	3,4
	Mo deficiency	Mo (MoO_3)	0.05–0.2 kg/ha	4

1. Ridge (1984).
2. Armour et al. (1985).
3. Isbell and Edwards (1988).
4. Rayment (1978).

(average annual removal of 185 kg/ha), but are also related to the generally high leaching environment (Reghenzani 1987). Nitrogen rates are also high (120–150 kg/ha at planting and 160–200 kg/ha on ratoon cane), and these contribute to soil acidity generation and leaching of bases.

The problem of low cation exchange capacity and leaching of bases may be reduced in the future with the increasing use of green cane harvesting and the retention of the cane trash on the soil; the subsequent increase in soil organic matter level would be expected to increase cation retention. Annual removal of phosphorus by sugarcane is lower than for nitrogen and potassium (average of 17 kg/ha), and rates of 20–40 kg/ha of the element are commonly used (Reghenzani 1987).

Application of limestone to remove calcium deficiency in cane has resulted in the development of zinc deficiency in some northern areas; application of 10 kg/ha of the element as zinc sulfate has been shown to correct this problem (Reghenzani 1987).

Pastures

On the elevated Atherton Tableland in north Queensland, temperate grass and legume species dominate pastures established on krasnozems (Oxisols) for dairy production. Responses to limestone rates of 2.5–5.0 t/ha have been observed on these pastures (Isbell and Edwards 1988) (Table 5), but there is some uncertainty as to the specific limiting factors in these situations. Kerridge et al. (1972) showed that part of the response to lime of legumes grown on these soils was due to increased availability of molybdenum.

Tropical grass and legume species dominate in pastures established elsewhere in Queensland. In a review of establishment and maintenance fertiliser requirements for these pastures in coastal southeast Queensland, Rayment (1978) indicated that the most common limestone rate for establishment on acid soils was about 0.6 t/ha. A recent study of rain-grown pastures on 12 dairy farms in southeast Queensland over a 5-year period has shown that the annual addition of 200–600 kg/ha of nitrogen resulted in pasture decline due to aluminium toxicity and/or calcium deficiency, and that periodic applications of limestone are necessary to maintain pasture production (G.E. Rayment, pers. comm.).

Molybdenum at rates from 0.05 to 0.2 kg/ha has been used for establishment of tropical legumes in Queensland acid soils (Rayment 1978). Johansen et al. (1977) found that the rate of molybdenum required for maximum growth of legumes in the field depended on the responsiveness of the legume and on the soil properties; the residual value of the application depended on the rate of immobilisation of the element by the soil. With responsive legumes such as *Neonotonia wightii* cv. Tinaroo, Johansen et al. (1977) suggested a rate of 0.2 kg/ha of molybdenum would be required every 2 years on the soil with the highest immobilising capacity (xanthozem) of the six studied.

Other micronutrient deficiencies such as copper and zinc occur in pasture soils of the wet tropical coast of Queensland (Bruce 1978), but their deficiency is not unique to acid highly weathered soils. Similarly, soils used for pasture production in the tropics are invariably deficient in phosphorus and occasionally in sulfur, but these limitations are shared by many soil types across Australia.

Conclusions

Calcium deficiency (particularly in subsoils) and molybdenum deficiency appear to be more common limitations than aluminium toxicity or manganese toxicity to plant growth in virgin acid soils of tropical Australia. However, potential for aluminium toxicity development exists in these soils when they are fertilised. sugarcane is highly tolerant of aluminium toxicity, and responses by that crop to application of lime are due to alleviation of calcium deficiency. Inclusion of other more aluminium-susceptible crops in rotations with sugarcane, or as replacement crops for sugarcane, are likely to lead to the occurrence of aluminium toxicity problems.

Soil test procedures are available for assessing the nutrient status of acid soils in Queensland, with the notable exception of molybdenum. A need exists for many of the currently used soil tests to be calibrated against plant yield response or fertiliser requirements. Soil acidity management is based upon the use of lime (or dolomite) to alleviate acid soil infertility constraints to growth of agriculturally important plant species.

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Management of Acid Soils in Africa

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Abstract

Acid soils are widespread in many parts of tropical and sub-tropical Africa. Traditional slash and burn techniques and use of local adapted crop varieties have provided a low but sustainable level of production for subsistence farmers. However, population pressure has led to shortened fallows which are inadequate to restore soil fertility. Aluminium toxicity and phosphorus and micronutrient deficiencies are now widespread. Technologies developed to overcome these problems should integrate acid- and drought-tolerant crop varieties with lime and fertiliser inputs and composting or other traditional practices. Technologies should also be tailored to the farmers' expectations and socioeconomic environment.

Introduction

The so-called acid soils cover extensive areas in western, central, eastern and southern Africa. They occur under almost any climatic condition and often show little relation with the underlying rocks. Traditionally, these soils are managed by cutting and burning the vegetation and cultivation of the soil enriched by the ashes usually until weed infestation becomes too severe (the so-called 'slash-and-burn' technique).

In many areas local crop varieties have developed that can stand the adverse soil conditions. Usually they are not high yielding, and outside influences like insufficient rainfall or pests and diseases can dramatically reduce their yields.

Population pressure in many countries has led to shortening or even abandoning the fallow period required in the traditional management system to regenerate the soil fertility. Soil degradation, declining yields, changing vegetation and even desertification has been the result. There is an increasing demand for new management technologies for the African small farmer, so that the farmer is able to cultivate the lands successfully.

Research in this field has mostly concentrated on a single component of the production system, such as improved varieties, alleviating the soil acidity or response to fertiliser. Integrated research has seldom been carried out on all components and their interaction, mainly because of the complexity of the problem. Yet if new technologies are to be introduced and applied successfully, a multidisciplinary research effort will be necessary. This multidisciplinary approach should at least include soil science, climatology, agronomy, agroeconomy and socioeconomics.

Acid Soils in Africa

The acid soils in Africa we are concerned with are mainly the more or less well drained upland soils with a pH (H_2O) of less than 5.5 (pH (KCl) usually less than 4.8). They cover a wide range of soils in the Oxisol, Ultisol and Inceptisol orders of the Soil Taxonomy (Soil Survey Staff 1975). They are usually extremely deep, although in western Africa moderately deep soils dominate which also often contain a stone line.

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The common adverse chemical and physical properties of these soils are: low pH and high aluminium saturation (often more than 60%), low amount of available macro- and micro-nutrients, imbalance between the various nutrients, low nutrient holding capacity, fixation of phosphorus, often low organic matter content, low water-holding capacity as a result of coarse-textured surface layers, and/or micro-aggregation, adverse surface characteristics like liability to crusting or sealing, in some cases low infiltration rates, and sensitivity to erosion.

The low pH and high aluminium saturation are well-known features in these soils. Under natural conditions topsoil pH is usually the highest and the aluminium saturation the lowest, quite often not more than 10–20%. This changes drastically in the subsoil where often at a depth of 30–50 cm an aluminium saturation is measured exceeding 60%. This dramatic increase causes shallow rooting resulting in extreme sensitivity to even short drought periods.

In an absolute sense, because of the usually low cation exchange capacities, exchangeable aluminium is not high and in theory, can be easily corrected by small amendments of lime. However, as experience has shown, it seems to be extremely difficult to move the lime downward to correct subsoil acidity. In northern Zambia experiments on liming showed that 8–10 t of lime were necessary to affect significantly the aluminium saturation at 60 cm depth in soils having an exchange capacity of no more than 10 cmol(p+)/kg clay (Aulack, pers. comm.).

The low amount of available macro- and micronutrients is yet another setback to be overcome. Usually the nutrients are concentrated in the surface layer where organic matter and nutrients released from the organic matter accumulate. Quite often the total amount of macro- and micronutrients in the subsoil does not exceed more than 2 cmol(p+)/kg soil, except where soils are significantly influenced by deposits of volcanic ashes, as is the case in parts of Cameroon and in the highlands of Rwanda, Kenya, Uganda and Tanzania. However, here the production of nutrients from weathering of the volcanic minerals under acid soil conditioning is accompanied by the release of similar large amounts of aluminium, which in absolute figures can be very high compared to the amount of aluminium in soils not affected by volcanic admixture, sometimes even over 10 cmol(p+)/kg soil.

Micronutrients in the strongly weathered African soils are almost always insufficient. Most crop stands show in one way or another deficiencies in zinc, iron or boron, while experiments almost always show a response to sulfur.

The lack of almost all essential nutrients brings imbalance between the nutrients once fertiliser is supplied. If the sort of lime is not carefully chosen to correct the soil acidity, an imbalance between calcium and magnesium will show up immediately, affecting the crop.

Phosphorus is also in short supply in many African soils, especially in the deeply weathered soils of the Central African Plateau. Common figures reported from these areas are 5–10 ppm available P (Bray method) in their usually thin topsoil and less than 5 ppm P in their subsoils. In the more shallow soils of western Africa, and in soils with an appreciable high organic matter content these figures tend to be higher, as well as in soils which are regularly supplied with organic manure.

The acid soils under a woodland savanna type of vegetation normally have thin surface layers, no more than 10 cm in thickness with an organic matter (OM) content not exceeding 2–3%. Upon cultivation the OM content usually drops by a third, leaving at the most no more than 2% but very frequently around only 1% OM in the surface layer. In contrast, soils of the higher altitudes as in Rwanda and Burundi, or the soils in the more humid parts of Africa like Cameroon and Congo, have a much higher OM content, usually 4–7%, but in cases more than 10% in the surface layer, which are also much thicker as compared to the surface layers of the acid woodland savanna soils. The effects of cultivation on the content of organic matter in these soils can safely be ignored.

Microaggregation in many African soils affects considerably their water-holding capacity and the water movements through the soil. Strongly microaggregated soils such as some of the Oxisols of Cameroon act as sands. When there is abundant rainfall the microaggregation may be a blessing as water can percolate rapidly even through clayey soils. However, if rainfall very rapidly lose their water available for the plants. Also frequently soils are encountered that have coarse-textured surface layers (loamy sands or sandy loams) overlaying fine-textured subsoils. Whether this textural differentiation is due to clay eluviation, chemical breakdown of the clay (by for instance ferrolysis), colluvial processes, or biological, notably termite activity, still remains an open question. The fact is that these surface layers have a low water-holding capacity and consequently influence crop performance considerably when dry spells occur.

On the other hand, these soils quite often show a considerable increase in clay over a short distance. This hampers rapid infiltration of water necessary to absorb the large quantities of rain that fall in short periods. When this clay increase occurs near the surface, it often causes water to stagnate for hours and gives rise to the formation of a seal.

On the Central African Plateau soils are frequently encountered that are locally referred to as developing a 'hardpan' when cultivated. In fact these soils do not have a pan but can better referred to as 'hard-setting' (Mullins 1987). Upon drying the subsurface layers get extremely hard and appear to be indurated to such an extent that disc-ploughs only scrape the surface and are not able to penetrate. Ripping these soils in dry state results in huge chunks of soil lying on the surface. The soil is manageable again only after remoistening, and quite often farmers have to wait until after the first rains before they can cultivate their fields.

Traditional Management Techniques

A still widely used traditional management technique is the slash-and-burn shifting cultivation. Two variations occur. In one a whole field is cleared and the logs and foliage are burnt to release the nutrients and to raise the soil pH. In the other variant trees are left standing and only branches are taken off and burnt. Sometimes the farmers cleverly use the termite mounds which have a higher fertility than the surroundings. This is especially the case if the soils they work are extremely poor.

In savanna regions where trees are scarce, systems are based on burning of grasses have developed. In Congo for instance, the system called 'mala' involves cutting of the grass and putting it in bunds. These bunds are then covered with topsoil material and the grass inside is burnt. Maize or other crops are then planted on the bunds as soon as the rains start.

Another management system encountered in Africa is the multistorey, multiculture system. In this system the farmer leaves the useful large trees, either for shading, ground protection or erosion control, or because they produce fruits. The second storey usually consists of plantains or bananas, while the third storey at ground level is used for annual crops, often a mixture of maize, beans, groundnut and vegetables. The farmer is always assured of some food and/or income. Quite often one finds this system in fairly densely populated areas and one may wonder if it has not developed as a natural transition from the shifting cultivation to a more sedentary type of agriculture.

Where population is even more dense, as in Burundi and Rwanda, the shifting cultivation techniques are no longer practiced. Instead a mixed farming type has developed with homestead gardens, small fields, pastures and perennial crops. Cattle usually consist of some goats and pigs, and one or two cows, which are usually kept near the house to facilitate collection of manure. Also quite often compost is produced for fertilisation.

Recently Introduced Management Techniques

Traditionally land was cleared by hand, which is by far the best way. With the development of large farms by European settlers in Africa, mechanised clearing was introduced. This practice has often been taken over by land development departments when, after independence in many countries in Africa, state farms, parastatal or private enterprises were started. In many cases this mechanised clearing has had disastrous effects on these fragile soils. As discussed before, organic matter and nutrients are very often concentrated in thin surface layers. Mechanised land-clearing practices, that aim at complete removal of the vegetation including roots, are likely to destroy this layer and thereby destroy any fertility left in the soil. It also leads to compaction of the subsoil. For these reasons mechanised land clearing using bulldozers and mechanised land clearing using bulldozers and other heavy equipment should not be used when developing acid soils.

Considerable research has been directed to fertiliser studies. This has for a long time concentrated on lime application and NPK. Lime requirements based on soil analyses are now well understood and models including economic components are now available to assess the most profitable balance between lime input and crop yield. Recently the emphasis has shifted more to micronutrients and sulfur, as well as to the interactions between the nutrients (imbalance studies). Consistent results of these studies are, however, not yet available to be incorporated in the soil management practices.

Crop varieties tolerant to the main soil constraints like the soil acidity or drought stress, have been developed over the past years. In a number of cases they have been introduced successfully, in other cases they have been ignored because local varieties performed better or had a better taste. This for instance has been the case with a number of new maize varieties developed for short growing periods. A success story one may recall has been the introduction of an acid tolerant wheat variety from Brazil called 'Whydah' in the high rainfall areas in the north of Zambia. Through its introduction, combined with proper soil management techniques such as moderate liming and final land preparation just after the first rains, production of wheat jumped to such an extent that Zambia is now almost self-sufficient.

Fertilisation and the choice of the right crop variety alone does not make up a proper soil management technique. Many farmers, especially the small-scale farmers, do not have the means to buy lime and fertilisers or do not have access to it. They need techniques that they can easily master and that do not require high inputs. This has been realised and research has been directed to this approach with variable rates of success.

The use of leguminous crops in rotation is being accepted more and more, as is the awareness to return crop residues to restore or at least to maintain appropriate organic matter levels. New techniques like agro-forestry are being accepted as well.

Agroforestry research is proving to be valuable. By using the right species adapted to the environment and to exploit their potential the proper way, it is possible to maintain crop production at acceptable levels with very little input. However, introduction of agroforestry in Africa encounters one major constraint. It is very hard to convince an African smallholder farmer to start using a technique from which he will benefit only in a couple of years. This social aspect of introducing new technologies in Africa, namely that the African farmer wants to see results immediately, has often been overlooked.

Shrub Legumes for Acid Soils

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Abstract

Leucaena, the most widely grown tropical shrub legume, is not well adapted to acid soils. Recent problems caused by the leucaena psyllid reinforce the need for alternative species. Experiments in Indonesia and Australia have shown that *Calliandra calothyrsus* and an *Acacia* species yield well under adverse conditions, but in these nutritionally deprived soils all shrub legumes require fertiliser for acceptable production levels. There should also be a place for fast-growing, shorter-lived species such as *Codariocalyx gyroides* and *Sesbania sesban* for initial food production. To fully evaluate the potential economic benefits of shrub legumes, animal nutrition studies are required.

Introduction

Leguminous trees and shrubs have played an important role as fodder since people began the domestication of animals (Brewbaker 1985). Trees and shrubs can provide a valuable source of feed for animal grazing and cut-and-carry systems and also provide fuel, fencing, and shade; they also promote soil improvement and stabilisation. It is unreasonable to expect any one accession to be able to fulfil all these roles in all environments; but *Leucaena leucocephala* is considered the best candidate. However, while having the virtues of high production of good quality feed and excellent coppicing ability, this species is poorly adapted to acid soils (Hill 1971). This poor adaptation, together with the recent spread of the leucaena psyllid (*Heteropsylla cubana* Crawford) to Southeast Asia and Australia, make it imperative that an alternative shrub legume to *L. leucocephala* be found. We note, for future reference, that many of those tropical species which have been studied in detail, with an adequate genetic range of material, have usually been found to contain both 'calcicoles' and 'calcifuges'; bulking information from the literature where genotypes are not specified, even though necessary, can be confusing (R.L. Burt, pers. comm. 1989).

There is a paucity of information on the comparable performance of these shrub legumes over a range of sites and environments, and in particular a lack of knowledge on their responses to soil nutrients. As there are vast areas of low pH soils in the tropics it is of some importance to investigate just what aspects of acid soil nutrition are affecting differential species responses, both to enable the selection of suitable species for a particular site, and to derive criteria for future selection programs.

Reasons for the poor growth of leucaena on acid soils have been variously reported as due to aluminium and/or manganese toxicity or calcium deficiency (Wong and Devendra 1983). Hutton (1984), in a study of acid tolerance of leucaena on an Oxisol in Brazil, also suggested that calcium deficiency rather than aluminium toxicity was limiting growth. This suggestion is

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supported by the recent work of Blair et al. (1988), also on an Oxisol, who reported little effect of increased soil pH on growth but a marked response to calcium application. In the same study, but on Ultisol, growth was improved by increasing soil pH and there were no responses to increased calcium. This lack of response to calcium could be due in part to the higher level of soil calcium in the Ultisol relative to the Oxisol (0.17 meq/100 g and 3.78 meq/100 g, respectively). These results highlight the need for a more quantitative measure of 'high' and 'low' calcium and aluminium status of the soil.

Panjaitan and Blair (1984) in a review of research on the use of leucaena and other tree and shrub legumes in Indonesia conclude that 'Research is required to identify the most productive and persistent species/cultivars for specific climatic/soil/farming system situations. For this long-term comparative studies of tree and shrub legumes must be undertaken'. Panjaitan et al. (1986) in a multilocational trial using a range of shrub legumes reported that *L. leucocephala* var. Cunningham outyielded other species on a neutral soil in West Java. On the more acid soils at other locations *Gliricidia sepium* and *Calliandra calothyrsus* outyielded the *L. leucocephala* in both leaf and stem production, whereas at Sei Putih in North Sumatra these three species gave similar yield. At all sites the *Sesbania grandiflora* had died by the eighth harvest; it appears to have little tolerance to defoliation. It was also noted that responses to fertiliser applications were apparent in the establishment phase but in general did not persist. Catchpool et al. (1986) reported similar leaf production for *L. leucocephala*, *G. Sepium*, and *C. calothyrsus* when grown on an alluvial soil of pH 6 in South Sulawesi, Indonesia. In a study using a more extensive range of shrub/tree legumes conducted at Ciawi, Yuhaeni et al. (1986) recorded preliminary data showing high yields in five lines of *Desmanthus virgatus*. This result is supported by recent work in Indonesia where an accession of *D. virgatus* is reported as well adapted to a wide range of soils (J. Keoghan, pers. comm.).

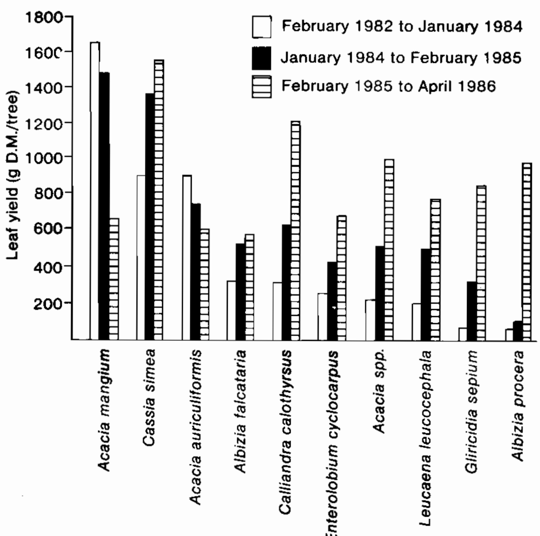

Fig. 1. Leaf production (g DM/tree) of the 10 most productive species for three growth periods at Nakau, South Sumatra.

Blair et al. (1988) compared the performance of a range of tree/shrub legumes on an acid Ultisol in South Sumatra, Indonesia. Leaf production for the ten highest-yielding accessions of the group of 16 originally planted at the site is shown in Fig. 1 (from Blair et al. 1988). *Cassia siamea* produced the greatest long-term leaf production and in the third year *Calliandra calothyrsus* was the second highest-yielding accession. However, the authors state that when both leaf quality and yield are taken into account *C. calothyrsus* would appear little different to the lower-yielding *G. sepium.*

These studies have been continued in the ACIAR project 8363, a joint ACIAR-CSIRO-Government of Indonesia project entitled 'Multipurpose Shrub Legumes for Infertile Soils in the Tropics.' In the first phase of this program four sites were chosen, two in Australia (Utchee Creek and Silkwood) and two in Indonesia (Sei Putih and Sembawa), to represent the range of acid infertile soils of the region.

Materials and Methods

At each site two experiments were established, one a nutrition experiment using *Leucaena, Calliandra* and *Gliricidia*, the other a comparison of 20 shrub legumes, with and without fertiliser application.

Table 1. Some soil properties from the experimental sites.

Site	Depth	pH	Ca	Mg	Na	K	%A1 sat
			[Exchangeable cations (meq/100 g)]				
Sei Putih	0–10 cm	5.3	1.76	0.50	<0.02	0.41	8
	30–40 cm	5.1	0.72	0.17	<0.02	0.12	51
Sembawa	0–10 cm	4.9	0.42	0.32	<0.02	0.11	85
	30–40 cm	5.0	0.12	0.04	<0.02	0.03	97
Utchee Creek	0–10 cm	5.3	1.44	0.60	0.12	0.23	11
	20–30 cm	5.1	0.53	0.19	0.10	0.09	14
Silkwood	0–10 cm	5.3	0.34	0.23	0.11	0.15	77
	20–30 cm	5.0	0.03	0.05	0.06	0.03	91

Site Description

Some relevant soil characteristics are given in Table 1. The sites in Australia are both located approximately 200 km north of Townsville, Queensland, and have an annual rainfall of approximately 3500 mm. Long-term rainfall data shows a pronounced wet and dry season with only 20% of the annual precipitation falling between June and December. The Utchee Creek site is classified as an Oxisol and is a highly weathered uniform textured soil of basaltic origin. The Silkwood soil is classified as an Inceptisol and is described as a mottled gradational soil with a dark A horizon and is formed from a well drained alluvium. These soils are described in detail by Murtha (1986). The Sie Putih Site is 50 km southeast of Medan in North Sumatra and the Sembawa site is located 40 km northwest of Palembang in South Sumatra. The Sei Putih site has an annual rainfall of 1900 mm that is well distributed throughout the year; the soil parent material is probably an old alluvium that was derived from redistributed acid volcanic tuff. The soil which is classified as a Tropudult appears well drained and is in excess of 150 cm deep. At Sembawa the soil is classified as a Paleudult and receives an annual rainfall of about 2000 mm with a well-defined dry season from June to October. Both of these Indonesian soils are referred to locally as Red Yellow Podzolics and represent a unit used to describe most unproductive red and yellow soils. They cover a large portion of the Indonesian land surface, approximately 30%, or 50 million ha (Driessen and Seopraptohardjo 1974).

Each of the soils chosen had a pH of about 5 in water and what was considered low exchangeable calcium. In each country one site was selected with high aluminium saturation, the other with lower.

Fertiliser Regime

The rates of fertiliser application are given in Table 2. All fertilisers were applied in a band 50 cm wide along the rows of trees. The lime treatments were applied one month prior to transplanting. Other fertilisers were applied immediately prior to transplanting. All fertilisers were cultivated into a depth of 10 cm by raking.

The fertiliser treatments (Table 2) used in these experiments were:

No fertiliser applied	(F1)
P	(F2)
P + Ca (nutr]	(F3)
P + Ca (nutr) + TE	(F4)
P + Ca (nutr) + Ca (lime)	(F5)
P + Ca (nutr) + Ca (lime) + TE	(F6)

These fertiliser treatments were chosen to examine the effects of various aspects of plant nutrition in these acid soils (e.g. to separate the effects of calcium deficiency and low pH). In the nutrition experiment all six treatments were used with three species of shrub legumes with three replicates and in the experiment comparing the wide range of species only nil fertiliser (F1) and the complete fertiliser treatment (F6) were used with two replicates.

Plant Material

The plant species used in these experiments are listed in Table 3. These accessions were

Table 2. Rates and type of fertiliser applied to field experiments.

Fertiliser	Product	Kilograms element/ha		Lime (t/ha)
P	Diammonium phosphate [a]	33		
	Monoammonium phosphate [b]	33		
Ca (nutr)	Gypsum	40		
Ca (lime)	Calcium hydroxide		Sembawa	2.0
			Silkwood	2.0
			Sei Putih	0.4
			Utchee Creek	0.4
Trace elements (TE)				
Cu		3.0		
Zn		3.0		
Mo		0.2		
B		1.5		
Mg		20.0		
Basal treatment K;S		36/18;16/8[c]		

[a] Indonesia; [b] Australia; [c] Split dressing.

chosen to cover in part the range of material that may have the potential of growing well in the more acid soils of Southeast Asia. They include material that has rapid first year growth with little possibility of persistence and material with less satisfactory early growth but with the potential for longer term production. Both these types have a role in forage production either planted separately or in combination.

The first harvest was made 6 months after transplanting. Plants were harvested to a height of 75 cm and separated into leaf (including small stems to 6 mm diameter) and wood components for dry weight and subsequent chemical analysis. It was intended to take subsequent harvests (H2, H3 ...) at 3-monthly intervals. This however was not feasible at the Silkwood and Sembawa sites where growth was insignificant in the dry season. Specific comparisons of growth should be made only within a site. In the nutrition experiment the *L. leucocephala* was regularly sprayed for insect control, whereas in the experiment comparing species the data presented for *L. leucocephala* were without insect control.

Table 3. Plant species used in field trials.

Species	CPI number[b]	Code
Acacia angustissima	40175	A.ang.
Acacia species	85998	A.spp.
Cajanus cajan	65946	C.caj.
Calliandra calothyrsus	110395	C.cal.[a]
Codariocalyx gyroides	76104	C.gyr.
Desmodium discolor	39075	D.dis.
Desmodium rensonii	46562	D.ren.
Gliricidia sepium	60796	G.sep.
Gliricidia sepium	110397	G.sep.[a]
Leucaena collinsii	46570	L.col.
Leucaena sp.aff.*diversifolia*	33820	L.d-5.
Leucaena diversifolia	46568	L.d-6.
Leucaena leucocephala cv. Cunningham		L.1-1.[a]
Leucaena leucocephala	85929	L.1-2.
Leucaena leucocephala	90814	L.1-3.
Leucaena leucocephala	85176	L.1-3.
Leucaena pallida	84581	L.p-8.
Leucaena pallida	85891	L.p-9.
Sesbania grandiflora	96461	S.gra.
Sesbania sesban	69484	S.ses.

[a] Used in nutrient experiment.
[b] Commonwealth Plant Introduction Number, Australia.

Results and Discussion

These data must be considered as preliminary as longer term studies are required when working with perennial crops. At the Silkwood and Sembawa sites, because of the poorer growth, fewer harvests have been taken (three and two respectively) than at the Utchee Creek and Sei Putih locations (four and five respectively).

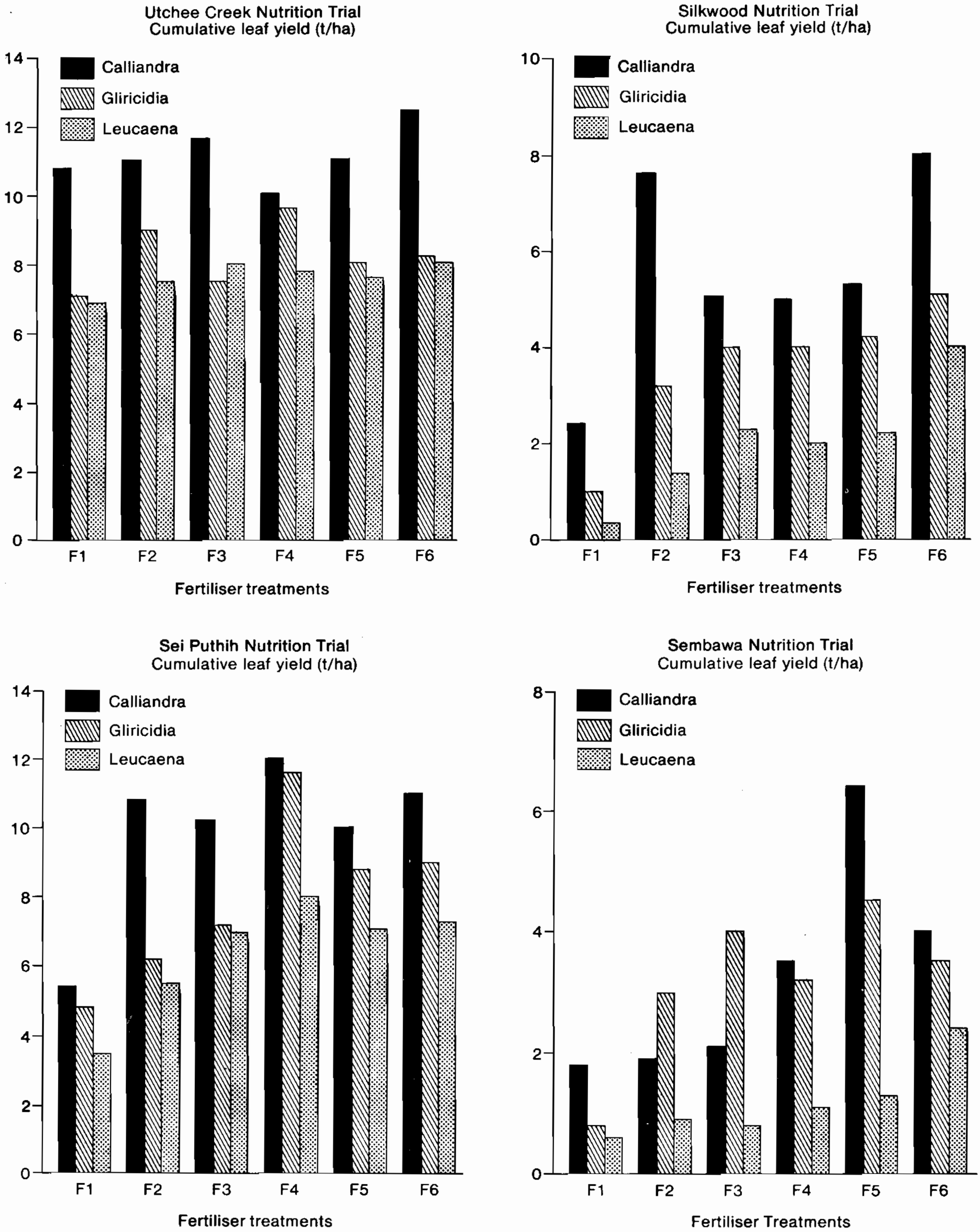

Fig. 2. Cumulative leaf yields (t/ha) at four sites for each species at each fertiliser treatment.

Nutrition Experiment

Cumulative leaf yields for the *Calliandra, Gliricidia* and *Leucaena* are presented for the six fertiliser treatments at each of the four sites (Fig. 2). Response to fertiliser additions were markedly lower at the higher-yielding Utchee Creek and Sei Putih sites. At Utchee Creek *Calliandra* outyielded *Leucaena* and *Gliricidia* while the latter two species gave similar yields. *Calliandra* also gave the highest leaf at Sei Putih followed by *Gliricidia* and then *Leucaena*. In the case of *Calliandra* the major response was to phosphorus additions, whereas in the case of *Gliricidia* there was a marked response to trace elements after the applications of phosphorus and calcium as a nutrient. No significant responses were observed to lime applications for any species.

At Silkwood *Calliandra* again outyielded the other two species with a major response to phosphorus application. The reduction in yield of *Calliandra* after the gypsum application cannot be explained at this time but when chemical analysis is available some reason may be forthcoming. After lime addition (F5) to the *Calliandra*), visual symptoms of zinc deficiency were observed and a marked growth response to trace element applications (F6) with the alleviation of the symptoms was obtained. *Gliricidia* gave a calcium response in addition to that from phosphorus whereas *Leucaena* responded to both calcium and to the lime plus trace element treatment.

As with the other sites, *Calliandra* outyielded *Gliricidia* and *Leucaena* where no fertiliser was applied and in treatments F4, F5 and F6. However, with the phosphorus alone, and phosphorus plus calcium (perhaps analogous to triple superphosphate) treatments (F2 and F3), *Gliricidia* was the highest yielding species. No explanation is offered for the marked reduction in yield of *Calliandra* after the trace elements were applied in addition to the lime (F6 vs F5) at Sembawa.

Species Evaluation

At each site a selection of the better-yielding species has been chosen for discussion. *Leucaena leucocephala* cv. Cunningham is included at all sites for comparison even though it performed relatively poorly at both the Silkwood and Sembawa sites.

Figure 3 shows leaf yield for individual harvests both with and without fertilisers at Utchee Creek, Silkwood, Sei Putih and Sembawa.

The *Acacia* spp. gave the highest yield at Utchee Creek followed by *C. calothyrsus* and *Codariocalyx gyroides*. At the most recent harvest (not yet reported) the *C. gyroides* has died out as have the two *Sesbania* and the *Cajanus cajan*. There were few responses to fertiliser at this site. In contrast, at the Silkwood site, the responses to the fertiliser application were extremely high. It is noted that at the second harvest (H2) *L. leucocephala* cv. Cunningham had produced no material above the cutting height of 1 m. During the first year (H1 and H2) there was very little growth for most species where no fertiliser was applied. The *C. calothyrsus* outyielded all other species where no fertiliser was applied and showed a marked response to fertiliser addition.

At the Sei Putih location the *Acacia* spp. again produced the highest yield by fifth harvest (H5) with most species giving marked responses to fertiliser addition. The *Cajanus cajan* and *Sesbania sesban* showed a marked reduction in yield at the later harvest (H5 vs H2). This effect was also apparent for the *S. grandiflora* and *C. gyroides*. The *Leucaena, Gliricidia* and *Calliandra* all did well at this site.

At the Sembawa site the outstanding early performance was given by the *C. cajan* to which fertiliser was applied. Both *C. gyroides* and *S. sesban* also performed well when fertilised. None of these three species, however, continued to yield well. In fact, by the end of the first year all plants of *S. sesban* had died. *Gliricidia sepium* and *Calliandra calothyrsus* seem to have the most potential for long-term growth.

Conclusions

Of the woody perennials evaluated *C. calothyrsus* is well adapted to the range of soils used in this study. Little information is available on the feeding value of this species and what is available suggests the value is poor. The *Acacia*

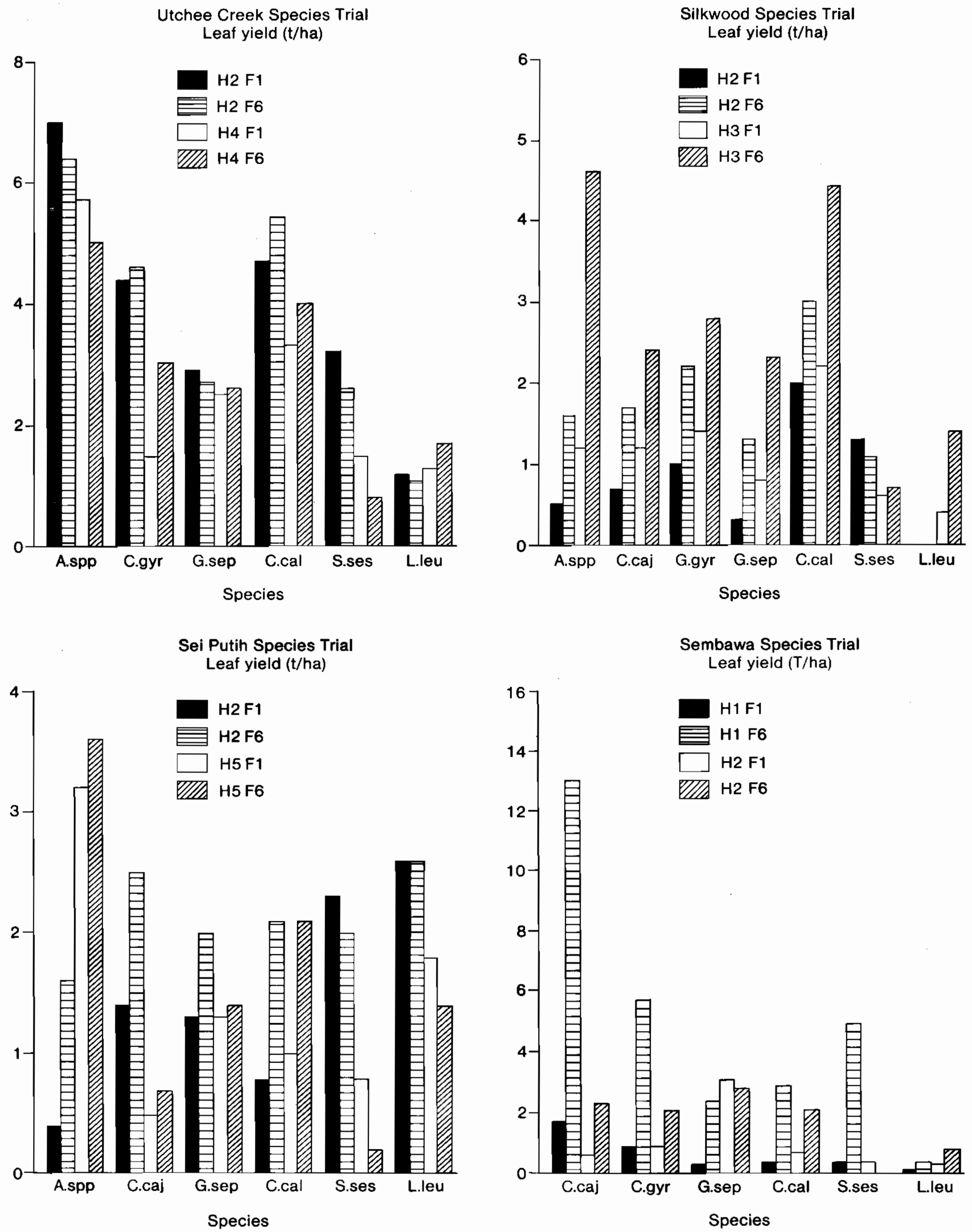

Fig. 3. Leaf yield (t/ha) at four sites for a range of shrub legumes at two harvests, both with and without fertiliser.

spp. also performed well and show excellent growth at the later harvests. Again no promising information is available on their value as an animal feed.

For sustainable agriculture we need diverse types of plants to cover their important niches; *Cajanus cajan*, *Codariocalyx gyroides* and *Sesbania sesban* which are fast growing but do not persist have a role in feed production for the first year. Other species can be used to maintain subsequent production. A possible model is to plant alternate rows of these two types, removing the former after the first year to allow more space for the woody perennial to grow later. Specifically, *C. cajan* could be sown in alternate rows with *Gliricidia sepium*, the *C. cajan* having the advantage that some accessions produce edible seed in addition to leaf material amenable to hay production.

Further long-term studies are required on the nutritional differences of these species especially on the symbiosis of plant with rhizobium and/or mycorrhiza. As noted earlier, specific results should not be generalised across species where only a single genotype is evaluated as much variation usually exists within species. It is also important to have information on the nutritive value of any accession to be recommended for animal feed as the yield of animal produce and not dry matter of leaf is the measure on which plants will be judged.

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Use of Organic Matter/Manure on Upland Acid Soils in China

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Abstract

The significance, accumulation and loss of organic matter and sources and uses of manures on upland acid soils of China are discussed. Erosion and a rapid decomposition under upland conditions cause soil organic matter content to decline. Organic materials applied to soils include animal and human excreta, green manures and plant residues, among which green manures occupy an important position. Green manure crops are cultivated in a fashion of single cropping, mixed cropping, interplanting or intercropping. Various kinds of organic materials are applied directly as fertiliser, used initially as feed and then as fertiliser, or used initially as fuel and then as fertiliser. These manures account for one-third of the N, one-half of the P and almost all of the K, of the total fertilisers.

Significance

China has long used organic materials as manures. Historical records from the third century B.C. describe how the ancient Chinese ploughed under weeds and processed animal bones as fertiliser. In the third century A.D., a vetch–grain crop rotation was developed. Use of human and animal excreta as fertiliser was practiced even earlier than ploughing under of weeds. These rotation and fertilisation methods utilising organic matter have maintained soil productivity despite several thousand years of continuous farming. During the last two or three decades, organic manures have still been important sources of plant nutrients applied to the soil, although the amounts of chemical fertilisers have increased tremendously. It has been estimated that in 1979 the amount of N, P and K supplied by organic manures in tropical and subtropical China amounted to 6 million t, accounting for about one-third to one-half and almost all of the nitrogen, phosphorus and potassium of the respective total fertilisers applied to the soil. It has also been found that in some areas the productivity of soils declined markedly in recent years due to the decrease in organic matter content as a result of incorrect ratio of chemical fertilisers to organic manures. It is generally observed that for most soils the fertility is highly correlated with the content of organic matter. Therefore, practices aiming at maintaining and increasing soil organic matter content are of primary consideration in soil management.

Accumulation and Loss

Tropical and subtropical areas of China in which most acid soils are distributed are characterised by high temperature and high rainfall. Under natural conditions the vigorously growing plants, particularly forests, return to the soil large quantities of litter yearly (Table 1). Therefore, in the surface layer of soils the organic matter content may be as high as 5–7%. However, two main causes lead to the decline in

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the organic matter content. In some regions soil erosion is a serious problem. The loss of surface soil by erosion is of course accompanied by a loss of organic matter. As a result, the organic matter content of eroded soils is much lower than that of noneroded soils, even under natural vegetation (Table 2).

The situation becomes worse after cultivation of the soil for upland crops. In some areas of tropical regions shifting cultivation is still practiced. This would lead to rapid destruction of soil organic matter. Besides, soil erosion becomes more serious, especially on sloping lands. Under extreme circumstances soil erosion is so severe that subsoils are exposed, with the result that the cultivated layer has an organic matter content of only about 0.5%.

Another reason for the decline of soil organic matter content after the cultivation of upland crops is that the decomposition of soil organic matter is more rapid under upland conditions than under submerged conditions. As can be seen from Table 3, the residue of milk vetch, a green manure, and rice straw after 2 years' decomposition in the field, is less under upland conditions than under paddy conditions. The rapid decomposition of soil organic matter in the former case leads to the formation of more fulvic acid (Table 4), which would in turn be more liable to further decomposition. Therefore, it is generally observed that within the same region the organic matter content of upland soils is lower than that of paddy soils. Table 5 shows such an example.

Table 1. Amount of litterfall under different vegetation (Wen and Lin 1986).

Location	Vegetation	Litterfall (t/ha)	Soil OM formed (t/ha expected)
Yunnan	Rain forest	11.00	3.42
Hainan	Monsoon forest	10.30	3.20
Yunnan	Rubber (mature)	8.28	2.84
Hainan	Rubber (8 years)	5.21	1.79
Hainan	Sweet potato – peanut	–	0.34
Hunan	Mixed forest	4.58	1.57
Hunan	China fir	1.99	1.00

Table 2. Effect of erosion on organic matter content of the surface of tropical and subtropical soils under natural vegetation (Wen and Lin 1986).

Soil	Condition	OM (%)	N (%)
Latosols	Noneroded	4.04 (30)*	0.167 (29)
	Eroded	1.73 (29)	0.080 (25)
Red earths	Noneroded	4.39 (51)	0.173 (42)
	Eroded	1.56 (28)	0.071 (20)
Yellow earths	Noneroded	6.69 (55)	0.258 (45)

* number of samples in parentheses

Table 3. Residue of organic matter after 2 years' decomposition under different conditions — Guangzhou (Wen and Lin 1986).

Material	Soil	Residue (%) Upland	Paddy
Milk vetch	Red earth	20	22
	Yel. brown earth	16	20
Rice straw	Red earth	19	22
	Yel. brown earth	19	21

Sources

In order to supply plant nutrients and to supplement organic matter to the soil, various kinds of organic materials are applied by farmers. The most important ones, arranged according to relative importance, include pig excreta, human excreta, green manures, cattle

Table 4. Effect of land use on composition of soil organic matter (Institute of Soil Science 1987).

Soil	Land use	C (%)	Composition (in C %) Humic acid	Fulvic acid
Latosol	Upland	1.35	8.5	27.1
	Rice	2.25	16.7	17.7
Red earth	Upland	0.63	4.5	31.6
	Rice	0.80	8.0	20.7
Yel. brown earth	Upland	0.96	20.4	33.0
	Rice	1.13	17.0	23.3

Table 5. Effect of land use on properties of red earth —Guangzhou (Institute of Soil Science 1987).

Land use	OM (%)	N (%)	CEC (meq/100g)	Base sat. (%)
Wasteland	0.71	0.039	7.2	23.7
Upland 9 years	1.68	0.084	9.9	42.4
Rice 7 years	2.72	0.123	11.3	83.0

excreta, plant residues and rape seed cake. An estimation of the quantities of various organic manures used in tropical and subtropical regions of China, made in 1979, is given in Table 6. However, it must be remembered that the quantity and relative proportion of each kind of organic manure differ from place to place and also from year to year. For example, while in the fifties and sixties there were large areas of paddy fields that were cultivated for green manure crops in the winter, in the last decade the area of green manure crops on such lands showed a trend of decrease due to the increase in cropping index. On the other hand, while on upland fields the cultivation of green manure crops was quite rare in the fifties, the area of such land increased markedly during the last two decades. It has also been been estimated that the numbers of domestic pigs, cattle and sheep in these regions changed by 2.6, 1.2 and 2.7 times respectively from 1952 to 1979. Generally speaking, despite the tremendous increase in quantities of chemical fertilisers manufactured and applied in the last decades, the absolute quantity of organic manures applied to the soil still increased.

Here mention must be made of the role of green manures, because in these regions green manures are an important source of organic manure for supplying nutrients and supplementing organic matter to the soil. Green manures contain about 10–30% of dry matter, 0.4–0.8% of nitrogen, 0.1–0.15% of P_2O_5, and 0.3–0.5% of K_2O. One harvest of green manure crop has a yield of 15 000–60 000 kg/ha. Besides, there are also large quantities of plant roots left in the soil. It has been estimated that the ratios of the above-ground part to underground part of leguminous green manure crops, nonleguminous green manure crops and graminaceous forage grasses are 0.93–1.56, 0.82–1.05 and 0.68–0.79 respectively. An

Table 6. Estimated use of organic manures in tropical and subtropical regions of China, 1979[a] (Wen 1985).

	Quantity available (10^6 t)	Nutrient content (%) N	P	K	Loss of nitrogen (%)	Nutrients (10^3 t) N	P	K
Human feces[b]	34.6	1.00	0.22	0.31	40	207	76.12	106.24
Human urine[c]	84.0	0.50	0.06	0.16	50	210	47.63	132.80
Cattle feces[d]	162.0	0.32	0.11	0.12	35	337	176.98	201.69
Cattle urine[e]	32.2	0.50	0.01	0.79	40	97	4.37	253.98
Pig feces[f]	148.0	0.50	0.18	0.42	40	444	259.14	615.03
Pig urine[g]	152.0	0.30	0.03	0.33	50	227	39.77	502.98
Goat and sheep feces[h]	6.7	0.65	0.22	0.21	40	26	14.86	14.11
Goat and sheep urine[i]	0.6	1.40	0.01	1.74	50	4		9.96
Plant residues[j]	32.6	0.60	0.09	1.08	–	195	28.40	352.75
Straw ash[k]	70.1	0.60	0.09	1.08	–	–	55.06	529.54
Green manures[l]	11.9	2.74	0.31	1.59	–	327	36.71	189.24
Azolla	8.8	0.22	0.02	0.07	–	19	1.75	6.64
Rape seed cake	1.3	4.60	1.10	1.16	–	60	13.98	14.94
Total						2 153	754.77	292.99

[a] Source: 1980 Almanac of China'a Agriculture (Editorial Committee of Almanac of China's Agriculture, 1981).
[b] 90 kg per capita, 80% available; population 480 million.
[c] 350 kg per capita, 50% available.
[d] 5.4 t/head per year, 70% available; population 42.9 million.
[e] 3 t/head per year, 25% available.
[f] 0.95 t/head, 90% available; population 173 million.
[g] 1.25 t/head per year, 70% available.
[h] 0.35 t/head per year, 50% available; population 38 million.
[i] 0.15 t/head per year, 10% available.
[j] 825 kg/ha per year.
[k] Assuming 146 kg straw is used as fuel per capita, loss of P=10%, loss of K=30%.
[l] 15 t/ha, 7.8 million ha.

analysis showed that for nine species of leguminous green manure crops in a tropical region the underground part contained 31–40% of N, 30–50% of P_2O_5, 23–30% of K_2O, 21–41% of CaO and 35–46% of MgO of the respective total element of the plant. Therefore, the effectiveness of the cultivation of green manure crops in improving soil fertility is so remarkable that in these regions there is a proverb among farmers saying that 'three years cultivation of green manure crops makes a poor soil fertile.'

Green Manure Crops

There are a variety of green manure crops currently cultivated on acid soils of tropical and subtropical regions. For winter growing, they include *Astragalus sinicus* L. (milk vetch), *Raphanus sativus* L. (radish), *Vicia cracca* L., *Vicia sativus* L., (Rye grass) etc. For summer growing, they include *Sesbania cannabina* Pers., *Crotalaria juncea* L., *Crotalaria spectabilis* Roth., *Vigna sinensis* Sav., *Phaseolus calcalatus* Roxb., *Phaseolus radiatus* L., *Stizobobium cochinersis, Angshucarpoea edgewarthii* etc. Perennial green manure crops and forage grasses include *Lespedeza davidii* Franch., *Peuraria thunbergiana* Benth., *Amorpha fructicosa* L., *Cajanus cajan, Clitoria ternatea* L., *Kummerowia striata, Eragrostis ferruginea* Beauv. etc. The adaptation of these plants to different climatic and soil conditions differs markedly. The principal soil factors in this regard are fertility status and water regime.

Most of these plants are leguminous in nature. Grasses are occasionally cultivated as cover plants to protect the soil from erosion and as forage. Radish (*Raphanus sativus* L.) occupies a special position. For a long time this plant was cultivated as a green manure crop rather extensively, mainly on paddy soils but also on upland soils. At present it is still an important green manure crop in acid soil regions. It is more adaptable to poor fertility and low moisture regime of soils than most leguminous species. Therefore, it is often cultivated as a pioneer plant on newly cultivated acid soils. A study showed that radish possesses a characteristic feature in that it can take up phosphorus from not easily soluble sources of phosphate, such as rock phosphate, more effectively than do other plants. This feature can be clearly seen from Table 7. The table also shows that this feature is related to physiological properties of its root system, e.g. a larger cation exchange capacity and a stronger acidity of the root surface. This peculiar ability of utilising not readily available phosphorus from the soil is of special significance in acid soil regions of tropical and subtropical China, because most of these soils are severely deficient in available phosphorus. Therefore, although radish cannot obtain its nitrogen from the air, its position as a green manure crop cannot be replaced in many areas even at the present.

Table 7. Calcium and phosphate uptake from rock phosphate in relation to properties of plant roots (Institute of Soil Science 1987).

Plant	Root surface			Uptake(%)	
	CEC (meq/100 g)	H-sat. (%)	Ultimate pH	CaO	P_2O_5
Barley	9.5	32	4.07	5.0	0.8
Buck-wheat	29.6	15	3.59	59.3	51.6
Radish	36.7	13	3.52	114.8	56.0

Green manure crops are cultivated as either single cropping (or monocropping), mixed cropping, interplanting or intercropping, depending on local conditions.

If practicable, mixed cropping is generally more profitable than single cropping. For example, the total yield of fresh above-ground part is higher by 30–80% or even more if milk vetch and radish are cultivated in mixture than when one single plant species is cultivated. Likewise, the benefit of mixed cropping of *Pueraria javanica* and *Clitoria ternatea* L. in rubber plantations is also quite remarkable.

In fields used for commercial forests, such as rubber trees, citrus and tea tree, interplanting with green manure plants is a common practice. For instance, in rubber plantations the growing of creeping legume covers in the interrows can check the growth of weed, protect the soil from erosion, and improve soil fertility. This is because in young rubber plantations there exist large bare spaces between rows at the early stage of establishment, while creeping legumes grow very fast and cover the ground quickly.

Besides, the fresh annual stems and foliage may amount to as much as 30–50 Mt/ha. It was found that *Pueraria javanica* could produce 15 000 kg/ha/year of dry stems and leaves containing 363 kg N, 27 kg P, 321 kg K, 53 kg Mg and 80 kg Ca. One-and-a-half years after the establishment of *javanica,* soil N content increased by 150 kg/ha, equivalent to applying 750 kg/ha N fertilisers during the 5 or 6 years of the immaturity period of the rubber plant. In addition, it has been observed that while a loss of 2900 kg/ha of organic matter occurred in fallow land over an interval of one-and-a-half years, the organic matter content remained at the same level in soils under cover crops in the same period.

Fertilisation of green manure crops, particularly with phosphates, is so profitable that there are two proverbs among farmers in this regard. One of them is 'getting nitrogen through phosphate fertilisation'. Fertilisation with phosphates can result in an increase in yield of green manure crops by 60–100% or even more. Experiments show that 1 kg of calcium-magnesium phosphates induced an increase of fresh weight of vetch or milk vetch of about 70 kg. If it is assumed that these fresh green manures contain 0.45% of nitrogen, corresponding to 1.6 kg of ammonium sulfate. This is what is meant by 'getting nitrogen through phosphate fertilisation'. The proverb is so widespread that during the last one or two decades China has had much profit from this practice.

Another proverb 'getting more fertilisers at the cost of less fertilisers,' is also well-known to farmers. It has been estimated that on some Oxisols the application of 5 kg of N as fertiliser to green manure crops resulted in the increase of 20–30 kg of nitrogen coming from the atmosphere.

Use of Organic Matter

Various methods have been developed to make full use of organic matter. They include direct application as fertiliser or mulch, initial use as feed and then as fertiliser, and initial use as fuel and then as fertiliser.

Direct Application

Most farm manures are applied directly to the soil as basal dressings. Some liquid manures, such as human urine, are also applied as top dressing after dilution. Green manures are mostly ploughed under in the field or, if the yield is very high, cut partly and transported to another field for ploughing under.

In rubber plantations, mulching on planting strips has a favourable effect in retaining water and increasing organic matter content of the soil. An experiment showed that 2 years after mulching with 100 kg of grasses on 100 m^2 of land, soil organic matter content increased by 62% compared with the unmulched area. In plantations of fruit trees and tea trees, mulching is also a frequently adopted method of using organic materials.

In order to make organic materials more effective when used as fertilisers, they are composted for a certain period of time before application to the soil. Two methods of composting, 'dry' composting and waterlogged composting, are practiced. Generally, waterlogged composting can maintain more nitrogen and organic matter than dry composting. However, in the former case more labour is needed during transportation.

As Pig Fodder

Some green manures can be first used as pig fodder and then used as fertiliser. An experiment showed that 1.25 t of fresh milk vetch caused the pigs' weight to increase by 26.5 kg, and application of the resultant excreta to rice plant caused a grain increase of 27 kg. Direct application of the same amount of milk vetch gave a comparable grain increase. Thus, the utilisation of green manure crops in this way is more profitable than direct application to the field.

As Sludge and Effluent of Biogas Plants

Biogas fermentation uses rationally and effectively various kinds of organic materials such as plant residues, green manure crops, and human and animal excreta. Experiments show that through biogas fermentation every kilogram of organic matter can produce about 0.20–0.38 m^3 of gas which may be used as fuel that is in short supply to farmers in many regions of the country, leaving 32–60% organic carbon which may serve as a source of soil organic matter. Furthermore, biogas fermentation is more advantageous for the preservation of nitrogen and carbon than composting or waterlogged composting, as can be seen from Table 8. Through biogas fermentation, sizeable amounts of nitrogen and phosphorus become available. The effect of sludge and effluent on crop yield is similar to that of pig manure when compared on the basis of equivalent amount of nitrogen. Therefore, in the last decade the use of organic materials through biogas fermentation has become increasingly popular in many regions of tropical and subtropical China, provided that sources of organic materials are abundant locally.

Table 8. Percentage of C and N in organic materials retained after decomposition under different conditions (Wen 1986).

Method	C (%)	N (%)	Gas production (m^3/kg)
Composting	19.4	53.0	–
Waterlogged-composting	33.8	82.9·	–
Biogas fermentation	38.9	94.3	0.26

Organic materials with different chemical composition vary in both the amount of biogas produced and in the production pattern. Fresh milk vetch and weeds are rich in easily decomposable components and produce biogas quickly but are not long lasting, with about 85% of their total output produced within 15 days at 30°C. For rice and wheat straw and husks with a composition difficult to decompose, only 9–16% of the total production comes within the same period at the same temperature. With various kinds of farmyard manure, an even production is generally observed during the whole period of fermentation. Therefore, depending on local conditions, a proper regulation of proportions of different raw materials is exercised, so that an even and lasting biogas production is ensured.

Effect on Physicochemical Properties of the Soil

As is well-known, soil organic matter affects many properties of the soil. For acid tropical soils, which mostly belong to Oxisols and Ultisols with a low activity clay, the effect of organic matter on charge characteristics and their related properties deserves special consideration.

Soil organic matter carries far more negative charges than does the mineral part of these soils. Figure 1 shows that for an Oxisol the removal of organic matter from the clay fraction resulted in a decrease in negative charge, particularly in net negative charge, within the pH range commonly encountered, thus leading to an increase in zero point of net charge to about 4.5 from the original value of pH 3.9.

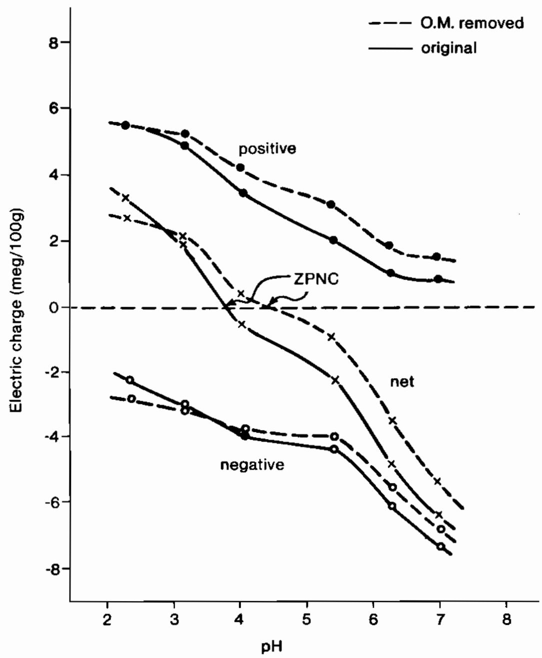

Fig. 1. Effect of organic matter on electric charges of an Oxisol (Yu and Zhang 1987).

The contribution of soil organic matter to negative charge and thus the cation-retaining capacity are of special significance in tropical regions where the rainfall and thus the leaching loss of nutrients are high. Suppose that the mineral part of a soil has a cation exchange capacity of 4 meq/100 g and the organic part a cation exchange capacity of 100 meq/100 g. If the soil contains 2% of organic matter, the contribution of the latter to total cation exchange capacity would be 33%. On the other hand, for a soil of temperate regions with a cation exchange capacity of 20 meq/100 g the contribution of the same amount of organic matter would be 9%.

The erodibility of natural soils is to a large extent related to the aggregation status. For soil particles to be aggregated, coagulation is a prerequisite. As can be seen from Fig. 2, organic matter affects the zeta potential and the isoelectric point of an Oxisol markedly. This would affect the aggregation process. Besides, organic matter, particularly its colloidal part, can act as a cementing agent in soil aggregation.

For leaching loss of nutrient cations to occur, the cations must first dissociate from the exchange sites. Organic matter which carries negative charges would make adsorbed cations, such as calcium ions, less dissociated (Fig. 3), thus hindering leaching loss.

Organic materials can furnish electrons during their decomposition, leading to an intensification of reduction processes of soils. Therefore, it can be observed that even under upland conditions the oxidation–reduction potential of the surface layer of forest soils which have a higher organic matter content is lower than that of subsoils, due to the presence of a larger amount of reducing substances, and generally the higher the organic matter content, the stronger the reduction. Figure 4 shows this clearly. A reduced condition is favourable to the activation of some elements, such as iron and manganese, which would be inactive under oxidised conditions. This activation of these elements would make them more available to plants. Of course, if the content of organic

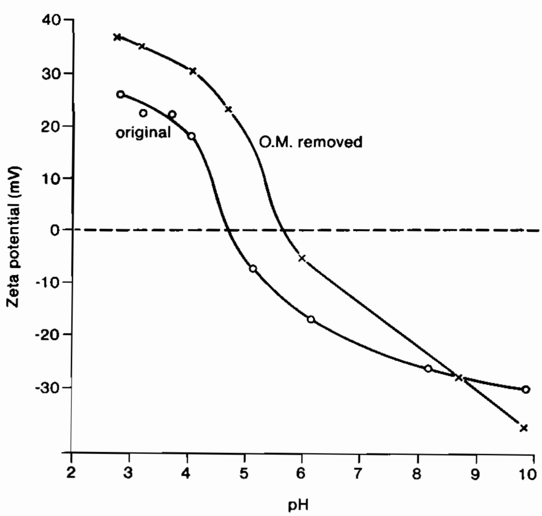

Fig. 2. Effect of organic matter on zeta potential of the clay fraction of an Oxisol (Yu and Zhang 1986).

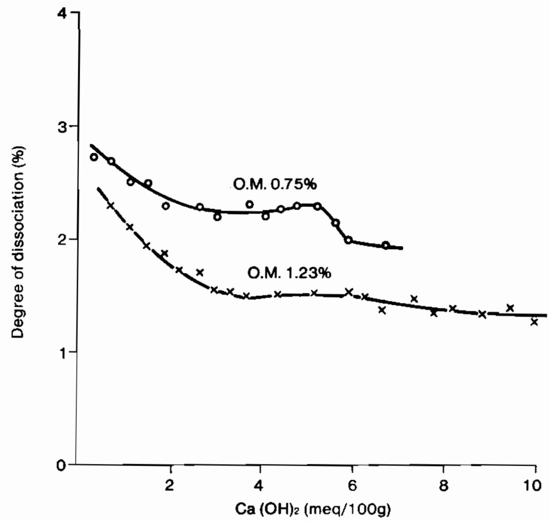

Fig. 3. Effect of organic matter content on dissociation of adsorbed calcium ions from an Oxisol (Wang 1986).

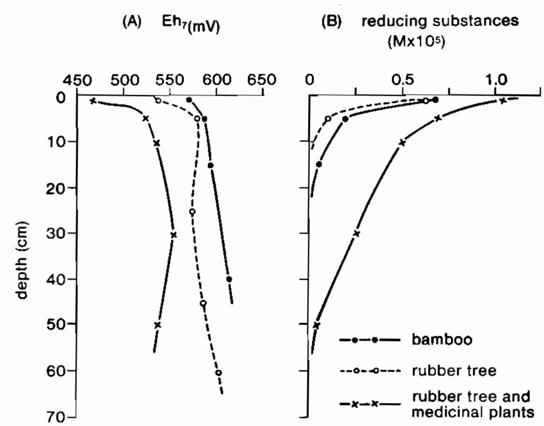

Fig. 4. Redox potentials and contents of reducing substances in tropical soils under commercial forest (Ding et al. 1984).

matter is too high, particularly if the soil is very wet, toxicities of large amounts of reduced manganese and iron may also occur.

From what has been mentioned in the above it is clear that, while the role of organic matter in affecting many properties related to soil fertility is universal to all types of soil all over the world, it is of special significance in soils of tropical and subtropical regions. This is the reason why farms take all practicable measures to maintain and increase the organic matter content of soils.

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Section 2

Country Reports

Management of Acid Humid Tropical Soils in Indonesia

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Abstract

Research on acid humid tropical soils in Indonesia has been carried out by several institutions. Most of the results are not well documented. The research has been mainly on rate studies and interaction studies related to crop production, and is designed to support the ongoing transmigration projects. The main factors that restrict research on acid soil management in Indonesia are poor coordination and organisation, and lack of experts, equipment and funding. It is essential to coordinate the work of agencies involved in acid soil management research. Comprehensive soil research programs such as those of IBSNAT and TROPSOILS must be encouraged.

Introduction

The food problem is very serious in Indonesia as well as in other developing countries, both because of population growth and difficulties encountered in increasing food crop production.

One of the government's policies to overcome the food problem is to expand and intensify agricultural land. This policy is based on the fact that Indonesia still has extensive potential areas for food crops expansion outside Java and Bali and that the opportunity to increase food crop production by better soil management is promising.

Efforts in these areas have been made. Thousands of hectares of acid soils have been surveyed and mapped. The results have been used by agencies involved in the agricultural expansion and intensification program. Techniques and methods of soil surveys and land evaluation are now being improved, and computer techniques are being used. Efforts have also been made on soil and crop management.

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At the early stages of soil and crop management research in 1973, this program was simple (McIntosh 1984, 1986) and was merely a crop management program with little attention to soil management. Most of the programs at that time were focused on cropping patterns and cropping systems.

In 1976 Bogor Agricultural University (IPB) initiated a relatively holistic farm management approach in Rimbo Bujang, Jambi (Leiwakabessy et al. 1984), but it isn't working effectively. This kind of research must be supported by basic soil–plant relationship research as well as social, economic and cultural factors of the farmers.

The need for such research in Indonesia now is increasing rapidly. The IBSNAT (International Benchmark Site Network for Agrotechnology Transfer) Soil Project is the first advanced acid soil management research in Indonesia, which was initiated in early 1979 in collaboration with CSR/AARD (Silva 1985). At present there are several programs on acid soil management in transmigration areas such as TROPSOILS program in Sitiung, Jambi, operating since 1984. This program is one of collaborative research among the Centre for Soil Research (CSR), AARD, the University of Hawaii, and the North Carolina State University (Widjaja-Adhi et al. 1988). The CSR also is working on a project called 'Research on Farm Management Pattern to Support Transmigration Area in Kuamang Kuning and Kubang Ujo, Jambi' (Sudjadi et al. 1988).

Agrilime Study Group (TSK) from Bogor Agricultural University has also been working on acid soil management since 1984. This liming program was developed basically to sustain the government policy on self-supporting soybean production. At the early stages, the program resembled a demonstration farm, spread in several transmigration locations in Sumatra, Kalimantan, Sulawesi as well as in West Java. At present the team is working on improving and monitoring the program.

Between 1978 and 1983 there were research programs on land clearing and soil preparation involving several institutions. Studies were conducted in Baturaja (South Sumatra), Pasir Pangarayan (Riau), Sitiung II (West Sumatra), and Pamenang, Jambi (South Sumatra) by the Bogor Agricultural University and at Sekayu (South Sumatra) by the University of Gajah Mada (UGM).

Although there are so many research activities on acid soil management, the results have not yet affected the farmers because of the following factors: low income of the farmers, low inherent soil fertility and other soil and land constraints, low technical know-how of the farmers and the extension workers, poor organisation and coordination at the farmer level, poor coordination in research programs and between researchers, and the poor flow of research information. Besides those constraints, Suwardjo et al. (1985) list the constraints and weaknesses of the transmigration program which also influence crop production.

For the government's food program to become effective a network and comprehensive research program on acid tropical soil management is urgent. If those extensive areas are able to produce a reasonable yield, the welfare of the farmers may be improved and the national food program sustained, helping other countries. Other advantages might also be obtained from a well defined, well organised and well operated network.

If the objective of IBSRAM'S network as assigned by Sanchez (1986) can be realised, it will be very helpful to the national food program on the extensive acid soils in Indonesia.

Management of Acid Soils in Indonesia

Soil Properties

Vast areas of arable land outside Java especially in Kalimantan, Sumatra and Sulawesi consist of highly leached soils, very acid in reaction, high Al-saturation, low inherent macro- and micronutrient status, very low content of weatherable minerals, etc. The soil is dominated by low activity clays which compact especially in the subsurface and are susceptible to erosion.

Appendix 1 shows chemical characteristics of soils from several locations. The role of organic matter in management of such soils is very important. However, the production per hectare is very low when no fertiliser and lime are applied.

Indigenous and Transmigrant Farmers

Both kinds of farmers are poor and have different farming systems which are usually the result of differences of land resource and other factors. The transmigration farmers come from better soil conditions and are somewhat familiar with better cultivation practices on permanent fields. Indigenous farmers practice shifting cultivation, or ladang, and use acid-tolerant crops and minimum tillage in their farming systems to overcome soil problems. They depend solely on the natural fertility of the soil.

Traditional land clearing in Indonesia as in other humid tropical regions is slash-and-burn. Trees are felled and the branches are cut and burnt after a period of drying. The effect of slash-and-burn on pH, exchangeable acidity and exchangeable bases is positive (Table 1), and therefore improves plant growth.

Also they never dig the soil deep in order to prevent the top soil (±10–15 cm) from mixing with the subsoil which is more infertile and higher in Al saturation. These practices cause little physical damage and give some minor improvement to the rooting environment. The only food crop they plant is upland rice (local varieties) which is tolerant to acid conditions. Hudri and Leiwakabessy (unpublished) found that some local upland varieties can grow well on soils with 79% of Al saturation.

Although the production is low, it is difficult to change this traditional system as long as land is available. An understanding of how the indigenous farmers manage the soil is important in order to improve their soil management practices.

The transmigrant farmers, on the other hand, cultivate a permanent acreage of land which has been cleared and prepared by the project. Each family is provided with 2 ha of land consisting of 0.25 ha for houselot, 1.0 ha for food crops and 0.75 ha for tree crops. The first 1.25 ha is cleared and prepared by the project, and the other 0.75 ha is provided later. They are also provided with three kinds of fertiliser packages: 300 kg of urea and TSP plus 2000 kg of lime in the first year and 300 kg of urea and TSP in each of the second and third years.

The rate of fertiliser per hectare used varies between families depending on the area of land they cultivate. The rate and kind of fertilisers were established at the national scale regardless of soil characteristics.

Although several techniques of soil management have been introduced, most farmers still apply their own experience in soil and crop management. This is mainly due to: the poverty and low technical knowledge of the farmers; fertilisers and other agricultural materials unavailable to the local market, and delivered late to the government market. Technologies and methods of development are not widely understood and practiced due to poor information and guidance.

Table 1. Some soil chemical characteristics before and after land clearing (Agus et al. 1986).

Soil depth (cm)	Sampling time[a]	pH	Meq/100 g soil Al+H	Ca+Mg	K-Metlich-I
0–1	BB	4.2	2.87	0.55	0.12
	B_0	3.9	2.76	1.20	0.14
	B_1	4.4	1.72	3.80	1.15
	B_2	6.6	0.16	9.70	2.07
10–20	BB	4.5	2.15	0.50	0.03
	B_0	4.0	2.08	1.50	0.13
	B_1	4.4	1.82	1.60	0.28
	B_2	5.1	0.92	2.40	0.52

[a]BB = before land clearing;
B_0 = post land clearing, no burning;
B_1 = post land clearing, partly burnt;
B_2 = post land clearing, completely burnt.

The general cropping pattern practiced by the transmigrants is the planting of upland rice usually in the wet season which begins in September, as monoculture, followed by secondary crops such as maize, soybean or peanut as monoculture or intercropping in March. Cassava is grown throughout the year especially in the houselot. Under these conditions low yield levels are achieved (Tables 2, 3). Without a comprehensive approach to this subject, it will be hard to raise the welfare of the farmers.

Management by Institutions

As has been mentioned before, several institutions are involved in acid soil management in transmigration projects. Some approach the problem first by careful identification of soil constraints and other basic information needed in a farm model development. Others use common sense and experience from some other environment (usually Java) with minor information about the soil and few field studies. In both approaches, some apply low input management (traditional) while some apply medium input (improved traditional) or even higher input levels. Those different approaches are the result of donor agencies wanting instant results. Therefore the research projects are usually not complete. Some results of several research projects are presented below:

Cropping Patterns. Several important results on cropping patterns have been obtained such as yield potential of food crops with different inputs, effect of lime and fertilisers, analysis of personpower required for each cropping pattern and on socioeconomic aspects, etc. (Imtias et al. 1984; Ismail et al. 1984; Sudana and Imtias 1984; Rumawas 1984; Leuwakabessy et al. 1984; Hakim et al. 1988; Suwardjo et al. 1988; Wigeno et al. 1988).

Table 4 shows the yield potential of some important food crops in Indonesia planted on acid humid tropical soils. With medium and relatively high inputs of fertiliser and lime,

Table 2. Yield of several food crops at 12 transmigration settlements (Manurung and Nataatmadja 1984).

Location	Planting period	Yield (t/ha) Upland rice (unhulled)	Corn (grain)	Soybean (grain)	Peanut (grain)	Greenbean (grain)
Pasir Pangarayan	1981	1.45	–	–	0.47	–
Kuro Tidur	1981	1.10	0.90	–	0.40	–
Batu Marta	1980	2.09[a]	2.75[b]	–	–	–
Rosuan	1980	1.80[a]	2.80[b]	–	0.42	0.35
Sitiung II	1980	2.35[a]	0.54	0.58	0.74	0.80
Sungai Tambangan	1980	1.53	0.87	0.60	0.40	0.35
Kaleena Kiri	1980	1.49	1.12	0.70	1.40	–
Kaleena Kanan	1980	1.42	0.63	0.80	0.41	–
Uepei	1980	0.92	1.31	0.92	0.36	–
Lapoa	1980	1.80	0.32	–	–	–
Malonas	1981	1.40	2.40	1.40	0.90	0.80
Toili X	1981	1.50	2.00	0.70	0.80	0.60

[a] With panicle.
[b] Ear.

Table 3. Range of soybean yields obtained by farmers at several locations in Jambi with lime allocated freely by the government.

Location	Yield (kg/ha)
Singkut	500–650
Kubang Ujo	400–560
Hitam Ulu	360–450
Kuamang Kuning	210–300

Sources: Agrilime Study Group (TSK), Fac. of Agriculture, Bogor Agricultural University, Bogor, 1986 (Iswandi and Soepardi 1987).

upland rice produces 1.8–4.1 t/ha, corn 3.4–10.7 t/ha grain, soybean 1.17–2.5 t/ha seed, and peanut 1.5–1.6 t/ha seed. With three kinds of fertiliser packages, i.e. 2-2-1 t/ha, 2-1-1 t/ha and 1-1-1 t/ha on 0.25 ha plots, Leiwakabessy et al. (1984) produced 2.5, 2.0 and 1.8 t/ha unhulled dry paddy respectively. From these figures it is evident that by correct additional inputs the yield of food crops can be increased. The question is: what kind of technology can be introduced to such farmers in such environmental conditions? Can the farmers achieve high input levels of soil and crop management without being subsidised by the government? Can the government prepare such a policy in present economic conditions? To answer these questions, thorough research is necessary and the soil–plant–farmer relationship approach must be thoroughly planned and implemented. A better understanding of soil and plant behaviour in relation to the use of fertiliser, lime and organic matter will help to produce a better technology for each level of farm management.

Soil Management Research. As pointed out earlier in this paper this research is of minor interest compared to crop management research. It starts actually from the attempt to understand the nature of the soil in detail: its genesis, classification, reserve minerals, clay minerals and other colloidal fractions, its chemical, physical and biological properties, etc. and its behaviour with fertiliser, lime organic matter and other physical inputs. With this information it may be possible to predict the effect of any treatment on soil and correlate it with crop response.

The importance of vast areas of acid soil to support the government's crop intensification programs was realised by Indonesian soil scientists. In 1971, Professors A.M. Satari, O. Koswara, S. Arsyad, and G. Soepardi from the Soil Department of IPB pioneered a research program on tropical soils: 'Penelitian Pengembangan Potensi Tanah-tanah Tropika di Indonesia' (Research on the Development of Potential Tropical Soils in Indonesia). This research program relates to the University Project: 'Proyek Peningkatan Mutu Perguruan Tinggi' IPB (University Education Quality Improvement Project of IPB).

Table 4. Yield potential of some food crops on acid humid tropical soils.

Food crop		Yield (t/ha)/Source					
	1*	2*	3*	4*	5*	6*	7*
Upland rice (unhulled)							
1. C–22	2.8	–	–	–	–	–	–
2. Gati	2.8	–	–	–	–	–	–
3. Gama 61	2.6	2.5	–	–	–	–	–
4. Seratus malam	2.6	–	–	–	–	–	–
5. Cartuna	2.2	–	–	–	–	–	–
6. Klemas	2.2	–	–	–	–	–	–
7. PB–26	–	2.3	–	–	–	–	–
8. PB–32	–	2.2	–	–	–	–	–
9. PB–30	–	2.3	–	–	–	–	–
10. PB–36	–	2.1	–	–	–	–	–
11. Serai	–	2.5	–	–	–	–	–
12. Bantaran merah	–	2.5	–	–	–	–	–
13. Bantaran putih	–	1.8	–	–	–	–	–
14. Gama Gundul	–	2.5	–	–	–	–	–
15. GIAT 7	–	–	4.1	–	–	–	–
16. IR–9575	–	–	3.8	–	–	–	–
17. PB–42	–	–	2.8	–	–	–	–
18. Bicol	–	–	2.7	–	–	–	–
19. Sentani	–	–	–	1.9	–	–	–
Corn (grain)							
1. Arjuna	3.4	–	5.4	–	5.5	–	–
2. BC–24	3.4	–	–	–	–	–	–
3. BC–10	3.7	–	–	–	–	–	–
MS–4							
4. Harapan	–	4.7	–	–	–	–	–
5. H–6	–	–	5.4	–	–	–	–
6. Bromo	–	–	5.6	–	–	–	–
7. H–159	–	–	5.9	–	–	–	–
8. 18 x 2 (Hybrid)	–	–	5.5	–	–	–	–
9. 19 x 2	–	–	5.7	–	–	–	–
10. 18 x 15	–	–	6.4	–	–	–	–
11. 19 x 15	–	–	6.1	–	–	–	–
12. 18 x 16	–	–	6.4	–	–	–	–
13. 19 x 16	–	–	5.7	–	–	–	–
14. Muneng 8128	–	–	–	5.1	–	–	–
15. Hybrid C–1	–	–	–	4.7	–	–	–
16. Corn(var.?)	–	–	–	–	10.7	–	–
Soybean (seeds)							
1. Orba	1.1	–	–	–	–	–	–
2. Shakti	–	2.5	–	–	–	–	–
3. Soybean (var.?)	–	–	1.5	–	–	2.2	1.7
Peanut (seeds)							
1. Gajah	–	1.5	1.6	–	–	–	–
2. Kidang	–	–	1.6	–	–	–	–
3. Banteng	–	–	1.6	–	–	–	–

*Sources:
1. Ismail et al. 1984;
2. Leiwakabessy et al. 1984;
3. Rumawas 1984;
4. Sukristiyonubowo et al. 1984;
5. Uehara et al. 1987;
6. Iswandi and Soepardi 1987;
7. Rochayati et al. 1987

The program is supported by the MUCIA-Acid Program and assisted by soil experts Dr E.C.A. Runge, Professor R.B. Corey, Dr W.R. Kussow, and Dr J.T. Murdock.

A soil testing program was then encouraged. Because there is a scarcity of soil scientists with postgraduate degrees, a training program and courses have been conducted and staff sent abroad for further degrees. Soil scientists from other universities and CSR are also involved but the program has stopped for several reasons, among them funding, quick yielding research and soil survey programs of the government's agencies which involved CSR and the universities, limited soil scientists, and other factors.

With such a background of soil management research programs, coordination and organisation, it will be difficult to disseminate research activities and results completely. However the following broad topics will give some idea of the kinds of research projects that have been undertaken:

- Rate studies and crop response.
- P-fixation and fractionation studies and residual effect on crop yield.
- Soil test correlation and calibration studies.
- Studies on interaction among nutrients, lime and organic matter.
- Research on amelioration of acid soils:
  - –methods for testing lime requirement
  - –liming rate studies related to Al saturation with acid-tolerant varieties and HYV
  - –organic matter rate studies in relation to some soil chemical characteristics especially on the availability of nutrients, exchangeable Al, P-fixation, pH, etc.
  - –alley cropping studies related to organic matter production.
- Research on soil conservation:
  - –effect of several practices such as mulching, land preparation, etc. on soil erosion, surface flow.
- Research on acid-tolerant varieties (IPB's Program):
  - –screening test for several local upland rice varieties, soybean and corn
  - –breeding for acid-tolerant varieties of upland rice, soybean and corn.
- Research on soil microorganisms on N and P.
- Soil genesis and classification:
  - –studies on genesis and mineralogy of soils with low activity clays
  - –studies on genesis and classification of red soils in Indonesia.

At present a serious research program on acid soil management is being carried out by the CSR/AARD, the University of Hawaii, and the North Carolina State University in a collaborative research project in TROPSOILS Programs. The topics covered are (Caudle and McCants 1987): soil variability; soil management and people; productivity in farmers' field; land reclamation; soil physics and soil reclamation. Some preliminary results have been published.

There are probably several research programs on acid soils which are not covered in this paper because of limited information. However, the paper gives a general picture of the research on acid tropical soils in Indonesia.

Research Priorities

Based on several problems mentioned earlier, it is clear that long-term research dealing with soil, plant, moisture and human aspects is necessary. In deciding soil and plant management for the transmigrants or indigenous farmers, the human factor is often not considered, although this factor is very important if management practices are to succeed.

Research priorities must be allocated so that the poor farmers in the transmigration area can improve their welfare by cultivation of the poor acid humid tropical soils. Consequently research on management of acid humid tropical soils in Indonesia must cover the following items:

1. solving acid soils problems confronting the farmers;
2. transferability of results to other locations;
3. ensuring the research is future-oriented;
4. determining practical approaches to soil management; and
5. preparing research that matches the future demand of farmers for soil and plant analysis information.

Based on these considerations, research priorities will be as follows.

1. Applied research covering current needs of the farmers (short term):

- identifying soil problems for each crop;
- rate studies for each problem identified;
- screening and selection of varieties tolerant to acid condition or high Al saturation;
- study of rhizobium and micorrhiza in relation to N and P;
- lime and P placement studies related to water stress;
- mulching and organic matter rate studies with different kinds of organic matter produced in the area;
- studies of the effects of different soil tillage;
- methods of lime and fertiliser application; and
- ash and night soil studies.

2. Basic soil management research (long term)

- thorough identification and mapping of soil characteristics in each site;
- soil-plant-moisture relationship studies;
- studies on methods to determine fertiliser and lime requirements for each crop;
- identification of critical levels of each major nutrient, Al and pH for each major food crop;
- plant breeding program for acid- or aluminium-tolerant crops;
- identifying the relationship between nutrient content in the soil or plant and the phenomenal production component; and
- research on quick test methods of lime and major nutrient requirements.

3. Demonstrations on farmers' fields; testing for soil management practices.

4. Research on the possibilities of establishing a mini-scale soil laboratory in the future to help the farmers in identifying soil problems, and fertiliser or lime recommendations.

With this research information it is hoped the traditional or low input soil management practices of the farmers can be improved as well as benefiting the modern farmers.

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Farming Acid Mineral Soils for Food Crops: an Indonesian Experience

Tejoyuwono Notohadiprawiro*

Abstract

Acid mineral soils are multi-stress soils of submarginal potential for food crops. As the entire production of food crops is with small farmers, this adds to the serious constraints of attaining productive use of the soils. High-import technology relying heavily on commercial imports from off-farm sources is not the best choice from two points of view: (1) sustainability of production, and (2) compatibility with farming practices.

Low-import technology in terms of limited use of commercial energy should be advocated. It applies biotechnology as the core of soil management with the objective of strengthening the soil-plant association through the mediation of microorganisms. In this respect biological nitrogen fixation by the symbiotic association of legume plant–rhizobium and improvement of phosphate bioavailability in the soil by the symbiotic association of plant–mycorrhiza are most crucial.

Extent of Acid Mineral Soils

The most extensive soils in Indonesia are the acid mineral soils formerly called red-yellow podsolic soils. They cover close to 49 million ha or 25.7% of the country's total land area. When one adds approximately 18 million ha of latosols and around 5 million ha of podsols, the total area of acid mineral soils becomes about 72 million ha or 37.7% of the total land area of Indonesia (Biro Pusat Statistik 1987; Driessen and Soepraptohardjo 1974; Driessen et al. 1976).

The greatest area of the acid mineral soils of about 24 million ha is found in Sumatera, covering 52.6% of the island. Kalimantan has almost 23 million ha, or 42.6% of its total area. In Irian Jaya there are about 13 million ha or 30.4% of its size. Thus slightly more than 83% of the acid mineral soils are in those three regions (Muljadi and Arsjad 1967).

According to the FAO/Unesco legend of the Soil Map of the World these soils are included in the Acrisols, Nitosols, Ferralsols, Podsols, and some of them in the Arenosols and Cambisols. Apart from their similarity in degree of acidity, these soils show clear differences in many characteristics such as mineralogy, morphology, exchangeable aluminium and degree of aluminium saturation, iron chemistry, content of microelements, and soil physical properties (see Appendix). So they are far from being uniform in many important aspects which are basic to soil management. This means that although they are commonly discussed as one class of soils, they cannot be treated as a single kind of soil. Their inventory needs more detailed specification.

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Indonesia's Serious Dilemma

Since 1959, self-sufficiency in rice, and more recently self-sufficiency in food, has been central to Indonesia's agricultural development policy. Java was for a long time the most important region for food production, especially rice. The region was provided with excellent and expensive infrastructures and projects of land development and land use intensification. Due to the national food policy which overemphasises rice, this commodity became the staple food of the entire population. Traditional communities of East Java, Sulawesi and the Southeast Archipelago used corn as their staple food. Sago had been the staple food of the indigenous population of the Maluku Archipelago and Irian Jaya. Many tribes in Irian Jaya also live on tubers. For the inhabitants of the marl and limestone hills of Java, cassava was the staple food.

Subsequently rice attained a strategic position in issues of national stability and security. Because Java is approaching population saturation, increases in rice production will more and more rely on expansion of agricultural land on the other islands. Land expansion for food production, and lately also for plantation crops, is within the framework of transmigration projects. Traditionally Sumatera is the main destination for transmigration. Since the 1970s Kalimantan and later on also Irian Jaya have been included as receiving areas. It means that food production will be increasingly dependent on acid mineral soils, and acid organic soils as well.

Another important fact is that the entire food production in Indonesia is with small farmers. Even land allocation for transmigrants engaged in food production is uniformly 2 ha per family only. Furthermore, the infrastructures and delivery systems outside Java are less developed than in Java.

With the intention of overcoming those biophysical and socioeconomic constraints promptly, soil liming has been decided upon as a compulsory basal treatment to all crops, and farming by government-controlled management using a single package of high-input technology has been chartered. To make them work, production inputs and outputs are heavily subsidised. Production credit is also generously provided.

Because farm management and the opting for production technology are dictated by centralised decision-making, regional variations and economic compatibility with small farming operations are not taken into proper consideration. Consequently, the margin obtained by individual farmers is not conducive to the close observance of the credit terms, especially the pay-off schedule. The scheme may be regarded as successful in terms of gross national food production, but not necessarily so from the point of view of mitigating the economic condition of farmers.

The intended quick solution to such a multilateral problem is evidently not the right decision from two points of view: (1) sustainable soil improvement, and (2) suitability for small farms. If Indonesia was not haunted by the credo of self-sufficiency in rice, the problem of acid mineral soils management may emerge less severe. The most logical choice of using these marginal soils will be for perennial crops. Perennials are by nature suited to such kinds of soil because: (1) they are more tolerant of soil stresses, (2) they are more ready for management on the principles of agroecosystem, leading to a stable production base to support a sustainable income-producing capacity of the system, and (3) smallholdings are more readily integrated into one sizeable plantation under one management, so that together they lend themselves to more efficient use of production inputs.

The statement does not mean to advocate the exclusive use of acid mineral soils for tree crops. It is inconceivable that all farmers in those areas should become planters. The point is that the problems of acid mineral soils arise more from their use for annual crops than from their use for perennial crops.

Potential of Acid Mineral Soils

The term acid mineral soils is used only for convenience in general discussions. In fact, it is impossible to draw a common line representing the potential of all acid mineral soils. The group consists of many kinds of soil which differ greatly in their potential-determining properties. Generally speaking, their natural potential is low to very low. In prescientific agriculture shifting cultivation was most adapted to acid mineral soils in the forested humid tropics. The system uses the forest trees to restore the supply of nutrients in the topsoil by their 'pumping action.' The restoration takes place by the interaction between the rate of litter-fall and the activities of decomposing microorganisms. When the required cycle of crop–forest rotation is strictly followed, production will be sustainable and the soil safe-guarded against deterioration, although production is at a low level.

In Indonesia 40–50 million people live in areas where shifting cultivation is practiced. They occupy an area of some 2.5 million ha each year. Assuming a typical occupation period of 2 years followed by an average of 13 years of fallow, the estimated total area involved is approximately 19 million ha. In Central Irian Jaya the cultivators customarily abandon their fields after only 6–8 months and allow them to regenerate for a period of 15–20 years (Driessen et al. 1976).

The average rice grain yield of shifting cultivated fields (ladang) is estimated at 1–1.5 t/ha. Under favourable conditions shifting cultivation can be very rewarding. Yields of 3–4 t of unhusked rice/ha are not uncommon. As a rule the second rice crop yields higher than the first one, particularly so on soils under heavy forest. This is due to the more advanced state of decomposition of the soil organic matter (Driessen 1976).

Shifting cultivation in Central Kalimantan is practiced by Dayak tribes. It has a strongly traditional character, strictly regulated by complex rules inherited from generation to generation. Even today the rules are still closely observed. The general ruling is that a ladang should be abandoned when weeds start to appear in noticeable quantities. At that time the surface soil is not yet depleted of nutrients. It is even richer in available nutrients than at the beginning of cultivation. This is contrary to the general belief that ladangs are abandoned because of fertility exhaustion of the soil. Thus the reason for abandonment is the difficulty of weeding with the consequence of weeds competing with the crop for nutrients and water, and hindering the ready regeneration of the forest.

After several years of study in the ladang areas of Kalimantan and Sumatera, Driessen et al. (1976) became firmly convinced that shifting cultivation is not a primitive kind of agriculture, but is a very sophisticated system and well adapted to the prevailing social and economic conditions. Its strength lies in the fact that it makes optimal use of the limited capability of natural resources and the limited capacity of cultural resources in such a way as to cause the least damage to the environment. Thus sustainability of production functions is the strong point of shifting cultivation.

It is true that shifting cultivation is not an optimal form of land use in terms of space. As such it cannot be maintained in an economic situation in which space is a valuable commodity. Shifting cultivation, however, is not just an agricultural enterprise. It is rather a way of life. Therefore, drastic changes in or adjacent to areas of shifting cultivation, even in the name of progress, should always be avoided. In areas of acid mineral soils where the natural balance is delicately counterpoised by the natural vegetation, and where shifting cultivation has been capable of keeping the balance, drastic changes brought about by the introduction of permanent cultivation may cause the whole system to collapse.

In advancing agriculture, soil potential is the income-producing capacity of the soil which results from the controlled interaction between the inherent soil characteristics, the environment, and the package of production inputs. Permanent cultivation on acid mineral soils in Indonesia is predominantly rainfed, comprising rainfed lowland rice and rainfed upland crops (including upland rice). All cropping systems are rice-based, or at least include one rice crop in their cropping pattern. The contribution of upland rice to rice production in Indonesia is still very small. About 94.4% comes from lowland paddy fields, either irrigated or rainfed (Ismail 1984).

The best management is one which incorporates a measure of organic recycling (Sudjadi 1984). Basically it is to simulate the crop–forest rotation of shifting cultivation. Organic recycling serves several purposes: (1) recycles soil nutrients, (2) enhances microbial activity for soil health, (3) maintains favourable soil physical conditions, (4) decreases soil erodibility, and (5) improves soil moisture relationships.

A major problem in cultivating podsolic soils is water shortage. Moisture release curves indicate a volume fraction of available moisture (pF 2.5–4.2) of as low as 0.10–0.15. Although soils and plant evapotranspiration rates vary, most annual crops will suffer from drought 1–2 weeks after heavy rain (Sudjadi 1984). For better moisture storage, in addition to organic recycling, the application of rainfall harvesting techniques may be useful.

In its natural state the structure of acid mineral soils is generally good, but its resistance to mechanical disturbance is rather weak, particularly when the soil moisture content departs distinctly from the critical moisture content. This is especially true with the podsolic soils and the podsols. Furthermore, the range of the critical moisture content of both soils is narrow, so that a nominal shift in soil moisture content may already mean a significant departure from the critical soil moisture content. Therefore, soil cultivation during the wet season should be carried out with special care. Otherwise it may compact the soil and cause drainage problems on level terrain, or water loss and erosion problems on sloping land. Soil cultivation during the dry season may disintegrate soil aggregates which means structure deterioration and the subsequent compaction of the surface soil by the impact of raindrops at the commencement of the rainy season. As a matter of fact those soils are not arable. This is one of the reasons why the soils are better suited to growing perennials.

A most widespread soil constraint is deficiency or low bioavailability of phosphorus. Experiments with corn on a Typic Palaeudult in South Sumatera showed that crop response to P application increased with the rise in the saturation of the P-fixing capacity of the soil (Hartadi 1988). V-A mycorrhiza inoculation had been tried by pot experiments to study the effect on bioavailability of P in acid mineral soils. Rock phosphate was used as the source of P. The treatment on upland rice grown on a Plinthic Ferralsol greatly increased vegetative growth and P uptake at the flowering stage. A labelled ^{32}tricalciumphosphate was used in the experiment with sugarcane on an Orthic Acrisol and a Plinthic Ferralsol. The inoculation resulted in an increased total uptake of P and efficiency of the use of fertiliser P (Hartadi 1988).

There was no interaction between the kind of P fertiliser used and liming in terms of effect on dry matter production of sugarcane grown on an Ultisol of Cintamanis (South Sumatera), Ketapang (Lampung) and Pleihari (South Kalimantan). TSP tended to increase dry matter production and available phosphate in the soil. In contrast, liming up to a rate of 3.2 times the meq% of exchangeable Al (in tons per hectare) tended to lower dry matter production and available phosphate in the soil (Suyanto et al. 1983). Another experiment conducted in West Java also on an Ultisol with an Al saturation of 71% demonstrated that soil liming up to 4 t/ha had no effect on corn provided the soil had been treated before with 40 kg P/ha. On this soil, liming did have an effect on soybean. The application of higher doses of P was restricted by the uncertain supply of water (Sudjadi 1984).

To get an idea about the availability of Cu and Zn in acid mineral soils, soils samples had been collected to represent the soils of the northern part of Sumatera, West, Central and South Kalimantan, and South and Southeast Sulawesi. About half of the samples had extractable Cu of <0.5 ppm and another half had <1 ppm extractable Zn. Using lowland and upland rice, corn, soybean, groundnut and mungbean as test plants, it was shown that liming tended to decrease extractable Cu and Zn with the consequent increase of plant response to applied Cu and Zn (Soepardi et al. 1988). Liming also speeds up organic matter decomposition. Since the soils are naturally poor in organic matter, this effect of liming should be regarded as detrimental to the already low soil productivity.

These findings lead to the suggestion that liming materials be used as a fertiliser supplying Ca or Ca plus Mg (if dolomitic material is used) nutrients, rather than as lime to correct soil acidity. Many of the soils consist of clay with variable charge, so that liming is ineffective to raise soil pH.

Even to establish a legume crop on an acid soil, liming is not as essential as one is inclined to believe. Some legumes are more acid tolerant than others, although in an acid medium they do not form root nodules. Nodulation can be induced by Ca in the rooting zone. One technique to ensure the availability of Ca in the rooting zone is by seed pelleting with lime or rock phosphate powder. It can also be done by filling each plant hole with a handful of partly burned rice husk mixed with a little lime. Before being planted the legume seeds are inoculated with rhizobium. Nodulation will be secured for the entire growing period of the legume plant. The recent development in rhizobium genetics reported at the Biotechnology Interuniversity Centre of the Gadjah Mada University will surely be of great advantage to acid mineral soils management. Rhizobium strains of broad pH spectrum covering the range of low pH are now available (Jutono 1983, 1988).

Soil Management System

From field trials conducted throughout Indonesia the following results may be highlighted. For sustained agricultural production it is essential to incorporate the following practices into the cropping systems:

1. *Maintain year-round crop cover.* By this method the soil will be shaded and protected from strong insolation and the impact of raindrops. This minimises soil evaporation, daily fluctuation of soil temperature, erosion and leaching. It also provides farmers with more harvest which in turn increases farm productivity and income.

2. *Increase and maintain soil fertility.* This practice interacts with the first mentioned practice. By applying well balanced fertilisation with P as the key nutrient, a vigorous crop growth securing high yield will be promoted. This, in turn, increases the availability of crop residues which will do good to the third practice.

3. *Return crop residues.* Maintaining the level of soil organic matter is essential, as has been said previously.

4. *Apply soil and water conservation measures.* If the three previously mentioned practices are considered not sufficient because of particular land conditions, other complementary practices such as contour planting, strip cropping and terracing should be used.

5. If some mechanised land preparation is to be done, it may best be carried out with disc plough and disc harrow and at the same time it should receive the benefit of the addition of a basal dressing with rock phosphate. By disc ploughing and harrowing soil disturbance can be kept to a minimum and topsoil inversion can be avoided. The basal dressing may be complemented with green manure. Pilot trials conducted in Onembuto (Southeast Sulawesi) on an Ultisol suggested a basal dressing of 750 kg rock phosphate and 6 t leguminous green manure per ha is sufficient (Sastrosoedarjo 1983).

Research and testing during the last 5 years have shown that the introduced cropping pattern with a relay-intercrops system of corn + upland rice + cassava + groundnut-cowpea (or rice bean) gave consistent results in 10 different sites. The productivity and economic potentials were higher compared with the farmers' existing cropping patterns (Ismail 1984).

Further Research Priorities

Acid mineral soil management in Indonesia faces four major problems: (1) use constraints inherent in the soils, (2) smallness of farms as production units, (3) less developed agri-support and agri-milieu, and (4) emphasis of national policy on rice (food) which limits room for options. These problems should be clearly understood to define sound objectives of acid mineral soils development, which in turn direct the setting of priorities of research on the most relevant aspects.

The objectives of acid mineral soils development are: (1) increased yields without the necessary absolute dependence on high-input technologies, (2) improved soil productivity the sustainability of which can be achieved through practices compatible with small farm operations, and (3) introduction of appropriate technologies to open up appropriate opportunities to small farmers for produce diversification and for producing higher-priced commodities. The objectives point to the development of low-input technologies for small farms producing food on marginal soils which imply site specificity. They are basically transformations of soil biotechnology into a combination of farm practices.

To this end research should be carried out on benchmark sites for easy transfer to similar sites, and the priorities of research should be set on the three most important components of soil biotechnology. They are: (1) securing nitrogen supply to the plant–soil system through the enhancement of biological N_2 fixation, (2) improving phosphate bioavailability in the soil through the establishment of an effective symbiotic association of plant roots and mycorrhizae, and (3) effective control of aluminium toxicity to plants by chelation of active soil aluminium using readily decomposable crop residues or off-farm organic wastes as the source of ligands.

Research on the three components will subsequently lead to the development of suitable cropping patterns for each specific land system. By the three components, farming systems will become self-contained to a significant degree. It is important that small farmers should not be too much controlled by external production inputs as they do not possess the needed power, ability or opportunity to take the necessary counter-measures whenever the situation demands correction.

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Appendix follows

Appendix. Soil chemical characteristics of some acid humid tropical soils in Indonesia.

Depth	pH		Texture (%)		Organic	P–Bray 1	CEC–soil (meq/100g)				Exchangeble acidity				Location
(cm)	H_2O	KCl	C	S	C (%)	(pp P)	Ca	Mg	K	Na	Al	H	pH 7.0	Eff.	
								0.6	0.15	.03	4.7	1.0	23.8	8.1	Rimbo Bujang,
0–17	4.4	3.8	44.3	6.1	4.8	6.6	2.6	0.08	0.06	.02	4.2	0.8	19.9	7.2	Jambi
17–41	4.8	3.9	50.3	3.0	1.2	tr	2.0	0.06	0.04	.01	3.2	0.2	19.4	5.4	
41–67	4.8	3.9	44.7	3.5	0.8	tr	1.9	0.07	0.04	.04	4.8	0.6	16.9	7.6	
67–92	4.7	3.9	41.5	3.6	0.8	tr	2.0	0.04	0.02	.04	5.2	0.5	18.6	7.1	
92–120	4.8	4.0	47.8	1.6	0.8	tr	1.3	0.2	0.03	0.04	1.7	0.5	11.3	4.9	
0–15	4.6	4.1	13.8	69.3	1.6	15.9	2.4	0.2	0.01	0.02	2.5	0.7	10.9	5.2	
15–40	4.7	4.1	27.2	60.7	1.5	3.1	1.8	0.2	0.01	0.01	2.2	0.7	10.9	4.6	
40–80	4.7	4.1	37.0	44.9	1.1	tr	1.5	0.2	0.01	0.01	2.3	0.6	10.0	4.2	
80–110	4.9	3.9	42.0	27.1	0.5	tr	1.1								
								0.1	0.1	0.1	6.3	0.7	26.4	7.5	Sitiung, West
0–4	4.3	3.6	–	–	3.1	–	0.2	0.1	0.1	0.1	6.3	0.7	22.3	7.5	Sumatra
5–22	4.7	3.7	–	–	1.6	–	0.2	0.1	0.1	0.1	5.5	0.4	20.0	6.3	
22–45	4.9	3.8	–	–	0.8	–	0.1	0.1	0.1	0.1	8.4	0.6	20.2	9.4	
45–82	4.9	3.9	–	–	0.6	–	0.1	0.1	0.1	0.1	9.1	0.6	25.0	10.1	
82–117	4.9	3.8	–	–	0.3	–	0.1	0.1	0.1	0.1	4.5	0.2	23.4	5.2	
117–200	5.0	3.7	–	–	0.2	–	0.2								
								2.4	0.1	0.1	6.9	0.9	27.8	17.4	Pasir Pangarayan
0–25	4.7	3.7	50.5	2.6	2.7	2.1	7.0	1.7	0.1	0.1	7.4	0.9	34.4	14.2	Riau
25–60	4.6	3.7	53.2	3.8	2.8	1.1	4.0	0.8	0.1	0.1	8.9	0.9	28.9	13.2	
60–75	4.6	3.7	71.8	2.0	1.9	0.8	2.3	0.9	0.1	0.1	11.6	0.8	31.5	15.7	
75–100	4.6	3.9	71.6	2.0	1.2	0.4	2.2	0.7	0.1	0.1	15.9	1.1	32.6	19.6	
100–120	4.7	3.9	72.2	2.3	0.9	0.4	1.7								
								4.4	0.9	0.2	7.1	0.6	36.4	20.9	
0–3	4.9	3.9	37.7	44.2	4.2	3.2	7.7	2.1	0.4	0.2	15.9	0.5	36.7	24.5	
3–20	4.8	3.7	43.8	46.9	1.9	2.0	5.6	1.7	0.1	0.2	20.2	1.6	37.1	26.8	
20–70	4.4	3.7	61.0	26.9	1.0	tr	3.0	1.6	0.1	0.2	14.8	0.5	29.3	19.3	
70–100	4.2	3.7	32.8	58.4	0.5	tr	2.1								
								1.7	0.3	0.2	1.2	0.2	11.8	6.4	Batu Raja, South
0–13	4.7	4.0	18.2	40.7	2.0	5.6	2.8	0.4	0.1	0.2	2.8	0.5	10.1	6.1	Sumatra
13–50	4.9	4.0	35.9	31.9	0.7	5.2	2.1	0.3	0.1	0.2	3.9	0.5	9.9	6.4	
50–72	4.9	3.8	40.2	29.6	0.4	4.2	1.4	0.3	0.2	0.2	6.8	0.8	11.5	9.7	
72–115	4.7	3.8	44.9	26.1	0.2	4.7	1.4	0.4	0.2	0.2	6.9	0.8	11.8	9.9	
115–130	4.5	3.9	43.8	28.3	0.1	5.0	1.4								
								0.6	0.1	0.1	4.2	0.4	10.6	7.1	East Kalimantan
0–20	4.1	3.4	31.3	49.7	3.9	6.8	1.7	0.2	0.1	0.1	4.8	0.5	9.0	7.1	
20–53	4.3	3.7	37.6	47.2	0.2	tr	1.4	0.2	0.1	0.1	4.1	0.5	9.9	6.4	
53–77	4.2	3.6	46.3	34.7	0.1	tr	1.4	0.3	0.1	0.1	4.8	0.5	10.2	7.1	
77–115	4.4	3.8	46.9	31.4	0.1	tr	1.3	0.3	0.1	0.1	4.9	0.4	8.1	6.9	
115–150	4.4	3.7	28.3	54.9	tr	tr	1.1								

Utilisation of Acid Soils in the Tropical and Subtropical Zones of China

Liu Gengling*

Abstract

The tropical and subtropical zones of China cover 2 030 000 km^2, or 21% of the total land area. Soil types in this region vary from Latosol, lateritic red soil, red soil to yellow soil, most of which are acid soils.

With high atmospheric temperature and rainfall and abundant varieties of plants and animals, this acid soil region is not only the country's main production centre of tropical fruits and timber, but also a major production base for grain, industrial crops, forage and other livestock products. Farmland occupies 2.8 million ha of this region, representing 28% of the country's total arable land. Annual grain output is 42–44% of the country's total yield, and annual meat production is 66%. Other products such as edible oil, sugar, tea and sericulture play important roles in the development of the national economy.

Introduction

About 42% of the farmland in the tropical and subtropical regions is low-yield soil with 11.7 million ha of this cropland estimated to be in need of improvement. Presently 1 ha of this low-yield soil can produce only 3250 kg of grain annually, so the potential to increase yields is quite high.

The region has 55 million ha of forestland, with 3100 million m^3 of timber. On the average, each hectare has only 56.7 m^3 of timber, so the tree production is low. Besides, there are 50 million ha of shrubs and remnant forest, 53 million ha of wasteland and waste hillsides. Although only about 50% of the region has been exploited, this wasteland has a high potential for development.

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Natural Characteristics of the Red Soil Region

In the past the disadvantages of tropical and subtropical red soil were stressed, such as high acidity, clayish texture, lack of nutritional elements for plants, unfavourable structure and low productivity. However, these areas do possess good water and weather conditions, and plentiful varieties of plants and animals, so the local environment has particular advantages. We should be aware of these positive characteristics and formulate measures and plans in line with local conditions to make full use of available resources. Thus, we can improve red soil, raise its productivity, and also encourage the development of plantation and animal husbandry. As a result, economical and social efficiency can be obtained. For example, in this region, temperatures and hours of sunlight in summer and autumn are high. We may adapt double-cropping of rice to fully utilise its rainfall in spring and summer and light and heat conditions from June to September. In many places, with double rice cropping, 1 ha can produce 15 t of rice, producing cash income for the farmers. The yields and quality of oilcrops, maize, sugarcane and jute are high and significant.

In addition, during winter there is a long non-frost period, high temperature, high soil humidity and low evaporation. We may grow oilcrops, legume crops, barley and wheat and forages and green manure plants to utilise light, water and heat conditions in winter and spring. Especially in spring, this region is characterised by rain and cloudy conditions, thus causing high humidity and low levels of sunlight. These conditions are particularly favourable for tea, vegetables, green and juicy forage. With higher production of forages, it is possible to increase the number of ruminant animals. And with rich water resources, this region could produce more aquatic plants and develop its fishery.

In acid soil areas destruction of natural vegetation and soil erosion are severe, resulting in low productivity, low tolerance and low buffering effects of soil. Moreover, in these areas, weather is changeable with frequent storms and extremely hot and dry weather in summer. So gradually the soil texture and structure deteriorates. Therefore, increasing vegetation cover is critical to the improvement of acid soils and to avoidance of the deleterious effects of severe weather.

There are two ways in which farmers can utilise acid soil:

(1) Some areas have better water conditions and flatter land. Farmers change this land into paddy fields and keep a layer of water to protect the soil. When planting rice, they spread large amounts of organic fertiliser in the field in combination with application of phosphate fertiliser and lime. After 4–5 years, this field can change into a high-yielding paddy field. On occasion supplements of Zn, K, Mn, Mg and B need to be applied.

(2) In dryland areas with poor water conditions and steep slopes, farmers use the land to cultivate wheat, sweet potato, legume crops and maize, etc. The field is usually covered with rice straw and organic fertiliser. When growing crops, farmers apply manure, ash and phosphate fertiliser. After 4 or 5 years, this acid soil can also change into a high-yielding soil.

To utilise large amounts of wasteland and hillsides, people are encouraged to restore natural vegetation and establish good ecological environments. In some areas with better natural conditions, the alternative ways are to develop forestry and pastureland or to plant economical fruit trees.

In the process of restoring natural vegetation and establishing ecological environments, we should particularly concentrate on the breeding, cultivation and protection of herbal plants and shrubs, and intercrop trees, herbs and shrubs.

Herbal plants and shrubs are plentiful and have many uses. Some can be used for animal feeds and diets, for fertiliser and firewood, and for soil enrichment through nitrogen fixation. Others protect soil and prevent soil erosion. These plants produce large numbers of seeds, growing and multiplying rapidly. They also possess strong resistance to cold, heat and soil deficiency and quickly cover the soil surface. As a result, they often act as precursors of forestry. If these plants multiply rapidly soil moisture content and relative humidity in the air will rise significantly, and soils temperature will be affected. According to observations at Qiyang Red Soil Experimental Station of CAAS in 1987, the maximum temperature of barren surface in acid soil could reach 56°C, but only 35°C on grassland, a difference of 21 C°. Twenty-two observations from May 17 to October 12, 1987, showed that the soil temperature of barren land at a depth of 10 cm ranged from 12.4° to 28.4°C, fluctuating 16°C, while soil temperature of grassland changed from 21.0°–27.0°C, fluctuating 6°C. These differences explain the stability and buffering effects vegetation has on the soil.

The vegetation's stabilising and buffering effects on the soil are closely related to the fact that vegetation changes solar energy transmission. The vegetation intercepts direct solar radiation which can only be transmitted into soil through vegetation and air in the vegetation. Because air is not a good conductor of heat, extreme heat current can be avoided and soil temperature can be stabilised.

Vegetation restoration and afforestation play very important roles in acid soils. According to our practical experiences, afforestation follows several stages. Afforestation should be done on the basis of soil preservation; soil preservation on the basis of grass cultivation; and grass cultivation on the basis of closing the hills and mountains. The Qiyang Red Soil Experimental Station of CAAS conducted an experiment of closing the hills and mountains at Qiyang and Lingling, Hunan Province. After closing the area for 5 months, vegetative output increased by 75 000 kg/ha; and the cover ratio rose to 90%. After a 5-year closure, more than 140 varieties of plants were growing and evergreen trees reached 7 m in height and 25 cm in diameter. Many humidity-enduring plants appeared one after another. Therefore, closing hills and mountains can not only provide farmers with firewood, but also ensure the establishment of forest which produces wood, provides stream protection and enhances the landscape.

The acid soil region has wide hilly and mountainous areas. With flat topography, these areas are outstanding bases to establish artificial pastureland and raise ruminant animals. The main obstacles for growing forage are cold temperatures in early spring, high temperatures in summer, drought in autumn and low soil fertility. To produce adequate forages, we must select proper forage varieties that have high resistance to cold and can grow rapidly in early spring. Suitable fertiliser must be applied, especially phosphate fertiliser and lime. When developing an overall plan for pastureland, sunshading tree belts or animal enclosures should be provided for animals to protect them from rain and heat in summer. To preserve rain in spring and summer and avoid drought in autumn, we once used a system of shallow ditches connected to pits to preserve the water. This technique resulted in a reduction in surface runoff, increasing soil water content and increased growth of vegetation. On the basis of our observations, this technique can increase vegetative output by 30–50% and is especially favourable for shrubs and trees.

Overall, the acid soil region is characterised by high rainfall and serious soil erosion. If we do not comply with natural laws, the existing situation in the acid soil region will inevitably be repeated bringing on serious problems. Since this region has high rainfall and temperatures we hope to find suitable means to restore vegetation and maintain a balanced ecological environment. We are confident about the future development of this region.

Management of Soil Acidity in Malaysia

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Abstract

Experiments were conducted to evaluate the effects of application of ground magnesium limestone (GML) on Bungor (Typic Paleudult) and Munchong (Tropeptic Haplorthox) series soils to maize and peanut. Six levels of GML were applied to Bungor series soil viz., 0.0, 0.5, 1.0, 2.0, 4.0, and 8.0 t GML/ha, while on Munchong series soil four levels of GML were applied viz. 0.0, 0.5, 1.0 and 2.0 t GML/ha. The results obtained showed that application of GML improved yields of maize grown on both soils, with the optimum rate of 2.0 t/ha for Bungor series soil and 1.0 t/ha for Munchong series soil. Calcium and magnesium were found to be deficient in maize planted on unlimed Bungor series soil and these deficiencies were corrected with the application for GML at the rate of 1.0 t/ha for Ca and 2.0 t/ha for Mg. However, application of GML at 4.0 t/ha or higher induced Zn deficiency while application at 8.0 t/ha induced Cu and Mn deficiencies.

Application of GML at 0.5 t/ha was sufficient to increase the yield of peanut to >90% maximum yields for both soils. However tissue analysis showed that Ca and P were deficient in peanut grown on Munchong series soil indicating that the rates of Ca and P applied were insufficient.

Soil analysis showed that GML application increased soil pH, reduced exchangeable Al and increased exchangeable Ca in both soils. Application of 1.0 t/ha GML on Bungor series soil increased the soil pH to 5.0, but needed at least 2.0 t/ha to maintain this pH up to 2 years. In Munchong series soil, application of GML at 0.5 t/ha did not affect soil pH or exchangeable Al.

Introduction

The upland soils of Malaysia are generally highly weathered and belong to the order Ultisol and Oxisol which are characterised by high acidity, low CEC, low base saturation and high Al concentration (Tessens and Shamsuddin 1983). As such most of these soils are currently utilised for plantation crops, especially rubber and oil palm which are known to be acid tolerant. For most other crops, which are not acid tolerant, these soils offer little chance of success due to severe limitations associated with soil acidity and low P availability which restrict growth and production. Earlier work by MARDI (1979) has indicated that P and liming are the major soil requirements for maize, soybean, peanut and mungbean grown on mineral soils, while P, Mo, K and liming are required for pasture legumes. Yields of peanuts, soybean and maize were adversely affected when Al saturation exceeded 65, 45, 15 and 25% respectively (MARDI 1979, 1980). Foster et al. (1980) suggested that for a reasonable growth of these above-mentioned crops, the soil must be limed such that Al saturation should be below the respective levels mentioned. Sharifuddin and Dynoodt (1985) reported that for sorghum grown on four Ultisols and two

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Oxisols, the Al saturation must be reduced to less than 40% to attain more than 80% relative dry matter yield. Shamsuddin and Tessens (1983) indicated the dominance of Al in soil acidity of acid Malaysian soils, and lime requirements of these soils could be derived by multiplying the base needed to raise the pH to 5.5 by a factor of 1.3.

However, rubber smallholders need to use these soils to grow some annual crops to supplement their income during the first 3 years of immature rubber plantings. Some of these soils which occur on undulating and slightly sloping terrain can also be utilised for food crop production. In 1986, a project entitled 'The Management of Soil Acidity for Sustained Crop Production' was started. This project was carried out by Universiti Pertanian Malaysia (UPM), Rubber Research Institute of Malaysia (RRIM) and University of Queensland (UQ), funded by the Australian Centre for International Agricultural Research (ACIAR). The objectives of this experiment were to assess the response of corn and peanut to application of ground magnesium limestone (GML) and gypsum, and to evaluate the long-term agronomic benefit of these soil amendments. This paper reports some of the results obtained from the studies on GML application on Ultisols and Oxisols conducted by UPM and RRIM respectively.

Materials and Methods

Soil Properties

Two of the soils used in these studies were Bungor (Loamy Kaolinitic Typic Paleudult) and Munchong (Clayey Kaolinitic Tropeptic Haplorthox) series. Both soils are acidic in nature, high in exchangeable Al and low in CEC, exchangeable bases and available P (Table 1). These two soils are widespread in Peninsular Malaysia and are utilised mainly for rubber and oil palm cultivation.

Treatments

In the first experiment on Bungor series soil, ground magnesium limestone (GML) was applied at six levels, viz at 0, 0.5, 1.0, 2.0, 4.0, and 8.0 t/ha, incorporated in the top 15 cm. Sweet maize (var. Thai supersweet) and peanut (var. Matjam) were grown alternatively starting with sweet maize in an annual cropping system.

Table 1. Chemical properties of Bungor and Munchong series soils (top 15 cm).

Soil properties	Soil series	
	Bungor	Munchong
$pH(H_20)$	4.7	4.2
pH (KCl)	3.8	3.8
Exch. Al [cmol (+)/kg]	3.3	2.8
CEC [cmol (+)/kg]	13.8	3.9
Exch. K [cmol (+)/kg]	0.22	0.13
Exch. Ca [cmol (+)/kg]	1.05	0.20
Exch. Mg [cmol (+)/kg]	0.30	0.06
Avail. P (mg/kg)*	4.1	0.8

*By Bray & Kurtz No. 2

The first crop of maize was planted 4 weeks after GML application at a distance of 75 x 25 cm, giving a population of 53 333 plants/ha. Fertiliser was applied at the rate of 120 kg N, 100 kg P, and 150 kg K/ha using urea, triple superphosphate, and muriate of potash. All fertilisers were applied as basal dressing except for urea which was applied 50% as basal and the other 50% as side dressing 1 month after planting. For the second crop of corn, fertiliser rate used was 100 kg N, 30 kg P and 50 kg K/ha, while for the third group fertiliser was applied at the rate of 120 kg N, 100 kg P and 50 kg K/ha. The first crop of peanut was planted uninoculated at a distance of 50 x 10 cm. It was not fertilised as we felt that the residual value of the high fertilisation rate of the first crop of maize was sufficient. For the second crop of peanut, fertilisation was done at the rate of 22.5 kg N, 29 kg P and 56 kg K/ha.

In the second experiment on Munchong series soil four rates of GML were applied, i.e. 0, 0.5, 1.0 and 2.0 t/ha. Here the crops (maize and peanut) were grown as intercrops in immature rubber planting, starting with peanut as the first crop in a sequence of peanut (var. local Spanish), maize (var. Thai supersweet), maize (var. Sg. Buloh hybrid 16), maize (var. Sg. Buloh hybrid 16) and peanut (var. Matjam). Fertilisation for both crops of peanuts was done at the rate of 45 kg N, 30 kg P and 56 kg K/ha, while maize fertilisation for all the three crops was at the rate of 124 kg N, 33 kg P and 63 kg K/ha. Sulfate of ammonia, triple superphosphate and muriate of potash were used as the fertiliser sources. Phosphorus fertiliser was applied as basal dressing, while N and K were applied 50% as basal and 50% as top dressing 2 weeks after planting. The peanut seeds were inoculated with RRIM rhyzobium compost strain 32-HI+NC 83.

In both experiments, GML was applied only once at the beginning of the experiment and the first crop planted about 1 month after GML application. After harvest, crop residue was left in the plots and ploughed in at the next planting season. All crops were grown under rainfed conditions.

Results and Discussion

Yield Responses

Bungor Series Soil: The effects of GML application on the relative yield of fresh cob of sweet maize grown on Bungor series soil is shown in Figure 1. The first crop showed an increasing trend with higher rates of GML application, and the highest yield was obtained from the application of GML at 8.0 t/ha. To obtain a relative yield of >90% of maximum, a liming rate of 2.0 t/ha was required for all the three maize crops. But in the second maize crop, liming at >4.0 t/ha reduced the yield to less than 90%, while in the third crop the yield dropped to less than 90% at the liming rate of 8.0 t/ha. The highest fresh cob yields obtained for the first, second and third crops were 8.31, 8.05 and 8.80 t/ha respectively. The cumulative yields for 0.0, 0.5, 1.0, 2.0, 4.0 and 8.0 t/ha GML application were 13.15, 17.86, 20.56, 24.37, 21.97 and 21.68 t/ha respectively. The unlimed plots managed to yield only 58.6, 45.6 and 52.3% of maximum yields of the first, second and third crops respectively.

The responses of peanut (relative yield of fresh pods) to GML application on Bungor series soil are shown in Figure 2. The application of 2.0 t/ha GML gave the highest yields for both crops, i.e. 2.92 and 2.31 t/ha for the first and second crops respectively. To obtain a yield of >90% of maximum, liming at the rate of 1.0 and 2.0 t/ha was required for crops one and two respectively. The unlimed plots were able to produce 79 and 64% of maximum yield in the first and second crop respectively, confirming a higher tolerance of peanut to soil acidity than sweet maize (Foster et al. 1980). The culmulative yields for 0.0, 0.5, 1.0, 2.0, 4.0 and 8.0 t/ha GML application were 3.81, 4.06, 4.46, 5.23, 5.01 and 5.09 t/ha respectively.

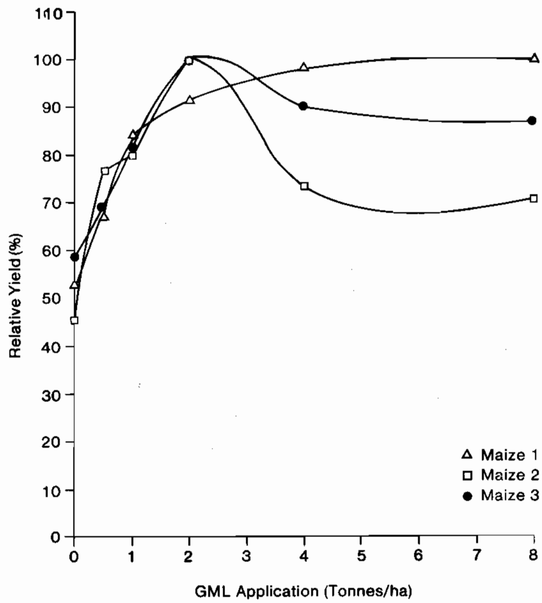

Fig. 1. Effects of GML application on relative yield of maize grown on Bungor series soil.

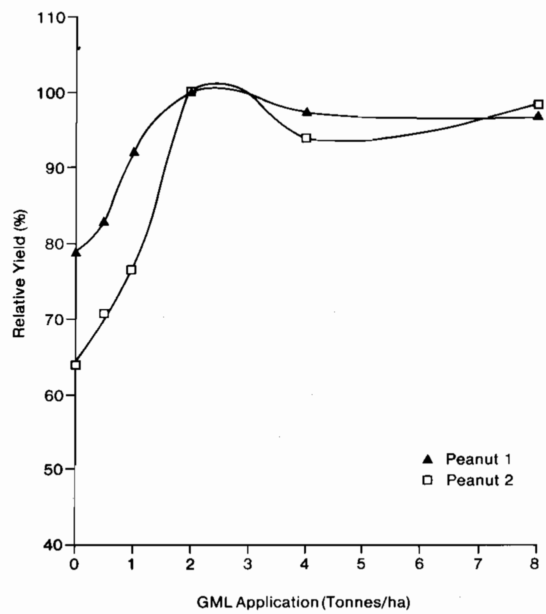

Fig. 2. Effects of GML application on relative yield of peanuts grown on Bungor series soil.

Munchong Series Soil: Five crops were successfully established on Munchong series soil, but the second crop (maize) failed due to severe drought during the planting season.

The relative grain yields of maize grown on Munchong series soil as affected by the application of GML are shown in Figure 3. For both crops, application of 1.0 t/ha of GML or more resulted in the yields of >90% of maximum. The maximum yields obtained were 2.75 and 3.32 t/ha for the first and second crops of maize respectively.

The response of peanut to GML application as measured by relative yield of fresh pod weight is shown in Figure 4. The first crop of peanut did not respond significantly to the application of GML. But the second crop responded significantly even to the lowest rate of application at 0.5 t/ha. For both crops application of 0.5–2.0 t GML/ha resulted in the yield levels of >90% of maximum yields. The highest yields for the first and the second crop were 4.47 and 2.97 t/ha. The highest cumulative yield was obtained from the application of 1.0 t GML/ha, which gave a yield of 7.22 t of fresh pod.

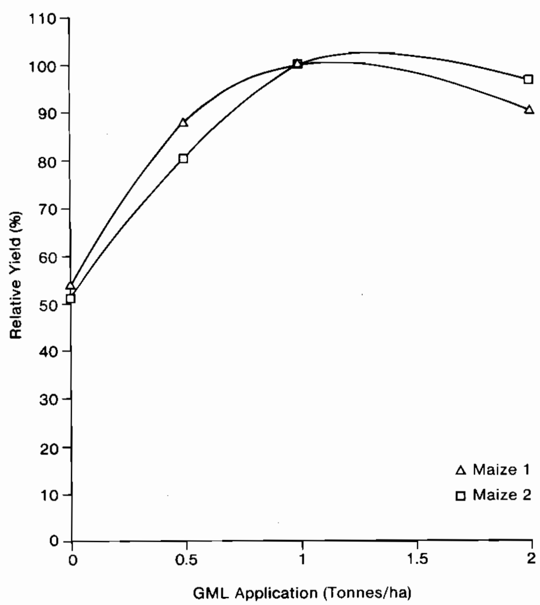

Fig. 3. Effects of GML application on relative yield of maize grown on Munchong series soil.

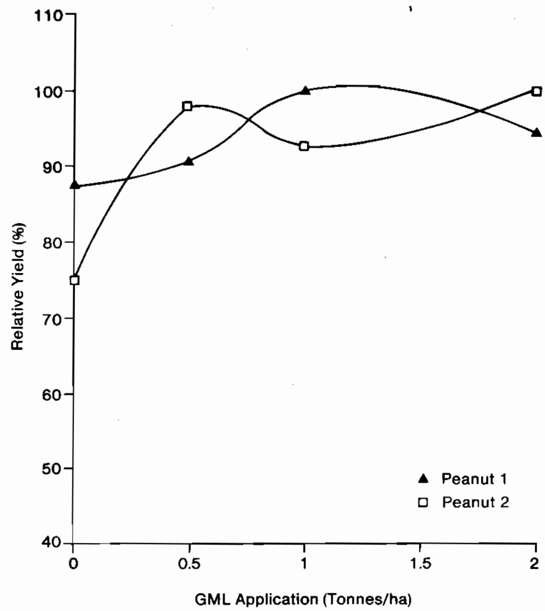

Fig. 4. Effects of GML application on relative yield of peanuts grown on Munchong series soil.

Plant Analyses and Interpretations

The earleaf of maize at silking and the youngest fully expanded leaf (YFEL) of peanut at flowering were sampled and used as the index leaves.

The nutrient concentrations in the earleaf of the second crop of maize grown on Bungor series soil are shown in Table 2. The results indicate that the plants were adequate in N, P, K, and Fe. However, the Ca level at 0.0 t/ha, Mg level at <2.0 t/ha, Cu and Mn at 8.0 t/ha and Zn at >4.0 t/ha were found to be critical or less than adequate (Melstead et al. 1969; Walsh and Beaton 1973). These results imply that without liming the plants were deficient in Ca and Mg. Liming with GML at 0.5 t/ha eliminates Ca deficiency, but Mg deficiency was only eliminated when 2.0 t GML/ha was applied. Higher rates of applications caused micronutrient deficiencies, where application at >4.0 t/ha caused Zn deficiency and at 8.0 t/ha caused Cu and Mn deficiencies.

For peanut grown on Bungor series soil, the nutrient concentrations in the YFEL of the first crop are shown in Table 3. These data indicate that the plants were adequate in Ca, Mg, Zn and De, but less than adequate in N for 0.0 t/ha, P and K for all treatments, and Mn for treatment >4.0 t/ha (Reuter and Robinson 1986). Phosphorus and potassium deficiencies may be due to inadequate fertiliser given to this crop where no fertiliser was given due to the expected residual effect of the previous fertiliser given to the first crop of corn. Application of GML at 4.0 and 8.0 t/ha caused Mn deficiency.

The plant tissue analysis of the first crop of peanut grown on Munchong series soil is shown in Table 4. These data indicate that N, K, Mg, Cu, Zn, Mn, and Fe were sufficient for all treatments. However the plants were deficient in P and Ca in all treatments, indicating that the GML treatment and the rate of P in the fertiliser formulation were inadequate for peanut grown on that soil.

The nutrient concentration in the earleaf of maize (fourth crop) grown on Munchong series soil is shown in Table 5. The crop was sufficient in N, P, K, Ca, Mg, Cu, Mn, and Zn for all treatments, but showed toxic levels of Fe in the unlimed plot which was alleviated by the application of GML at 0.5-2.0 t/ha.

Effects on Soil Properties

Bungor Series Soil: Thirty days after GML application, the pH of the topsoil had increased to 5.8 with the application of 8.0 t/ha, while the pH of the plot receiving 1.0 t GML/ha was only 4.4. After 2 years only the plots which received >2.0 t/ha GML had the pH of about 5.0 or higher (Figure 5).

Figure 6 shows the changes in exchangeable Al resulting from the application of GML. After 30 days of GML application, the amount of exchangeable Al was reduced to <50% of the original value, and at 8.0 t/ha the exchangeable

Table 2. Nutrient concentrations in earleaf of maize grown on Bungor series soil.

Element	Treatments (GML/ha)					
	0.0	0.5	1.0	2.0	4.0	8.0
N (%)	2.92	3.40	3.24	3.10	2.90	3.00
P (%)	0.28	0.31	0.32	0.31	0.33	0.36
K (%)	2.58	2.67	2.70	2.49	2.49	2.14
Ca (%)	0.31	0.44	0.58	0.60	0.67	0.72
Mg (%)	0.11	0.13	0.17	0.24	0.30	0.37
Cu (mg/kg)	10	9	11	11	9	7
Zn (mg/kg)	22	26	26	23	19	19
Mn (mg/kg)	36	42	55	35	32	16
Fe (mg/kg)	122	139	146	181	107	97

Table 3. Nutrient concentrations in YFEL of peanut grown on Bungor series soil.

Nutrient	Treatments (GML/ha)					
	0.0	0.5	1.0	2.0	4.0	8.0
N (%)	3.12	3.55	3.64	3.71	3.61	3.83
P (%)	0.19	0.20	0.20	0.21	0.20	0.20
K (%)	1.99	1.77	1.83	1.73	1.65	1.60
Ca (%)	1.41	1.56	1.71	1.57	1.76	1.95
Mg (%)	0.32	0.38	0.44	0.45	0.51	0.56
Cu (mg/kg)	5.50	4.00	4.50	4.00	3.50	3.50
Zn (mg/kg)	48	40	39	35	30	28
Mn (mg/kg)	117	70	78	57	39	38
Fe (mg/kg)	116	60	60	80	59	52

Table 4. Plant tissue analysis of peanut grown on Munchong series soil.

Element	Rate of GML application (t/ha)			
	0.0	0.5	1.0	2.0
N (%)	4.17	4.00	4.10	4.10
P (%)	0.19	0.18	0.19	0.19
K (%)	3.12	3.07	3.25	3.11
Ca (%)	1.14	1.16	1.20	1.16
Mg (%)	0.42	0.47	0.50	0.53
Cu (mg/kg)	13	12	12	12
Zn (mg/kg)	44	42	40	38
Mn (mg/kg)	532	469	308	316
Fe (mg/kg)	1 511	893	1 077	1016

Table 5. Plant tissue analysis of maize grown on Munchong series soil.

Element	Rate of GML application (t/ha)			
	0.0	0.5	1.0	2.0
N (%)	3.18	3.27	3.30	3.31
P (%)	0.30	0.30	0.30	0.30
K (%)	2.54	2.44	2.45	2.38
Ca (%)	0.44	0.46	0.50	0.49
Mg (%)	0.14	0.17	0.19	0.24
Cu (mg/kg)	8	8	8	8
Zn (mg/kg)	21	21	20	21
Mn (mg/kg)	159	188	134	104
Fe (mg/kg)	451	130	121	126

Al was reduced to negligible amounts. The exchangeable Al decreased further in samples taken 90 days after application. These decreases in exchangeable Al even in the unlimed plot may be due to the high P fertiliser application given to the first crop of corn. Samples taken at 210 days after application showed an increase in exchangeable Al for all treatments except at 8.0 t/ha. These increases continued to be observed up to 450 days after application for the plots which received 2.0 and 4.0 t GML/ha. After 450 days, all treatment except 8.0 t/ha showed a decrease in exchangeable Al. Generally after about 2 years, exchangeable Al was about the same level as at 1 month after application, except for the plots which received 8.0 t/ha where exchangeable Al remained negligible.

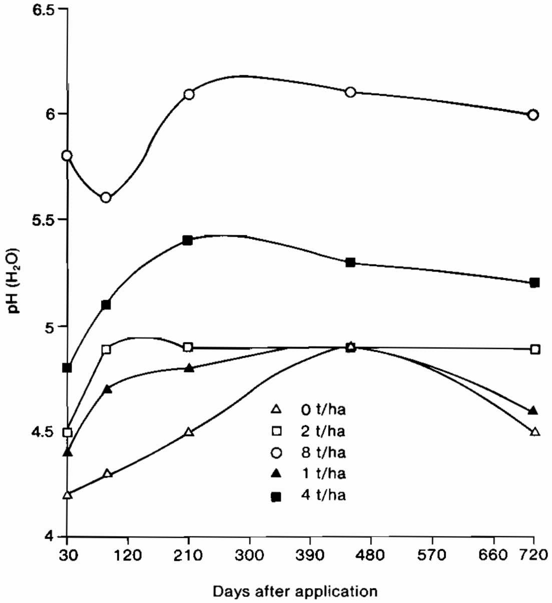

Fig. 5. Effects of GML application on pH of Bungor series soil.

Application of GML increased the Ca status of the soil. After 1 month, application of 8.0 t/ha increased the exchangeable Ca to 2.0 cmol(+)/kg and at the third month this value had increased to 4.3 cmol(+)/kg. Samples taken at 7 months after GML application showed a decline in exchangeable Ca, indicating that Ca may be present in the forms not exchangeable by neutral ammonium acetate, and some may have been removed by the crops (about 100 kg Ca were taken up by two crops of maize and a crop of peanut). At the 15th month this decreasing trend was still observed and there was only a slight difference between the plots treated with 4.0 and 8.0 t GML/ha. At the end of the second year there was no difference in exchangeable Ca between these two treatments (Figure 7).

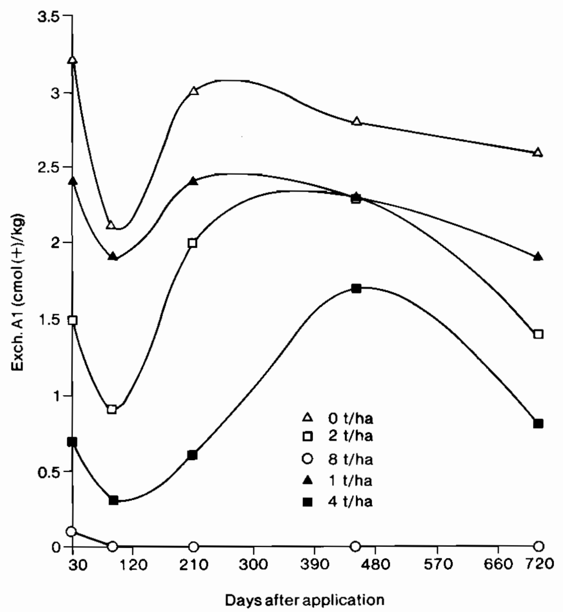

Fig. 6. Effects of GML application on exchangeable aluminium in Bungor series soil.

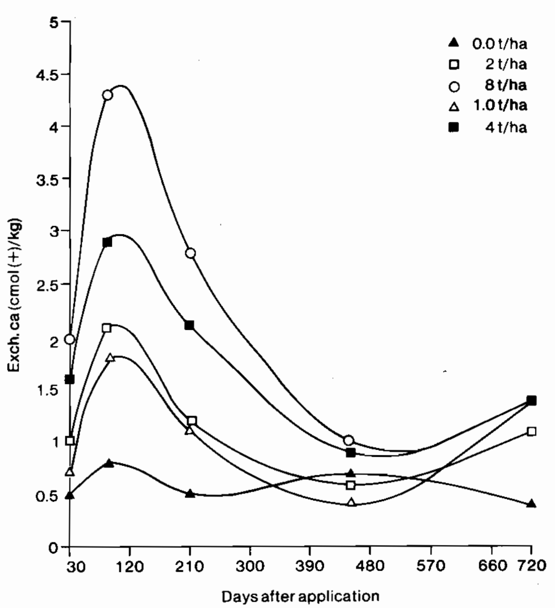

Fig. 7. Effects of GML application on exchangeable Ca in Bungor series soil.

Munchong Series Soil: The effects of GML application on some properties of Munchong series soil are shown in Figures 8-10.

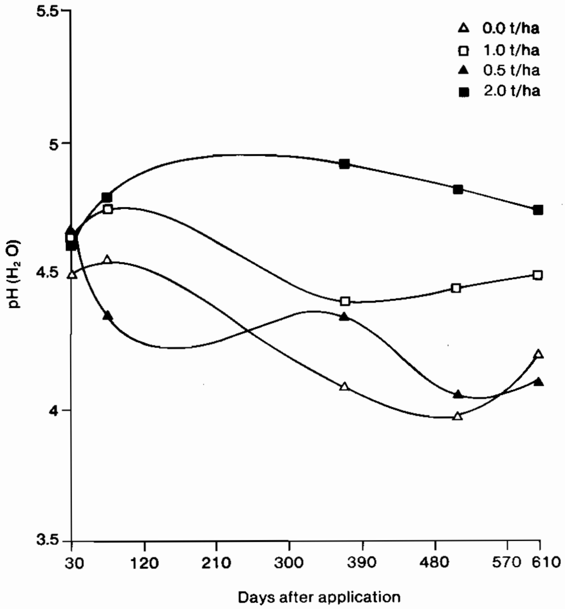

Fig. 8. Effects of GML application on pH of Munchong series soil.

The changes in pH values up to 580 days after GML application are shown in Figure 8. After 50 days of application there was only a slight difference in pH values of soil treated with 1.0 t GML/ha compared to that of 2.0 t/ha. But after 350 days the difference between these two treatments was about 1.0 pH units. At 580 days, the pH values of those plots treated with 1.0 t/ha or less were less than their original values indicating that the effect of GML on soil pH was no longer observed at these rates of application. Generally, it was observed that the pH values of plots that received <1.0 t GML/ha reduced below their original values after about 150 days after application.

Changes in exchangeable Al as a result of GML application on Munchong series soil are shown in Figure 9. Application of 0.5 t GML/ha did not decrease exchangeable Al, and at 450 days, it was found that the exchangeable Al had increased to 2.2 cmol(+)/kg from the original value of 1.3 cmol(+)/kg. This increase in exchangeable Al was also observed in the unlimed plots. At 580 days after GML application, only the plots which received >1.0 t/ha have the exchangeable Al below the original values.

The changes in the amounts of exchangeable

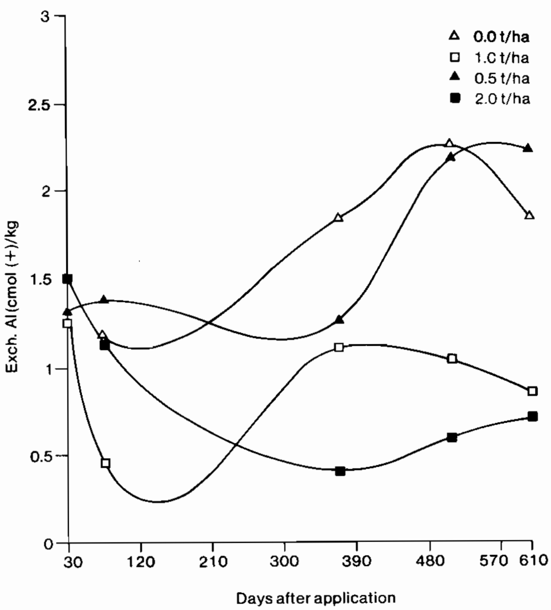

Fig. 9. Effects of GML application on exchangeable Al in Munchong series soil.

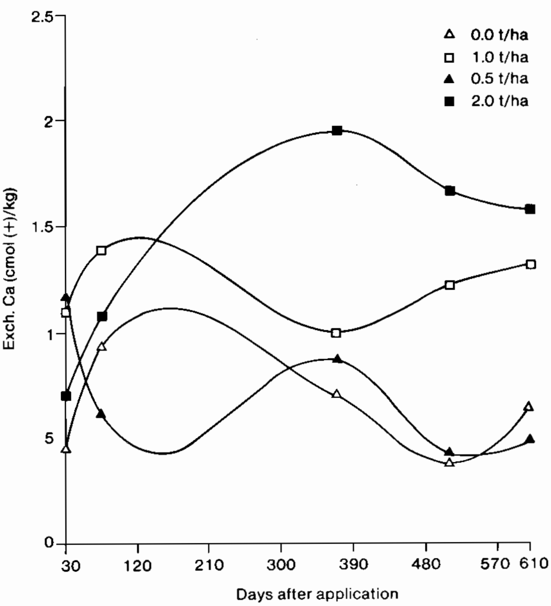

Fig. 10. Effects of GML application on exchangeable Ca in Munchong series soil.

Ca over time are shown in Figure 10. Application of 0.5 t GML/ha apparently did not increase the values of exchangeable Ca while applications of 1.0 and 2.0 t/ha as expected increased exchangeable Ca to 1.3 and 1.6 cmol (+)/kg respectively.

Conclusion

These experiments showed that liming with ground magnesium limestone improved the yields of maize grown on Bungor and Munchong series soils. The optimum rate of application was found to be about 1.0 t/ha for Munchong series soil and 2.0 t/ha for Bungor series soil. For maize grown on Bungor series soil, Ca deficiency was eliminated by the application of 0.5 t/ha and Mg deficiency by 2.0 t/ha. However, application of GML at >4.0 t/ha induced Zn deficiency while application of 8.0 t/ha induced Cu and Mn deficiencies.

For peanut, application of GML at 0.5 t/ha was sufficient to increase the yield to >90% of maximum yield for both soils. However tissue analysis showed that Ca and P were deficient in peanut grown on Munchong series soil indicating that perhaps for this soil the rate of Ca and P applied was not sufficient.

Application of GML increased soil pH, reduced exchangeable Al, and improved Ca status of the soils. In Bungor series soil, application of 1.0 t/ha GML increased soil pH to 5.0, but it needed 2.0 t/ha to maintain a pH of about 5.0 up to 2 years. After 7 months, a reduction in exchangeable Ca was observed. In Munchong series soil, application of 0.5 t/ha did not affect soil pH or exchangeable Al.

Acknowledgments

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Management and Utilisation of Acid Soils in the Philippines

Redia N. Atienza*

Abstract

As much as 58% of the Philippines is covered with acid soils and much of this area is classified as hilly land. The soils are mainly Oxisols and Ultisols which have traditionally been farmed by slash and burn but have now been abandoned in many areas. Although a great deal of research on liming has been done, few farmers use lime because it is too costly. Acid-tolerant crop varieties have been identified and phosphate rock application has been shown to be an effective way of overcoming the widespread phosphorus deficiency. Further research is needed to develop a package of management technologies that combines cheaper alternative sources of lime with green manuring and the use of crops tolerant of soil acidity.

Introduction

Like many of the tropical countries in Southeast Asia, the Philippines has a hot humid climate with generally two distinct seasons: wet or rainy from June to October and dry from November to May. The average temperature is 29. 3°C during the summer months of March to May and 25°C during the cool months of December to February. Annual rainfall is over 2000 mm. Interplay of these factors over the varied parent materials resulted in a wide range of soils in the country.

Agriculture plays a dominant role in the economic development of the Philippines, generating more than 60% of its total export. Development of the sector has been identified as a major strategy in the economic recovery program of the country.

Soils presenting problems related to acidity, workability, salinity, alkalinity and erosion have been identified, and cover large areas. Soils with pH 5.5 and below cover an extensive area (Fernandez and de Jesus 1980), and pose enormous problems not only in the Philippines but in other Southeast Asian countries. These soils present a major constraint to increased and sustained agricultural production.

Survey data show an estimated 17 million ha of acid soils, roughly equivalent to 58% of the total land area of the country. These soils are widely distributed throughout the country, predominantly found in hilly lands (Fig. 1) (National Land Use Committee 1985).

Characteristics of Acid Soils

Acid soils in the Philippines are described as generally well drained, deep, and with low fertility, occurring extensively as Ultisols and Oxisols (Soil Taxonomy Classification) classified as Haplustults and Haplustox at the great group level, respectively. Initial research results of a study by the Bureau of Soils and Water Management (Evangelista et al. 1988) and University of the Philippines at Los Baños in Palawan, the fourth largest province in the Philippines, showed that about 26 320 ha of the total area (about 1.5 million ha) of the province

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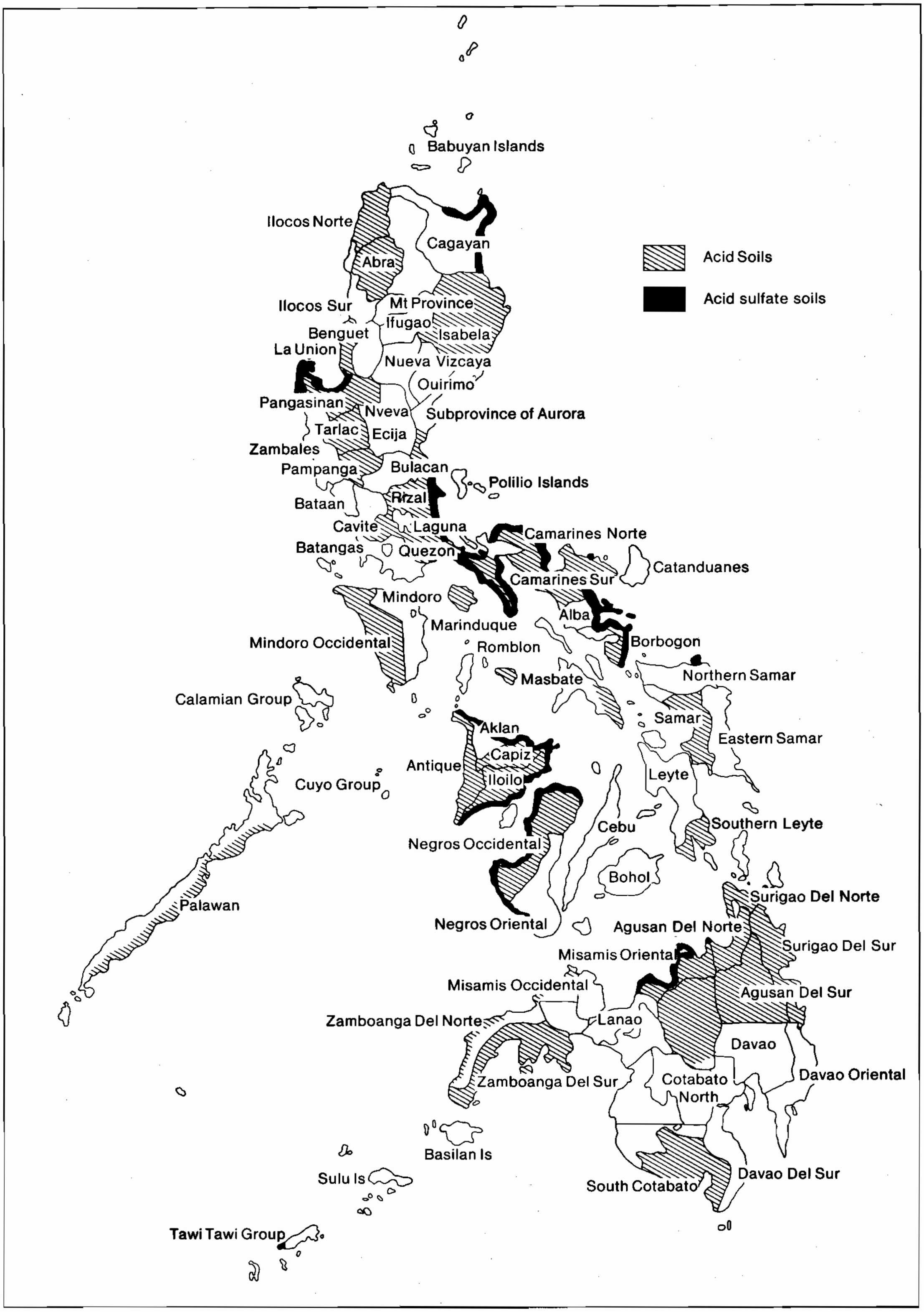

Fig. 1. Extent of acid soils in the Philippines.

is acidic. The soils were formed from sedimentary rocks which are composed of transgressive and poorly consolidated conglomerate, interrelated with thin bed lenses of sandstone and siltstone. They also consist of poorly sorted pebbles, cobbles, and boulders of ultramafic rocks, occurring on intensely dissected hills and knobs whose peaks are almost of uniform elevation.

Almost all the macronutrients and micronutrients are very low, resulting in low productivity. People in the area practice a slash-and-burn system of farming. They abandon the farms after substantial production can no longer be obtained.

Some of the specific characteristics of the soils are as follows:

The Diagnostic Horizons

a. *The Oxic Horizon.* The predominant subsurface horizons in the survey areas are at least 30 cm thick, with a fine-earth fraction that retains 10 meq or less ammonium ion per 100 g clay from an unbuffered 1N NH_4Cl solution. They have apparent CEC of 16 meq or less per 100 g clay by NH_4OAC unless there is an appreciable content of aluminium interlayered chlorite. They also have gradual or diffused boundaries between the subhorizons. The oxic horizon has more than traces of primary aluminosilicates such as feldspar, micas, glass and ferromagnesium minerals. It is sandy loam or finer in the fine earth fraction and has 15% clay.

b. *Argillic Horizon.* Another dominant diagnostic subsurface horizon in the surveyed area is the argillic horizon. It contains more total clay and more fine clay than the eluvial horizon. The increase in clay content is reached within a vertical distance of 30 cm or less.

Taxonomic Classification

The soils were classified into the orders Oxisols and Ultisols. The Oxisols include the soils with the oxic horizon within 2 m of the soil surface and no argillic horizon that overlies the oxic horizon. In consideration of the ustic soil moisture regime and a base saturation of 50% or more (by NH_4OAC at pH 7) in the major part of the oxic horizon, some soils were further classified as Eutrustox. Otherwise, they are classified as Haplustox.

The soils having argillic horizons with base saturation <35% were classified under Ultisols, which are further classified as Haplustults in the great group level.

Acid Sulfate Soils

In land used for aquaculture, the extent and severity of acid conditions have only been recently recognised.

The abundance of sulfates and organic matter in the sediment of mangrove areas favours the formation of acid sulfate soils. As organic matter decomposes, the sulfates are converted to sulfides. These sulfides may combine with iron in the soil to form iron sulfide. With further transformation, iron sulfide produces pyrite, the mineral source of acid sulfate soils.

When fishponds are constructed in this soil, especially in mangrove swamps, the pyrites are exposed. Combined with oxygen from the air, pyrites produce sulfuric acid. Thus when submerged, acid sulfate soils may be neutral, but upon exposure, the pH drops to less than 4, making it acidic.

Soil surveys revealed large tracts of acid sulfate soils covering at least nine provinces (Misamis Oriental, Bicol, Cagayan, Pangasinan, Quezon, Iloilo, Capiz, Aklan, and Negros Occidental).

Reclamation of these soils involves repeated sequence of intensive draining, drying and flooding before residual acids are neutralised by liming. It is started in the early part of the dry season and usually takes about 3 months.

Potentials and Constraints to Managing Acid Soils

In the Philippines, it is generally difficult to produce substantial yields of various crops such as corn, soybean, peanut, mungbean, etc. in acid soils. The practice of continuous cropping among Filipino farmers in those areas contributes to increased acidity of the soil, unless liming is done. There are many issues raised regarding potentials and constraints to the management of these particular soils.

Technical Issues

Acidity builds up slowly depending on the type of soil and the cultural management applied. However, the benefits of liming acidic soils for crop production cannot be readily recognised or easily observed, compared to the application of inorganic fertilisers, which are immediately observed. Furthermore, there is only limited information from field experiments on the beneficial effects of liming for the different acidic soils (Samonte 1987).

Limited information on the efficient techniques of lime application also poses a constraint. Considering the cost of liming materials, techniques that will minimise the amount used to have the same effect are worth developing.

Institutional Issues

The limited financial investment of the government for research serves as a major constraint in carrying out intensive studies on the proper management and utilisation of acid soils in the Philippines. Although this is a priority in the Philippine research and development program for agriculture, only about 7% of the total research and development budget was provided by the government due to other pressing needs identified by the FRSRD of PCARRD.

This therefore necessitates cooperation and collaboration among research institutions in the country to explore other possible means of tackling these issues with less dependence on government financial support.

Economic Issues

The high cost of lime has also resulted in the limited adoption of liming techniques to maintain soil productivity. In the Philippines, an estimated 70–80% of the population depends on the farm as their main source of livelihood, such that farmers are more concerned with increasing their income through intensive cropping schemes. They are not aware that in doing so, acidity of the soil will intensify causing yield reductions.

Intensive corn production due to high demands of the crop increases the acidity problem in the upland areas. This is being largely ignored due to economic reasons, the lack of alternative crops with attractive prices and the lack of technologies for low-cost liming materials.

Promising Management Practices (Technologies)

There are promising results from several research projects on acid soils conducted by various institutions in the Philippines. Although some of these are still to be verified, others are already practiced in some of the study areas in the country.

Liming and Fertilisation

On-farm lime and fertiliser experiments on corn production, conducted by the Central Mindanao University on Adtuyon clay soils (pH 4.3) and Adtuyon clay stony phase (ph 4.9) using IPB Var 2 corn variety showed that the application of lime at the rate of 3t/ha showed a significant increase in yield over the unlimed plots, particularly during the second (dry season) cropping (Daquiado 1988). The application of 30 kg P_2O_5 in limed soils showed highest corn yields of 5 t/ha for Adtuyon clay stony phase and 2.9 t/ha for Adtuyon clay. In the second cropping, the yield was 3.35 t/ha for Adtuyon clay stony phase and 3.34 t/ha for Adtuyon clay. The yield decreased as the rate of P was increased due to nutrient imbalance in the soil. In general, the experiment indicated that liming increased the efficiency of applied P which is attributed to the decrease in exchangeable Al concentration in the soil.

The application of combined N and P at the rate of 30 kg N/ha and 60 kg P_2O_5/ha on limed soils gave a yield of 5.71 t/ha on Adtuyon clay stony phase. In Adtuyon clay, with the addition of 60 kg N/ha and 30 kg P_2O_5/ha, the yield was 3.37 t/ha. In the second cropping, highest yields of 4.76 t/ha and 3.66 t/ha were obtained with the application of 90 kg N/ha and 30 kg P_2O_5 for limed Adtuyon clay stony phase soils, and 30 kg N/ha and P_2O_5/ha for limed Adtuyon clay soils, respectively.

Fertilisation and liming of acidic pasture soils in Nueva Ecija, Bohol and Cagayan provinces were also tested to improve forage production.

Yields of ipil-ipil, *Themeda triandra*, *Centrosema pubescens*, stylo and siratro forage grasses were evaluated. Results showed that liming increased the dry matter yield of ipil-ipil, while the application of NPK fertiliser increased dry matter yields of themeda, centrosema, stylo, and siratro. Application of P at 60 kg/ha likewise increased the dry matter yield of ipil-ipil, centrosema, and stylo.

For other acid soils, the lime requirements are shown in Table 1.

The yield performance of mungbean grown in Jasaan clay soil (pH 4.9) showed no significant effects on yield of *Rhizobium* inoculation at all locations, significant effect of P application in some locations and significant effects of liming at all locations (Table 2).

Pot experiments conducted in the dry season to test the response of mungbean to chicken manure showed a yield of 5.7 g/pot from 3 t chicken manure/ha against 1.1 g/pot from 20–17–32 kg NPK/ha + 3 t lime/ha and 1.3 g/pot from 86 kg P/ha applications. Grain yield and nodulation response is given in Table 3.

Results of N, P, K and lime applications showed most pronounced response to P. Mean yield from treatments without P was 66 kg/ha; from treatments with 17 kg P/ha, 168 kg/ha; from treatments with 17 kg P/ha and 3 t lime/ha, 256 kg/ha; and from treatments with 85 kg P/ha and 3 t lime/ha, 458 kg/ha.

In the same location, fertilisation studies showed that net benefits from fertiliser were highest with N at 25 kg/ha and with P at 9 kg/ha. There was a response to liming but the cost of 3 t lime/ha was not by the 0.6 t/ha grain yield increase. Response to 13 kg P/ha was highly significant at 0.9 t/ha.

Liming experiments conducted in Albay Province to determine the residual effects of applied lime (15 t/ha) and MnO_2 (50 kg/ha) in an acid sulfate soil (Sulfaquept, pH 3.9, organic C 1.0, ECE 2.3 days/month), using IR 21015–136–1–2–3 rice variety showed higher N, Ca, and Fe content in the leaves, regardless of MnO_2 treatment, 8 weeks after transplanting (WAT). Grain yields revealed a residual effect of liming regardless of MnO_2, but straw yields did not (Table 4).

Table 1. Lime requirement of some acidic soils for corn production.

Soil	pH	Lime requirement (t/ha)
Adtuyon clay	4.64	3.0
Tugbok sandy clay loam	4.67	2.8
San Manuel sandy loam	4.40	6.8
Jasaan clay	4.90	7.5
Lipa clay loam	4.67	9.2
Cauayan sandy loam	4.90	2.8

Source: The Philippines Recommends for Corn 1981.

Table 2. Yield of mungbean CESID-21 across five locations as affected by phosphate and lime application—Claveria, Misamis Oriental, Philippines, 1984. DS.

	Yield[a] (kg/ha) at each location				
Treatment	1	2	3	4	5
Unfertilised	45	231	91	104	300
13 kg P/ha	57	336	174	216	266
26 kg P/ha	62	357	184	178	313
3 t lime/ha	119	310	240	111	295
13 kg P/ha + lime	203	447	277	185	459
26 kg P/ha + lime	213	524	329	196	467
CV (%)	19	11	20	28	13

[a]Means over two inoculation rates and four replications.
Source: IRRI Annual Report 1985.

Table 3. Grain yield and nodule count[a] of mungbean as affected by inorganic fertiliser and chicken manure in pot experiments—Claveria, Misamis Oriental, Philippines, 1985 WS.

Treatment	Grain yield (g/pot)	Nodules[a] (no./plant)
Control	2.7	14
20-17-32 kg NPK/ha	3.4	14
2 t chicken manure/ha	7.4	33
4 t chicken manure/ha	10.6	48
6 t chicken manure/ha	13.0	52
CV (%)	20.0	30

[a]Means over two inoculation rates and four replications.
Source: IRRI Annual Report 1985.

Table 4. Residual effects of applied lime and MnO_2 in acid sulfate soil, one season after application and three replications.

	Grain Yield (t/ha)				Straw Yield (t/ha)			
Treatment	1	2	3	%	1	2	3	%
No lime no MnO_2	3.46	3.50	3.57	3.51	3.99	4.45	4.70	4.38
No lime with MnO_2	3.61	3.35	3.05	3.34	4.05	3.95	4.02	4.01
With lime no MnO_2	4.02	3.81	3.34	3.72	3.79	4.22	4.06	4.02
With lime with MnO_2	4.38	4.09	4.44	4.30	4.17	4.61	4.84	4.54
F-Computed								
Treatment	9.84^{*}		5.41^{ns}					
Lime	19.29^{**}		0.62^{ns}					
Manganese	2.27^{ns}		0.41^{ns}					
Lime x manganese	7.98^{*}		15.21^{**}					

Source: IRRI Annual Report 1985.

Liming Rate and Method of Incorporation

Studies on liming rates and methods of incorporation were conducted to show their effects on soil pH and enhancement. Lime was broadcasted and incorporated: (1) to a depth of 15 cm by an animal-drawn plough; (2) to a depth of 30 cm by a tractor-drawn plough; and (3) to a depth of 11 cm by an animal-drawn plough after which the field was reploughed to 30 cm by a tractor-drawn plough (AP + TP). Lime rates used were 3 and 6 t/ha. Results showed that rice yield benefited from deeper incorporation and higher lime rate (Fig. 2). Liming likewise increased the soil pH (Fig. 3).

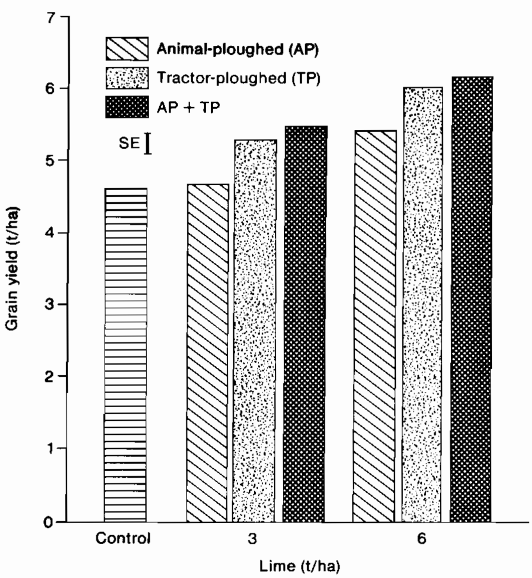

Fig. 2. Grain yield of UPLRi5 by rate and method of lime incorporation — Claveria, Misamis Oriental, Philippines, 1985 WS. Source: IRRI Annual Report 1985.

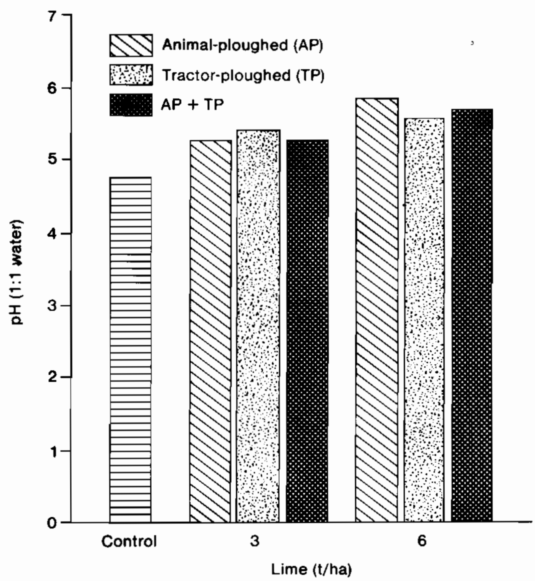

Fig. 3. pH changes in the soil as affected by rate and method of lime incorporated — Claveria, Misamis Oriental, Philippines. 1985 WS. Source: IRRI Annual Report 1985.

Timing of Lime Application

At La Trinidad, Benguet, the effect of time of lime application and soil pH on tuber yields of potato was evaluated. Liming 2 weeks before harvest resulted in higher tuber yield. Increasing soil pH from 5.04 to 5.74 increased tuber yield. On cabbage, however, the heads were more solid at pH 4.5–4.93 (no lime) than at higher pH.

Alternative Sources of P

The high cost of commercial inorganic P fertiliser prompted soil researchers in the Philippines to explore other possible sources of P for crop production in acid soils. In Iloilo, the Visayas Experimental Station of the Department of Agriculture (DA–VES) conducted a research study on the efficiency of rock phosphate combined with lime as a possible substitute for inorganic P fertiliser on Barotac fine sandy loam (pH 5.3) grown to corn and mungbean. Rock phosphate applied at 500 kg/ha gave yield of 5608 kg/ha of corn compared with the 4852 kg/ha yield obtained from 40 kg P_2O_5 /ha using solophos. On the other hand, highest yield obtained for mungbean was 515 kg/ha with the application of 40 kg P_2O_5/ha plus 2000 kg lime/ha which was comparable with the application of 1250 kg/ha rock phosphate which yielded 435 kg/ha of mungbean.

The effectiveness of an indigenous phosphate deposit in improving productivity of acidic soils in Southern Leyte was determined by the Visayas State College of Agriculture (ViSCA). Application of 90 kg P/ha from either apatite (containing 30% phosphorus) or organic fertiliser significantly increased the yield and yield components of corn and upland rice. Corn grain yield was 3.84 and 3.4 t/ha using inorganic fertiliser and apatite, respectively. For upland rice, yields of 1.46 t/ha using inorganic P fertiliser was comparable with 1.62 t/ha yield using apatite.

High reactivity generally characterises apatitic phosphate rocks, and consequently their direct application to acidic, P-deficient soils is beneficial. At an optimum rate of P application, comparable effectiveness of apatitic phosphate rocks and single superphosphate as P fertiliser for corn, upland rice and soybean was observed in a series of field experiments conducted on three acidic, P-deficient soils in three provinces (Camarines Sur, Sorsogon and Northern Leyte). At optimum P rates, broadcast application of the phosphate rock was found to be more effective (Briones 1983).

Acid Tolerant Crop Varieties

On-field screening for acid tolerance of different varieties of corn, mungbean, peanut, sweet potato and ipil-ipil on three acid soil series (Lipa clay loam (pH 4.67), Adtuyon clay (pH 4.64), and Antipolo clay (pH 5.4)) was conducted by UPLB (Samonte 1985). The experimental sites are in Bukidnon and Laguna provinces. A number of varieties of the different crops showed relative tolerance to acidity (Table 5).

Green Manuring

There is still a dearth of information on the use of green manure for upland crops specific to acid soils. However, ongoing studies on the use of green manure crops, particularly inexpensive legumes like forage crops (*Centrosema, Pueraria phaseoloides,* and *Dolichos lablab)* conducted in Adtuyon clay soils in Bukidnon Province show that this can be a potential for rehabilitating and managing acid soils.

Research Gaps and Problems

There is a lack of effective technology dissemination to the farmers on how to manage soils effectively. This necessitates, therefore, the establishment of an effective technology transfer system in which all the research institutions and agencies participate.

Another constraint faced by soil researchers in the Philippines is the dearth of information from field experiments on different acidic soils in the country showing the beneficial effects of liming (Samonte 1987). With this, there is a need to intensify research on liming effects of specific acid soils (thoroughly classified) grown to various upland crops. There is a need to further conduct soil classification research for various Philippine acid soils.

Other areas that need to be studied or strengthened further are:

Table 5. Acidity tolerance of some crop varieties on Lipa clay, loam, Antipolo clay and Adtuyon clay, Philippines.

Crop	Site/soil series	pH	Variety	Tolerance
1. Mungbean	UPLB, Los Baños, Laguna/ Lipa clay loam	4.67	CES M79–17–91	High
			CES M79–11–95	"
			CES M79–14–46	"
			CES M79–19–102	"
	UP Land Grant, Siniloan, Laguna/ Antipolo clay	5.4	CES M79–12–181	Moderate
			CES M79–15–87	"
			CES M79–16–51	"
			CES M79–22–108	"
2. Peanut	Manolo Fortich, Bukidnon/Adtuyon clay	4.64	BPI–P9	Moderate
			Dagupan Cream	"
			UPL–Pn 4	"
			PI–372238	"
	UP Land grant, Siniloan, Laguna/ Antipolo clay	5.40	CES 24–3	High
			UPL–Pn 4	"
			BPI–P9	"
			CES 24–6	"
			CES 24–2	
3. Corn	UPLB, Los Baños, Laguna/Lipa clay loam	4.67	IPB Var 1	High
			UPCA Var 1	"
			SMC 203	"
			Suwan 1	"
			DMR Comp 1	"
			SMC 102	"
			SMC 121	"
	Manolo Fortich, Bukidnon/Adtuyon clay	4.64	Sibagat Tiniguib 12	High
			Rep. Dominicana 270	"
			Tinimbaga Batas	"
	UP Land Grant, Siniloan, Laguna/ Antipolo clay	5.40	Phil. DMR	High
			SMC 121	"
			Rep. Dominicana	"
			Guadalupe Caribe Precoz	"
			UPCA Var 3	"
4. Sweet potato	UP Land Grant, Siniloan, Laguna/ Siniloan clay	5.40	G3r–1	High
			G232–4a	"
			G228–1	"
			Kinabakab	"
	UPLB Los Baños, Laguna/Lipa clay loam	4.67	Kinabakab	High
			G25 r–12	"
			G 3r–1	"
			G113–2b	"
5. Ipil–ipil	Manolo Fortich, Bukidnon/Adtuyon clay	4.64	Ipil–ipil accessions 4,11,3,13 and 25	Moderate

Source: Samonte 1985.

- the upgrading and strengthening of a data base system for soil resources sector;
- the thorough field screening of various crop varieties to come up with recommended acid-tolerant varieties for specific acid soils in the Philippines;
- the need to conduct frequent and detailed on-farm experiments to provide specific recommendations for lime-rates for variations in soil acidity;
- the further exploration of cheaper alternative sources of liming materials and fertilisers to reduce the cost of lime;
- field testing of green manuring practice to rehabilitate acidic soils, and research in appropriate green manuring crops for specific acid soils; and
- the packaging of recommended cultural management technologies to rehabilitate marginal acid soils in the country.

Strategies for Conducting Research

The major consideration that led to the creation of the Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD) in 1972 was the need for coordinated and relevant research and development activities. The council, for more than 15 years, has provided direction so that the country's research is focused on development, through coordinated and relevant planning implementation, monitoring and evaluation.

Planning and Priority Setting

PCARRD recognises the top-down and bottom-up approach to planning and priority setting. National goals and policies are embodied in the Medium Term Philippine Development Plan, the formulation of which is coordinated by NEDA. These are further translated/spelled out by the Department of Agriculture (DA), Department of Science and Technology (DOST), Department of Environment and Natural Resources (DENR) for agriculture, science and technology, forestry and natural resources sectors, respectively.

At the local level, the needs and opportunities are identified through the farming system (FS) approach. These are then analysed vis-a-vis national sectoral goals and then consolidated into the research and development program for agriculture and natural resources.

The FS approach features a bottom-up procedure in planning and implementation, and emphasises self-reliance and efficiency in the use of agricultural resources. It enhances multiagency and multisectoral participation. The farmer and household are always involved in the phases of technology development from the identification of gaps and needs up to the design, implementation and evaluation of activities that address the identified problems and concerns.

Implementation

The implementation of the research and development programs and projects is conducted by the members of the National Agriculture and Resources Research and Development Network (NARRDN), composed primarily of State Colleges and Universities (SCUs), the DA and DENR research stations and other agencies.

Basic and sophisticated research is usually undertaken by the SCU, applied experiments are conducted by the DA through the Regional Integrated Agricultural Research System (RIARS). The RIARS integrates agricultural research in crops, livestock, socioeconomic, and farm resources and systems sectors at the regional level. Trials in the 92 Production Technology Verification sites are replicated across several farms and conducted by extension workers who provide a direct link between the DA and farmers.

Research projects that will be undertaken in the network may be done by the SCUs, the DA and other agencies in the NARRDN. Support may come from foreign donors through the assistance of any specialised/international agencies/institutions with possible counterpart funding from the government, through PCARRD. Review and evaluation mechanisms follow those set by PCARRD.

Conclusion

The need for further research cannot be overemphasised if acid soils are to be fully understood and utilised successfully by the small farmers. A more detailed and comprehensive understanding of acid soils needs to be pursued to establish a better relationship between pedological characteristics and management practices. Of major consideration is a detailed economic analysis of any required crop management/soil amendments to determine the viability of the innovations of interest.

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Management and Utilisation of Acid Soils in Sri Lanka

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Abstract

Acid soils of the soil orders Ultisols, Entisols, Inceptisols, Histosols and Oxisols occur in the wet and semi-wet regions of Sri Lanka. Unlike the acid soils in tropical humid Asia, these soils have good chemical and fertility characteristics. The soil distribution, properties and hydrological conditions are described. The stable land use patterns existing in different natural regions are described. The principal food crops rice, vegetables, roots and tubers are grown mainly in soil orders Entisols, Inceptisols and Histosols. The progress made in understanding the behaviour of submerged soils and their fertility characteristics is discussed. The fields of urgent research needs such as fixation of added nutrients, toxicities and long term effects of excessive agrochemical inputs on the quality of the soils are highlighted.

Introduction

Soils, acid in reaction, are used extensively for agriculture in Sri Lanka. Several great soil groups of the acid soil category with pH values < 5.5-5.6 are managed under a wide range of environments for a range of crops including annual food crops, roots and tubers, perennial tree crops and many horticultural crops. The nature of the soil properties, the general setting of the soils in the landscape, the climate and their interactions usually determine the management possibilities and the choice of crops. The occurrence and distribution of these soil groups and the wide range of climates as determined by the pattern of rainfall distribution and temperature conditions provide a resource base for the adaptation of this wide range of agricultural uses and management practices. The location specificity of the hydrological conditions arising from the nature of the physiography at any site has given rise to management differences over short distances. The consistent policy of the government to attain self-sufficiency in food crops has prompted serious agricultural research in the food crop sector during the last several decades. In spite of many advances in the knowledge of the management of the acid soils, the demand for further research to sustain the productivity of these soils has become more evident.

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Soil Physical Environment

The problem related to the use and management of most of the soil orders arises from the interaction of soil properties, climate (particularly the rainfall), elevation above mean sea level, and the position of the soils in the micro-topography.

The Sri Lankan annual rainfall distribution pattern is distinctly bimodal for most parts of the country. The mean annual rainfall ranges from 5000 mm in the wettest parts to 875 mm in the semi-humid to dry areas. The rainfall in the acid soil region is high enough to provide a net leaching environment.

Five out of the ten soil orders (USDA 1975) are identified and mapped within the region of acid soils in Sri Lanka. The most extensive soil order that is agriculturally very important is the Ultisols; however, extensively used soils for food crop production are of the soil orders Entisols, Inceptisols and Histosols. The Oxisols are not very important either in extent or for food crop production and most of them occur outside the main acid soil region.

Traditionally in the Ultisol region, the soils in inland valley systems have been used for rice cultivation under rainfed, streamfed, and phreatic water supply conditions. The better drained soils on adjacent highlands, that cannot be controlled by stream diversions, were used for shifting form of cultivation of other food crops for subsistence under rainfed conditions, until the advent of commercial plantation agriculture with crops like tea, rubber, coconut, cocoa, coffee, etc. Presently most of the Ultisols region, except for the forest reserves, is developed for these perennial plantation crops, with a minor portion used for other food crops and vegetables.

The soil orders Entisols, Inceptisols and Histosols are used mainly for rice cultivation. The problems related to the geographical setting of these soils in the landscape and the associated hydrology include flooding, salt water intrusions, water logging and strong acidity development which severely limit the utilisation of these soils.

The elevation ranges from sea level up to about 2500 m above mean sea level, in an area of about 64 000 km^2 and acid soils are encountered at all elevations. Land elevation also has played a major role in the selection of crops. The management needs to a large measure are also determined by the elevation.

Based on the rainfall, vegetation, soils and present land use, three main agroclimatic zones have been demarcated. These three major climatic zones are further subdivided into 24 distinctive agroecological regions on the basis of rainfall expectancy at 75% probability, elevation and soil conditions.

Distribution of Acid Soils

In the 1971 version of the soil map of Sri Lanka, there are 31 map units which include 21 soil map units and four land-mapping units, namely eroded lands, rock knob plains, steep rockland and Lithosols, and erosional remnants. The soil map units consist of association of great soil groups. The area distribution of the more important soil associations is shown in Figure 1 which has been generalised from the

Table 1. Important acid soil groups of Sri Lanka with the equivalent great soil groups of soil taxonomy (USDA 1975).

Soil order	Suborder	Great soil groups	Great soil groups of Sri Lanka
Ultisols	Udults	Rhodudults	Reddish Brown Latosolic
		Plinthudults	Red Yellow Podzolic (Lateritic)
		Tropudults	Red Yellow Podzolic
	Humults	Tropohumults	Red Yellow Podzolic (prominent A_1 or DarkB)
	Aquults	Tropaquults	Low Humic Gley
Entisols	Aquents	Tropaquents	Low Humic Gley
		Sulfaquents	Acid Sulfate soil
	Fluvents	Tropofluvents	Alluvial soils
	Psamments	Quartzipsamments	Latosolic Regosol
Inceptisols	Aquepts	Tropaquepts	Half Bog
		Sulfaquepts	Acid Sulfate soils
		Haplaquepts	Low Humic Gley
Histosols	Fibrists	Tropofibrists	Peaty Bog
	Hemists	Tropohemists	Mucky Peaty Bog
	Saprists	Troposaprists	Mucky Bog

soil map of 1971. The great soil groups that are in the category of acid soils identified are given in Table 1. with the equivalent great soil groups (USDA 1975). Out of the soils shown in Fig. 1 only the acid soils are described in the following sections.

Ultisols

The most extensive soils that occur in the wet and the semi-wet intermediate zones are Ultisols. They occupy the well drained uplands of the undulating to rolling landscape in the low country (lands from sea level up to 300 m elevation), the hilly and mountainous slopes of the mid elevations (300–1000 m) and high elevations (over 1000 m) in the two zones. The dominant soil groups encountered are Rhodudults, Plinthudults, Tropudults, Tropohumults and Tropustults. Most commonly these soils consist of sandy loam to sandy clay loam surface soils underlain by sandy clay loam to sandy clay subsoil horizons. These soils are formed from the weathered products of crystalline metamorphic rocks of the pre-Cambrian. These soils are in the higher rainfall regions, where the dry periods are short and the profiles dry out rarely beyond the root zone of most crops.

Aquults

The low humic gley soils that occupy the inland valleys of the undulating as well as the hilly and mountainous landscapes are the Ultisols with an aquic moisture regime. Generally, due to high rainfall and interflow of water from the adjacent highlands, high water tables occur in these valleys. The properties of the Aquults are similar to other Ultisols that are associated with it, except for those characteristics arising from the reducing conditions brought about by the high water tables.

Entisols

Most of the soils in inland valley bottoms, stream levees and alluvial flats are formed from alluvial parent materials. Deposition of fresh material derived from the uplands and hill slopes on the bottomlands due to frequent flooding, the high water table conditions, and poor internal and external drainage have given rise to the poorly formed profiles. These soils have formed under reducing conditions, therefore intense gleying and mottling are common. Almost all these soils are used for rice production.

Inceptisols

The dominant acid Inceptisols occur mostly in terraced upland slopes where the erosion and deposition processes have prevented the development of an argillic horizon. They are usually formed from acid and acid intermediate rocks, under well drained conditions. Commonly the base saturation is low and poor in weatherable minerals. These soils are classified as Dystropepts.

Aquepts

The Aquepts are usually in the lower slopes and in inland valleys. The land development combined with other factors as above and the interflow and land use have retained the characteristics of Inceptisols. Some of the acid sulfate soils and half-bog soils are classified as Aquepts. The perennial saturation and high clay and organic matter probably have prevented the development of a textural subsoil horizon.

Histosols

The soils of the Histosol order occur in drowned valleys, which are the ill-drained lands in the low country wet zone. The main soil-forming process is the accumulation of organic matter. The same process occurs on lands between the river levee back slopes and the hinterland due to waterlogging. The great soil groups identified are Tropofibrists, Tropohemists and Troposaprists. These soils consist of dark brown to black organic layers overlying strongly mottled and gleyed mineral alluvial soil materials.

Soil Properties

The slightly acid to strongly acid soils of Sri Lanka have fairly good chemical and physical properties unless they are subjected to prolonged water-logging, submergence or very poor drainage. The cation exchange capacities range

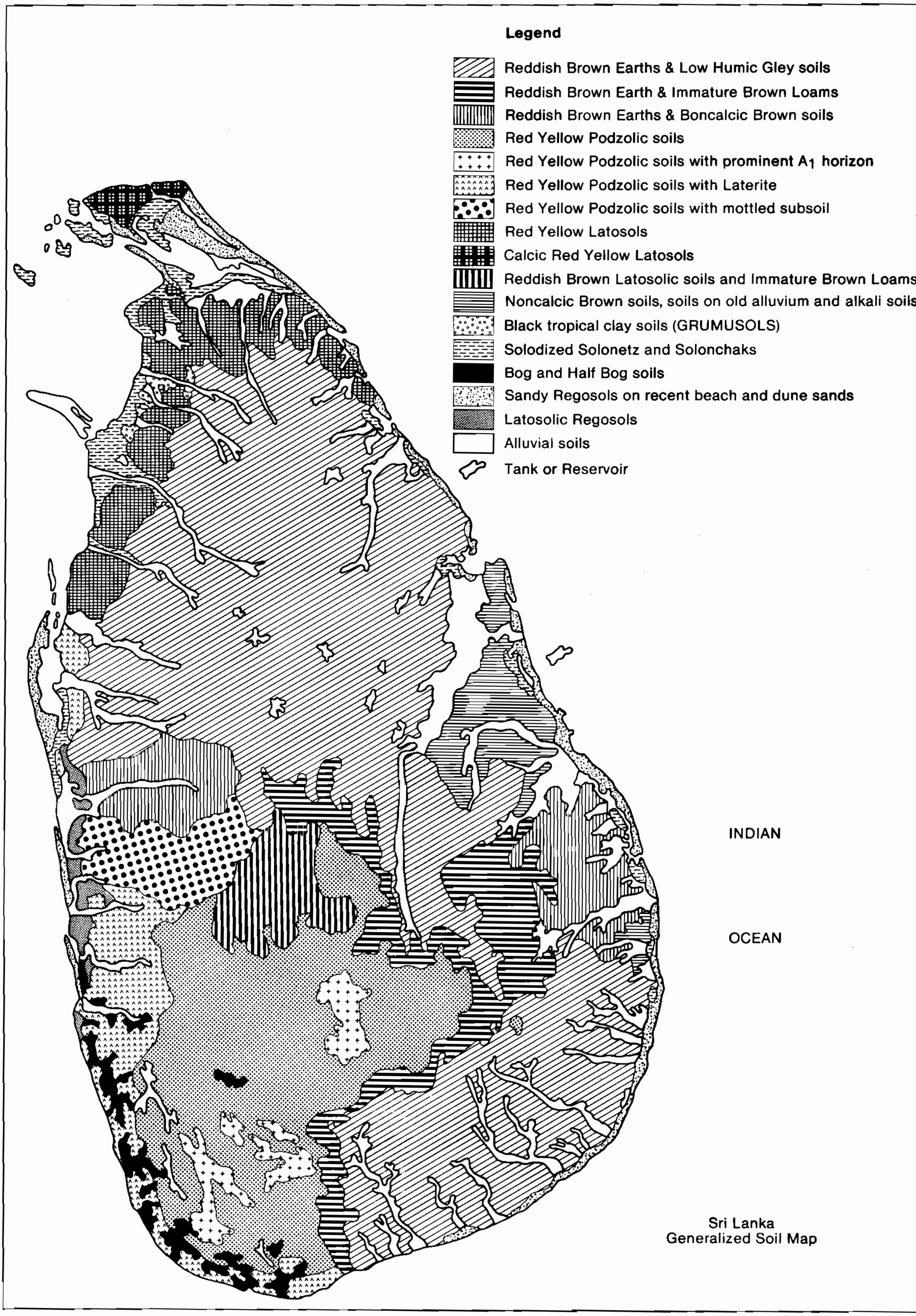

Fig. 1. Generalised soil map of Sri Lanka.

from 5 to 15 meq/100 g soil, while the base saturation is in the range of 5–40% in the subsoil. The dominant clay mineral is kaolinite. The next in abundance are the oxides of iron and aluminium. These soils are quite highly leached, but not as much as the acid soils in other parts of humid tropical Asia. Most of the soils are moderately fine or fine textured. The soils are loose to friable or very friable at the surface, and friable to firm in the subsoil. The upland soils are deep and well drained. Their average infiltration rate ranges from 25 to 100 mm/hour after 4 hours. The soils are more prone to gully erosion, slips and slides.

Entisols have a variable texture and drainage, but are generally clayey soils. The cation exchange capacities are fairly high and base saturation is variable. Gleying is a dominant feature. The Entisols formed in brackish environments are potential acid sulfate soils. If drained they develop acid conditions. The organic matter status of the soil varies according to the location in the landscape.

Inceptisols are associated with Ultisols of the uplands in the landscape. Generally the soil properties are related to the properties of the soils on adjacent uplands. However, most Inceptisols are fine textured. The soils that occur in valleys are poorly drained and gleying is a dominant feature. Half bog soils (Inceptisols) have a high organic matter content about 15–30%. The mineral fraction is clayey. The cation exchange capacity is variable, but generally high due to organic matter. It ranges from 15 to 40 meq/100g soil. Base saturation is low. Exchangeable bases are low.

Histosols are mainly fine textured. The organic matter content is more than 30%. The bulk densities are low. These soils can hold large quantities of water. The cation exchange capacity of the organic material is very high. Exchangeable bases are generally low and the base saturation is very low. Available nutrient content is low although the total nitrogen content is high and total phosphorus also can be high. Available silica is reported to be very low. Under submerged conditions, some compounds formed are toxic to rice. These soils subside quite considerably when excessively drained.

Land Use Patterns on Acid Soils

The acid soils are used for a wide range of agricultural pursuits. The uplands of the undulating to rolling landscape of the low country wet and intermediate zones are predominately under rubber and coconut. The high rainfall region is predominately under rubber, and the low rainfall region is under coconut, while rice is the principal crop in associated inland valleys. In coconut lands, intercropping with root and tuber crops or horticultural crops or pasture is a common practice.

The acid soils of the wet mid-country is mainly under tea or spice crops. The associated inland valley systems and terraced slopes are cultivated with rice and some vegetables in the drier season.

In the up-country wet zone, hilly and mountain slopes are used for tea while more level areas are cultivated with food crops such as potatoes and vegetables. The up-country intermediate zone uplands are under tea and food crops, while the valleys are intensively cropped with food crops such as rice, potato, and vegetables, usually with three crops per year on the same land.

The inland valley systems, the drowned valleys of the low country, and flood plains are almost exclusively used for rice, with only a minor component of leafy vegetables.

Management of the Acid Soils

The management of the acid soils in Sri Lanka must take account of the fact that there is a great diversity in its acid soils in terms of occurrence, properties and potential. Further, the climatic and the hydrological conditions are not uniform throughout the acid soil region. The agro-ecological regions map prepared by the Land and Water Use Division of the Department of Agriculture (1977) taking the soil properties, climate and land use in perspective provided the basis to regionalise the research effort so that the problems and constraints to agricultural development could be addressed by regional research. Regional research is better suited to identifying the problems peculiar to the area but important in the regional context.

The following review, therefore, is largely based on the ecologically homogeneous natural regions, while the predominant crop or the cropping system is given most consideration. The most important food crops in the acid soil area are rice, root and tuber crops, and horticultural crops.

Rice will continue to be the most important food crop on acid soils in Sri Lanka. Rice-growing areas occupy a major part of the low country wet and semi-wet intermediate zones, and the mid-country wet zone. The most important tuber crop is potato in the up-country wet and intermediate zones. Vegetables are dominant again in up-country wet and intermediate zones whereas, in other parts of the acid soil region, vegetables and fruit crops are grown mainly as home garden crops. Fruit growing has not developed into an economic enterprise.

Recent Investigations

A systematic program of research commenced in the early 1970s to solve the problems of rice production. At this stage it became apparent that a better understanding of soil and water resources was a prerequisite. Study of the soils in low-lying lands, the lands up to 1.5 m above MSL, were made. The dominant soil groups were identified and mapped. The soil properties were evaluated then management strategies were identified and recommendations were made (Dimantha 1977). At the same time, a rice land resource capability study was undertaken and a Riceland Classification System was developed. In this, the agroecological conditions, soil properties, hydrological conditions, etc., were used as the criteria for classification (Somasiri et al. 1978; Panabokke and Somasiri 1980; and Somasiri and Ratnayake 1988).

These studies identified the existence of different land systems and land elements with variable production potentials and highlighted the need for different rice varieties to meet the specific requirements, and also the need to develop different land management approaches in order to realise the potential of the lands. Further, these studies helped the researchers to identify the critical factors that limit rice production.

The distribution of Entisols, Inceptisols and Histosols in the low-lying lands has been documented (Dimantha 1977). The influence of the microtopography and related management problems, particularly those resulting from the adverse hydrological conditions, have been identified (Panabokke 1977; Balasuriya 1987). The main production constraints identified are flooding, water-logging, coastal salinity, acid sulfate soil-induced acidity, water shortages and lack of irrigation, soil physical properties and problems related to fertiliser management. For some of these problems there are no management alternatives without land development and water control. However, the timing of cropping and water-table control to prevent acidification are the easier measures. Studies have shown that flooding usually occurs in the early part of the season, and the soil pH increases in the rainy season with the high water-table and flooding. Salinity levels drop again with rains (Balasuriya 1987). The use of Histosols in the area requires special management practices such as no tillage and working from bunds (Dimantha 1977) because of the low elevation and poor workability of these soils.

Rice yields obtained in low-lying lands have been very low up to very recent times, and this has been attributed at least partly to the nutritional disorders. A characteristic feature of these soils is the high content of organic matter which influences the fertility status of the soil. The soils in the low-lying lands contain variable amounts of organic matter, total N ranging from 0.19–2%. However, response to applied nitrogen with new improved varieties of rice has been observed.

The cation exchange capacity of these soils is high on the basis of meq per unit weight (Dimantha 1977). Available phosphorus is low. Because of intense reduction, soluble iron and manganese ions are high enough to cause physiological problems. The potassium status of these soils is generally adequate. The studies of Panabokke and Nagarajah (1964), Ponnamperuma (1960) and Rodrigo (1964) show that silica is low and the addition of silica increases rice yield very markedly. Based on more recent work, fertiliser recommendations specific to low-lying ricelands have been made (Nagarajah 1986).

As some of the prevailing conditions cannot be easily changed, varietal improvement programs aimed at selecting varieties that can stand the adverse conditions specific to the low-lying areas were started. Furthermore, varieties that performed very well under stable conditions failed to give yields anywhere close to the potential yield of the variety. The new improved varieties bred for the specific environment of the low-lying area have been able to give more than 5 t/ha (Peries 1981).

Inland Valley Systems

The riceland survey indicated that the main soil orders in the inland valleys are Ultisols, Inceptisols, and Entisols (or the Low humic Gley soils and Alluvial soils groups). The hydrological conditions obtained are highly variable (Somasiri and Ratnayake 1988). Rice cultivation depends largely on the seasonal rainfall, and some phreatic water and stream diversions. The water availability varies from excess to inadequate. Management practices consist of puddling and wet sowing or dry sowing, less commonly transplanting. In areas with an assured supply of irrigation, water transplanting is more common.

Soil fertility and response to added fertiliser have been studied quite extensively for inland valley systems of the country. On the basis of these studies, fertiliser recommendations made in the early 1950s were altered in 1956, 1959, 1964, 1967, 1971 and 1980 (Nagarajah 1986).

The latest recommendations clearly recognise the soil, climatic and hydrological differences which consist of 19 different formulations for the whole country. The inland valley systems in the low country have more than half of the different formulations. Generally, phosphorus is deficient in coarse textured soils, otherwise both phosphorus and potassium are not limiting. However, for new high-yielding varieties, the addition of phosphorus is beneficial. The response of rice to nitrogen has been always very clear.

The use of organic matter as fertiliser is recommended. However, even if farmers are willing to add adequate quantities of organic matter it is not available in adequate quantities. The only systematic investigation is on the use of rice straw as an organic fertiliser. The studies show that the application of straw can replace about 25% and 100% of the recommended nitrogen and potassium fertiliser respectively. Several methods of adding straw to rice fields are now available (Amarasiri and Wickramasinghe 1983).

Mid-Country Wet Zone

The soil distribution, soil properties and the climate in the mid-country zone has led to the establishment of a wide variety of crops. Rice is the principal crop in inland valley systems and on terraced slopes. Perennial tree crops such as tea, rubber, coconut, spices and fruits occupy the uplands. The root and tuber crops and vegetables are also grown in the uplands.

Most of the research effort of the Department of Agriculture in the mid-country wet zone has been on the improvement of the rice crop. The Rice Land Evaluation Survey (Somasiri et al. 1978; Panabokke and Somasiri 1980) provided the basis to fully appreciate the impact of the microenvironment on the performance of the rice crop in this region. The impact of topography and the hydrology showed a distinct bearing on the production potential of any land element. The information from the above survey helped to identify the need for different rice varieties, management practices, fertiliser recommendations, etc., depending on the land system and the hydrological conditions of a land element. Detailed studies of some selected valley systems (Kularatne 1981; Vivekanandan 1984; Joseph 1986) indicated the close relationship of soils in the landscape, soil fertility and the production potential. The soil fertility status of different land elements within the same valley system differ according to the hydrology of the site. In particular, the soil phosphorus availability is related to the water movement and hydrology of the site. Soil fertility studies and response of rice to added chemical fertilisers have been a subject of investigation for a long time in this region. Fertiliser recommendations have been made on the basis of these investigations (Nagarajah 1986).

The use of rice straw as an organic fertiliser has been recommended to partially replace chemical fertilisers (4 t/ha rice straw to replace 100% potassium and 30% nitrogen; A review of crop research, Department of Agriculture 1987). Research to increase nitrogen-use efficiency also has been conducted. Based on trials the fertiliser recommendations have been made for most vegetables, roots and tubers, and fruits. The diversity of the soil, climatic and hydrological conditions obtained even within one single tract or within one valley system in this region provides the basis for breeding rice varieties that suited the different conditions in the region. Large scale testing of new improved varieties was undertaken. Tolerance to adverse hydrological conditions and low temperatures is among the priorities in rice breeding for this region.

Up-Country Wet and Intermediate Zone

Tea is the main perennial crop in this region. In other agricultural lands of this region food crops are cultivated year-round. The soil and climate are conducive to the development of a traditional agriculture, where rice and other food crops have been planted in rotation. The present cropping intensity is 300% or more, and commonly the crop rotation consists of rice/potato/vegetables per year on the same land. Because of the high intensity of cropping, the addition of organic matter (farmyard manure), chemical fertiliser and lime (2 t/ha) has been practiced for more than a decade.

For potatoes and vegetables, depending on the variety and kind of vegetable, the farmers tend to follow the recommended fertiliser rates or add more. The current rate recommended for potato is 1500 kg of the mixture 8-17-12 NPK/ha. The recommended rate for leafy vegetables is 625 kg of the mixture 14-21-14/ha as basal and a top dressing of 250 kg of urea. The recommended rate for root vegetables consists of 625 kg of 16-20-12/ha and top dressing of 375 kg of 30-0-20/ha. A study of the nature of organic matter in this region (Handawela et al. 1970) showed that humidification decreased with increasing elevation. This study also showed the C/N ratio in forest soils to be less than that of grassland soils. The forest soils contained more fulvic acid than grassland soils.

Other recent research consists of the introduction of other cereal food crops such as wheat, triticale and maize and the short rice varieties. Selection of potato resistant to diseases, potato and vegetable seed production and breeding of rice for cold tolerance and early maturity, are also being carried out.

Research on soil management has been very limited. The intensive use of agrochemicals is causing some concern, because there are indications of decline in productivity.

Current and Future Research

The current research programs and what may be required in the future are considered in this section in respect of the same regional categories considered earlier in this paper.

Low-Lying Lands of the Low-country Wet Zone

In a regional context, the challenge is to manage the acid soils under a very complex hydrological situation so as to increase the rice production in the lowlands and to produce root crops and horticultural crops on the uplands. In developing the research strategy it is important to understand the complex hydrology and the problems associated with it and also the influences of microtopography of the low-lying lands. Further, these low-lying lands behave somewhat differently, depending on the size of the drainage basin in which each is located. Flooding, salt water intrusion, acidity, and workability are determined by the elevation of the land with respect to the mean sea level. In higher elevations adjacent to highlands, commonly iron toxicity problems are encountered, which is a result of interflow of soluble iron and intense soil reduction. It is unlikely that some of these problems will be eliminated. Therefore, the strategy that may be followed by agricultural research is to develop varieties that will stand the adverse conditions and to develop management practices. The development of salinity and amendments to soil acidity are being investigated. A knowledge of soil fertility and response to added fertiliser is needed for the different land systems and subsystems in the area. Investigations on the nature, concentration, and formation of phytotoxic substances such as different organic compounds, and on the presence of soluble metallic ions injurious to crop plants, are needed.

Inland Valley Systems of the Low-Country Wet and Intermediate Zone

Breeding of rice varieties to suit the different soil and rainfall conditions is a priority. Rainfall variability is very high in this region. Rice varieties that can compete with weed growth are very useful in this situation. Nitrogen use efficiency needs to be evaluated under this environment. Frequent wetting and drying occur particularly in the Intermediate zone in the absence of irrigation. Studies of phosphorus fixation and availability of these soils have not been carried out. In general more detailed soil fertility studies would be required. Use of organic matter with chemical fertilisers is under investigation.

Mid-Country Wet Zone

The soil and hydrological conditions in the inland valley systems and terraced slopes are highly complex. Soil studies have indicated the need for more than one rice variety even within one valley system. Similarly different management practices are needed. For this region, rice improvement and field testing of new varieties have to be given high priority. In upland areas, the improvement of vegetables and fruit is a major research concern.

Soil fertility and the response of rice to added nitrogen, phosphorus and potassium is a continuing study. Further studies on potassium reserves and their availability are being made. Use of rice straw and green manure as organic fertiliser is being evaluated. In the region, the fertility status of soils is highly variable. Nitrogen use efficiency, and phosphorus availability and fixation, are some of the studies that must receive adequate attention.

Up-Country Wet and Intermediate Zones

In this region, vegetables and potatoes are economically the most important crops. However, grain legumes, roots and tubers and fruit are also grown. In this area of very high cropping intensity, the dominant crop rotations are rice/potato/vegetables throughout at least three crops. A good part of the research effort is to manage these soils for the production of these crops. The long term effects of adding nitrogen, phosphorus, potassium, lime and organic matter on potato and vegetables must receive adequate attention. In spite of a build-up of total phosphorus in these soils, responses to added phosphorus have been observed and the farmers continue to add phosphorus to the vegetables. At every season, for potatoes and vegetables, agrochemicals are added at more than the recommended rates. Extent and mechanism of phosphorus fixation and lime requirements have not been studied adequately. Exchangeable aluminium saturation levels and pH relationships, if any, may be useful in recommending lime rates.

There is apparent degradation of the soils in the region. The estimation of erosion damage and suitable protective measures are urgent.

Conclusions

A considerable body of information on acid soils in Sri Lanka with respect to occurrence, properties, management and potentials are available. Many of the management problems have been identified. Stable land use patterns are already established. A large volume of research information on the soil behaviour under current management practices is available. However, several areas of research appear to be urgent, in order to sustain the present levels of production. Long term effects of high agrochemical inputs need evaluation, because such practices appear to cause some decline in soil productivity. Immobilisation of added plant nutrients under different soil and hydrological conditions needs investigation. The relationships of nutrient uptake, and the ionic balance in the soil–water medium as influenced by the hydrological conditions in an acidic soil environment, may give an insight into the physiological disorders in crops such as bronzing in rice.

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Management of Acid Soils for Food Crop Production in Thailand

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Abstract

Acid soils are extensive in Thailand. Ultisols occupy 45% of the country's 51.3 million ha, and Oxisols represent 0.26% (0.13 million ha) in Thailand. Some upland Alfisols and Inceptisols (Dystropepts) can also be classed as acid soils. Acid sulfate soils in a broad sense can also be considered acid soils, but management practices on them can be slightly different from those on other well-developed acid soils.

Crops grown on these acid soils are quite diverse. Some of the important food crops cultivated included rice, cassava, corn, sorghum, mungbean, peanut, soybean, vegetable crops and fruit. So far, management of these acid soils for cultivation of fruit trees appears to be most successful but is based on high technology cultural practices. Since most areas of acid soils in Thailand, except those in Peninsular Thailand and some parts of the southeast coast, are under a tropical savanna climatic regime, field crop practices normally encounter a lack of moisture content due to intraseasonal drought, weed control problems and proper fertiliser application. Farmers' practices, though they have been improving, are still not able to cope with these adverse conditions. Research results and government recommendations so far cannot be effectively used to formulate acid soil management packages for crop yield sustainability.

Introduction

Thailand is one of the few countries in the world that has continued a long tradition of having surplus food for export. Generally, its main export is agricultural products, which account for approximately 70% of the total value of exports despite the fact that the country has a relatively small cultivated area compared to that of other food-producing countries (Moncharoen et al. 1987). This may be attributed to a strategy of agricultural development that mainly focuses on natural resources. Nevertheless, the agricultural productivity in Thailand is far from being the best. Crop yield per unit area and the rate of farm production are still low and not satisfactorily sustainable. Applied research projects based on agrotechnology transfer have been encouraged and they are being conducted by various agencies to improve crop performance. Some of the research projects have been supported by international funding agencies.

Though serious research on food crop production in Thailand started more than three decades ago, it is still not well established. Technologies on breeding to obtain higher-yielding cultivars and the development of irrigation schemes and water resources have been advancing quite satisfactorily. Many crop varieties have been handed on to the farmers to encourage a better crop yield and a better quality food product. Also, in lowland areas irrigation schemes have enabled farmers to increase crop production frequencies. Surprisingly, however, crop yield per unit area in farmers' fields has either remained static or declined in recent years (FAO 1984; TDRI 1987). Since integrated

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pest and disease control measures have also been developed extensively and proved to be quite effective, there is at least one aspect to reconsider more carefully — soil management practice. To stabilise the agricultural sector, planners and scientists in Thailand have agreed to include all four major components–cultivars, water resources, integrated pest and disease control measures inclusive of postharvest processing, and soil management practices into the development strategy.

Research on soils for crop yield improvement also started some years ago. Inventory research to document national soil resources started at least 50 years ago and the first general soil map of the country was produced in 1946 (Changprai 1973; Kheoruenromne 1983; Pendleton 1946). The more active period started in 1963 when the Department of Land Development was established. Fertiliser trials for improving crop production were started even before 1963 by staff of the Department of Agriculture, but soil types were given little attention. This situation continues to the present, but with a much better awareness of the problem. From soil resources data, it is evident that many factors can play a role in presenting crop yield improvements. Thailand has a vast area of acid soils, and farming in these areas is mostly under rainfed conditions, posing serious problems for sustaining yields of food and other crops. Only a few crops with strong inputs from the government can be managed successfully on these acid soils. Pot experiments and field trials have been going on for at least 20 years in the hope of developing improved technologies for the farmers. Though improvements have been made for some crops, much remains to be done. This paper summarises the current status on management of acid soils for production of food crops in Thailand.

Physical Environment of Thailand

Thailand can be subdivided physiographically into six regions (Moormann and Rojanasoonthon, 1972) (Fig. 1). The population of Thailand is approximately 57.2 million with a population density of 1–2 persons/ha, being most heavily concentrated in the Central Plain around Bangkok.

Climate, Land Use and Major Economic Crops

Thailand is dominated by the monsoon. Most parts of the country are under tropical savanna climatic regime (Aw) with some exceptions. A part of Southeast Coast and Peninsular Thailand are dominated by tropical monsoon climate (Am). The northern mountainous areas with higher altitudes have been classed as humid subtropical (Cw) according to Köppen (1931).

Annual temperature ranges are 24–26°C in the north at high altitudes, 28–30°C in the Central Plain area and 26–28°C for the rest of the country. The average annual rainfall ranges between 900 and 4000 mm with higher amounts of rainfall in some parts of the Southeast Coast and Peninsular Thailand. Long-term variability of the country annual rainfall generally ranges between 20 and 30% and the maximum variability does not exceed 40%. Nevertheless, greater variabilities of monthly rainfall are found in the northeastern and northern parts of the country. The generalised climatic data and conditions for Thailand are given in Table 1. Thailand is characterised by three major seasons; rainy season from May to October, cool and dry season from November to February and hot and dry season from March to May. Most of the country except parts of the Southeast Coast and the Peninsula have a pronounced dry season. April is the hottest month whereas January is generally the coolest month of the year.

Agricultural land use is of prime importance to Thailand. At present, five broad categories of land use are recognised (Table 2). Though the national forest reserve was estimated to be rather high, it has been reduced considerably. Agricultural land can be subdivided according to kind and type of crops. Rice and upland crops have been the major land use types in Thailand. The rice cultivation area has been relatively stable, but rapid expansion of upland cropping areas is continuing. This expansion is quite serious since there has been some encroachment on national forest reserves. Perennial cropping areas are more extensive in the southern and central parts of the country where tropical fruits are grown. Para rubber has been a very important crop for the South, and has been expanding in the eastern part of Thailand recently. The oil palm area in Thailand is strictly in the South. Urban areas are not as

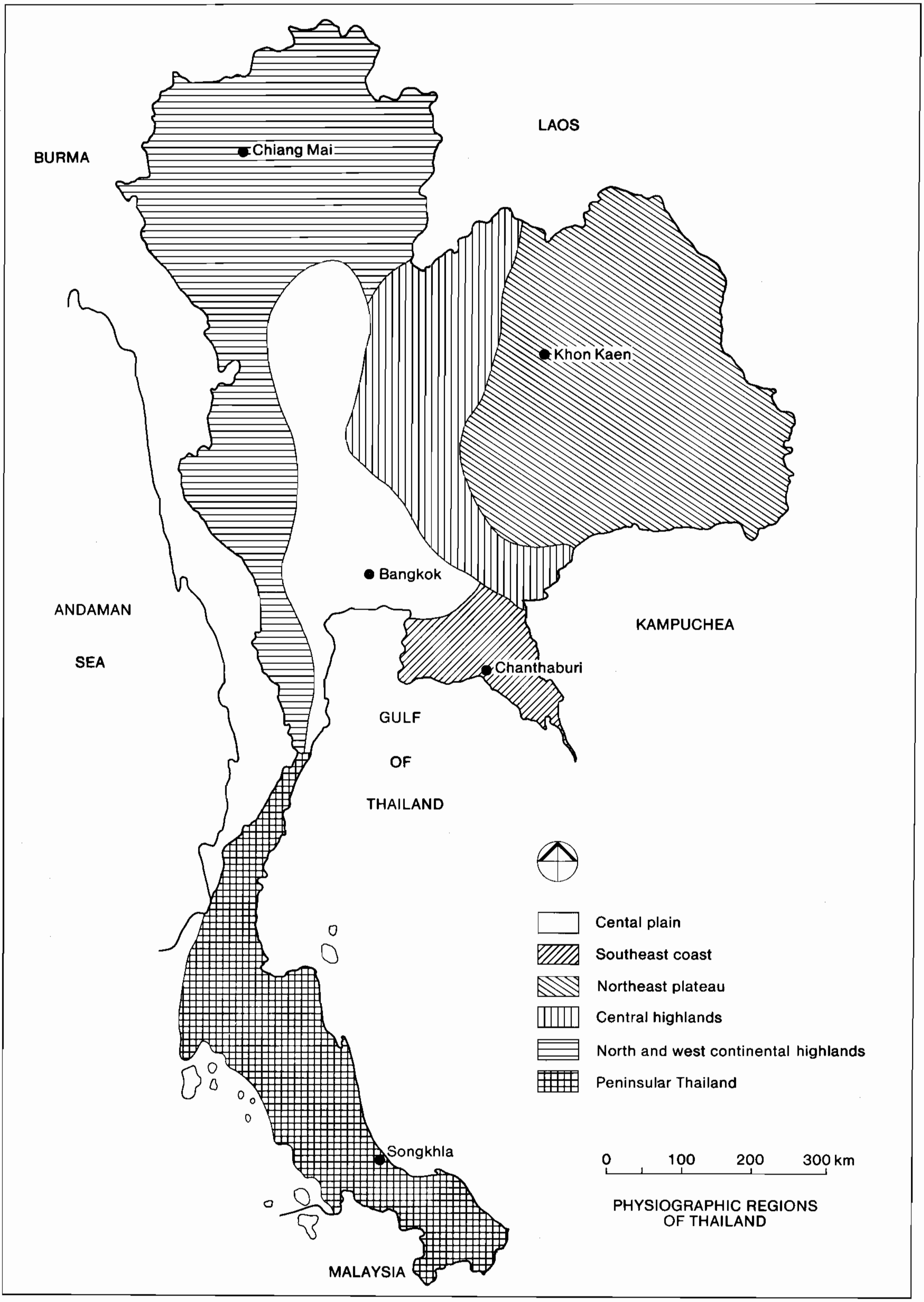

Fig. 1. Physiographic regions of Thailand (modified from Moorman and Rojanasoonthon 1972).

Table 1. Generalised climatic data for six physiographic regions of Thailand.

	Central Plains	Southeast Coast	Northeast Plateau	Central Highlands	Nth. and West Continental Highlands	Peninsular Thailand West Coast	Peninsular Thailand East Coast
Annual rainfall (mm)	1220–1592	1312–4456	1089–2136	1352	1054–1744	2177–5106	1018–2568
Annual mean humidity (%)	64–74	74–78	68–73	70–73	71–75	77–83	78–82
Annual mean temperature (°C)	27–29	27	26–27	26–28	24–28	27	27–28
Absolute maximum temperature (°C)	39–44	38	42–43	41–43	40–43	35	38–39
Absolute minimum temperature (°C)	5–12	9	2–4	2–7	2–6	19	14–18

Table 2. Land use of Thailand[a] (10^6 ha) modified from TDRI (1987).

Land use type	North	Northeast	Central	East	South	Total	%
National Forest Reserve[b]	10.37	5.41	2.04	1.41	2.57	21.80	42.48
Agricultural Land	5.60	9.95	3.74	1.91	3.13	24.33	47.41
Rice	3.43	6.23	2.11	0.56	1.15	13.48	
Upland crops	2.02	3.72	1.35	1.08	0.05	8.22	
Horticultural crops	0.01	–	0.01	–	–	0.02	
Para rubber	–	–	–	0.17	1.54	1.71	
Oil Palm	–	–	–	–	0.06	0.06	
Perennial crops	0.11	0.01	0.27	0.11	0.34	0.84	
Urban	0.07	0.08	0.19	0.03	0.07	0.44	0.86
Water bodies	0.10	0.16	0.10	0.03	0.10	0.49	0.95
Others (abandoned land, marsh, swamp, rock outcrop, beach, etc.)	0.85	1.27	0.88	0.05	1.19	4.24	8.30
Total	16.99	16.87	6.95	3.43	7.06	51.30	100

[a]Data based on TDRI (1987).
[b]Including already encroached forest lands.

extensive as water bodies in Thailand. Most cropping practices are under rainfed conditions.

Thailand has an impressive record as an exporter of food and feed grains, but crop yields are still below world average. The increase in economic crop production in the past decades was mainly due to the increase in cultivated areas. Major economic crops grown in Thailand included rice, cassava, rubber, sugarcane, corn, tobacco, coffee, cotton, beans (soybean and mung beans) and kenaf. In addition, tea, castor seed, sesame, kapok, tamarind, fruit, vegetables and pineapple are also considered significant economic crops.

Soils and Landforms

Soils and landforms are closely related and they generally play a combined role in cropping practices and soil management. The relationship between soils and landforms in Thailand was demonstrated by Scholten and Siriphant (1973). In Thailand, soils in the lower lying landscape are poorly drained, and are flooded annually for a certain period. Rice is the most important crop in this area. For the upland type of landforms diverse field crops are found. In Thailand, lower land with flat topography and heavy texture soils normally gives higher crop yields.

Based on taxonomic classification (Soil Survey Staff 1975, 1987) nine orders of soils except Aridisols are found in Thailand, areas of each being shown in Table 3. The major orders are Ultisols, Alfisols and Inceptisols. A study also revealed that a total area of approximately 10.88 million ha of problem soils exists in Thailand (Panichapong 1982).

Table 3. Soils of Thailand. Area is recalculated from the latest draft of the generalised soil map (1:1 000 000 scale).[a]

	Area		
Soil Order	10^6 rai[b]	10^6 ha	%
Alfisols	29.4079	4.7052	9.17
Entisols	14.2389	2.2782	4.44
Histosols	0.5132	0.0820	0.16
Inceptisols	31.1076	4.9772	9.70
Mollisols	4.2973	0.6875	1.34
Oxisols	0.8338	0.1334	0.26
Spodosols	0.4811	0.0769	0.15
Ultisols	143.7043	22.9926	44.81
Vertisols	1.7638	0.2822	0.55
Unclassified	94.3490	15.0958	29.42
Total	320.6969	51.3110	100

[a] Moncharoen et al. (1987).
[b] 6.25 rai = 1 hectare.

Acid Soils in Thailand

Ultisols in Thailand are quite extensive (44.8% of total land area). These are acidic (pH 5.5 and lower in general), highly leached and well-developed soils. They can be found both in upland and lowland areas and have been cultivated extensively in all parts of the country. Though Alfisols are considered more fertile soils, many upland Alfisols are quite acidic with a similar pH range to that of the Ultisols. The extent and distribution of Ultisols and Alfisols in Thailand are shown in Fig. 2. Some lowland Inceptisols (Sulfic Tropaquepts) and some upland Inceptisols (Dystropepts) can also be considered as acid soils in Thailand. Oxisols, the highly weathered soils with substantial accumulation of oxides, are also acid soils. Their extent in Thailand is rather limited (0. 26% of total land area). They have been found as spots in the lower part of the Northeast and the Southeast Coast. From the data it is clear that there is an extensive area and distribution of acid soils in Thailand. Diverse crop practices are found on these soils, and in general, crop yields are low, declining and not successfully sustained.

Management of Acid Soils

Acid soils are generally highly leached, well developed with low activity clays and variable charge characteristics (Buol et al. 1980; Theng 1980). One of the most basic constraints on crop production of the acid soils is the low level of available nutrients. Other constraints of acid soils for cropping practices have been studied and reported to include low pH, low cation/ion exchange capacity and base saturation percentage; high aluminium saturation percentage; in some cases high and often toxic concentrations of manganese; high phosphorus fixation capacity; low water-retention capacity; low organic matter content with the organic matter fraction consisting largely of coarse, purely dispersed materials and an absence of stable organomineral complex; low level of microbial activity; and some are sensitive to compaction and erosion (von Uexküll 1982, 1987). These conditions suggest that cropping practices on them need particular management to avoid excessive loss of plant nutrients and toxicity of some elements. Many of these soils (particularly the relatively sandy ones) in Thailand have quite low buffering capacity and fertiliser management is quite difficult. Adding to this problem are moisture deficiencies and weeds. It is a fact that most cropping areas in Thailand have been thriving under rainfed conditions of the tropical savanna climatic regime, where rainfall distribution is generally bimodal. The intraseasonal drought period is quite often too long and moisture deficiencies become very serious. Crop loss due to drought is not uncommon. Local weeds are more resistant to drought, and fertility status of the soils and problems of weed control also often cause crop failure.

Pests and diseases are important, though their types and behaviour are now well understood and

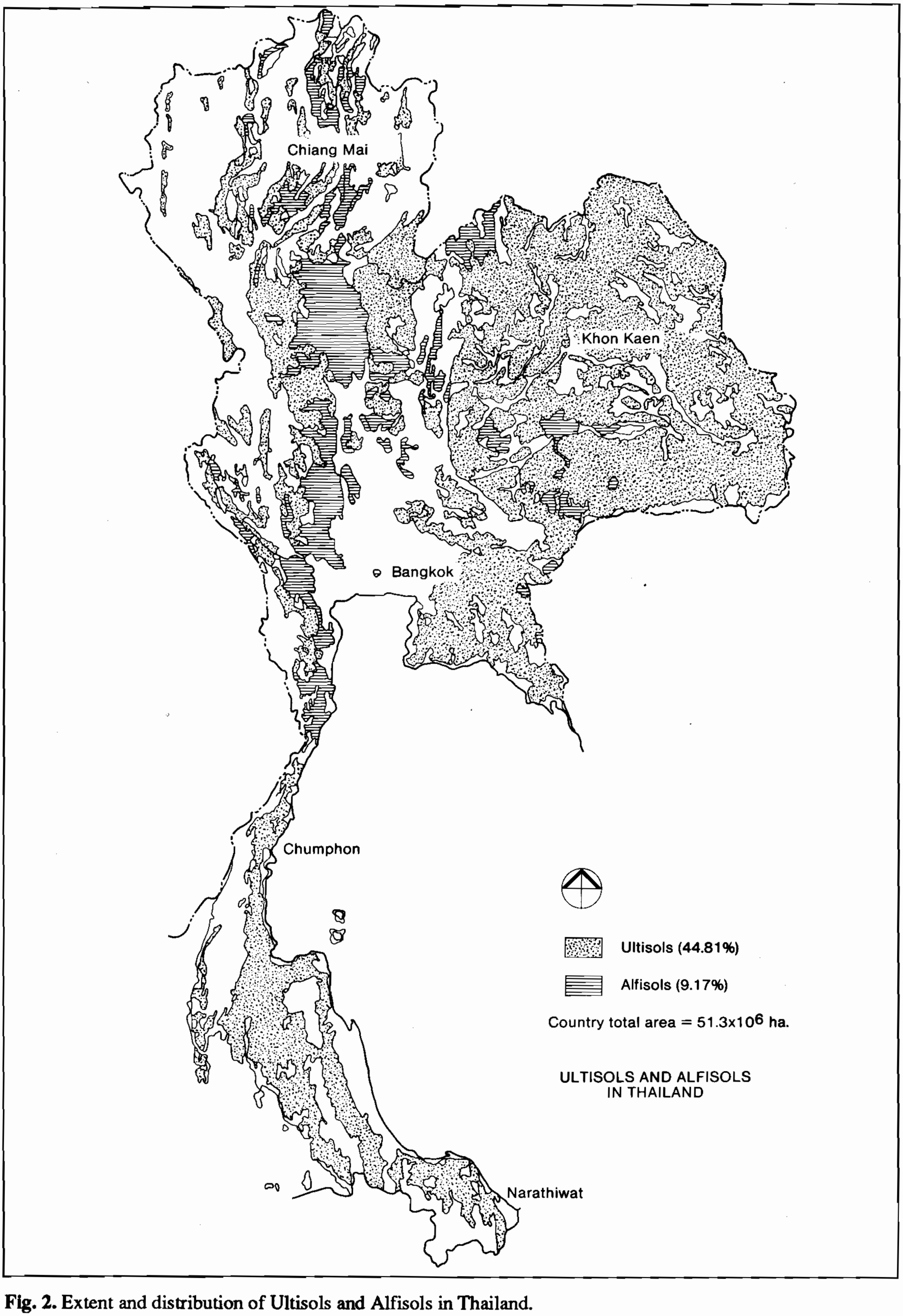

Fig. 2. Extent and distribution of Ultisols and Alfisols in Thailand.

integrated control measures have been developed and proved to be effective. To cope with the common problems of management of acid soils, cultural practices include the use of cover crops, green manuring crops and various kinds of organic fertilisers, combined with the application of chemical fertiliser and liming. Liming upland acid soils has not proved to be effective.

Food Crops Grown on Acid Soils

Crops grown on acid soils in Thailand are quite diverse, including rice, cassava, corn, sorghum, mungbean, peanut, soybean, vegetable crops (various kinds) and fruit trees. Sugarcane is grown extensively in some areas of acid soils.

Rice cultivation on acid soils can be both in upland and lowland areas. Cassava is most extensively grown on relatively sandy acid soils (sandy Paleustults). It is also grown extensively on other acid soils throughout other regions except in Peninsular Thailand. Corn and sorghum have been extensively grown on acid soils in the past but they are now mostly grown on higher pH soils. Mungbean, peanut and soybean are grown on acid soils but in a more restricted way. Crop losses for these crops are relatively more common and they are now extensively grown in lowland areas after rice, preferably with irrigation. Vegetable crops including chilli, tomato, onion and garlic are also grown on acid soils. However, their production under rainfed conditions is rather limited and the yield per unit area is generally low.

Fruit trees are grown extensively on acid soils, particularly in areas with a better distribution of rainfall. The Southeast Coast (mostly on Oxisols), southern part (on Ultisols mainly), northern part (Ultisols and Alfisols) are major fruit-producing areas on acid soils. Major fruit trees in these areas include durian (*Durio zibethinus*), rambutan (*Nephelium lappaceum*) and mangosteen (*Garcinia mangostana*) (Southeast Coast); longan (*Dimocarpus longan*), litchi (*Litchi chinensis*), mango (*Mangifera indica*) (Northern); rambutan and *Aglaia* spp. (Southern). Fruit trees are also grown on acid soils in the Central Highlands. The cultivars used are similar to those in the northern part of the country.

Acid Soil Management

Farmers' Practices

Conventional farming practices by farmers have been continued from the past, but are evolving towards mechanised practices. Low input is still the key for crop production in small-scale farming in Thailand. Most food crops are grown on acid soils (both upland and lowland) with little or no fertiliser. For large-scale farmers the practices are usually based on recommendations by agricultural extension workers, and fertilisers are much more heavily used. Farm machines used range from simple farm implements and hand-push tractors for small-scale farmers to well equipped farm machinery for large-scale farmers and corporations. Weed control is generally done by hand or with spades if the area is not large, but machines are used for large areas coupled with chemicals. Normally, in cultivation practice of some more important economic food crops, land is ploughed twice prior to planting and planting methods differ from crop to crop. General cultural practices done by small-scale farmers in production of some important food crops have been reported for rice, cassava, corn, peanut, mungbean, soybean, papaya, pepper and major fruit trees (Charoenrath 1983; Thai Fertilizer and Agricultural Marketing Association 1981). Farmers' practices are now leaning toward those recommended by government agencies. However, in most areas, acceptance of recommendations is still very low and sustainable yield per unit area is not expected. For field crops cultural practices are as follows:

1. Ploughing twice before planting;
2. Fertiliser application at planting (compound fertiliser 16–20–0 or 15–15–15) at variable rates mostly from approximately 78 to 156 kg/ha. Additional one to two applications as recommended by extension workers. This practice is somewhat more extensive than the one without fertiliser application.
3. Planting is generally in the beginning of the rainy season depending on moisture status (April to June).
4. Weed control is most commonly done by hand and simple farm implements/machines. Chemicals are also used in certain cases.

5. Pests and disease control varies from place to place, but mostly according to government recommendations or pesticide company recommendations.

6. Manures and other type of organic fertilisers are also used and they are slowly gaining popularity for small-scale farmers.

7. Burning the field after harvest (before land preparation) is still a common practice in some areas for both lowland and upland conditions.

Land productivity in Thailand has been rather poor and, in some cases, has been declining. For example, average yield per hectare of rice from 1982 to 1986 is only 1.9 t/ha which is about three times less than that of Japan, USA and Taiwan. Yield of rice varies by region ranging from 1.5, 1.7, 2.3 to 2.4 t/ha in the Northeast, South, Central and North respectively (TDRI 1987). Rice cultivation is mainly on acid soils in the Northeast and the South. Therefore, these data indicate that management of acid soils for rice cultivation is far from successful. Another good example of unsuccessful management of acid soils for food crop production is cassava. Most cassava cultivation is on acid soils under rainfed conditions, with declining yields. The average yields from 1982 to 1986 are 1.4, 1.6 and 1.7 t/ha in the Northeast, North and Central regions, respectively. The Northeast, which is the most important producing region, has the lowest yield. This is not a surprising situation since cassava in the Northeast is generally cultivated on relatively sandy acid soils. For other field crops, farmers' practices are similar to those for cassava cultivation on acid soils.

The more successful management practice of acid soils for food crop production is found in fruit tree cultivation. On upland clayey acid soils (i.e. Oxic Paleustults, Typic Haplustox (Northeast), Paleudults, Haplorthox (Southeast)), Ultisols having udic soil moisture regime in Peninsular Thailand and acid Alfisols in the North, fruit trees have been managed successfully. However, farmers' practices for fruit trees on those soils are generally on the high agricultural technology side with quite high inputs. Water and fertiliser have been quite well managed.

Acid Soil Management

Government Aspect

Research on management of acid soils has been underway for over 20 years by various agencies involved in agricultural development schemes in the country. Many pot and field trials for specific crops have been reported in the literature. From all of these research results, recommendations on some cultural practices and fertiliser applications have been published. Extension activities have also been underway to pass these recommendations to the farmers. It is a very slow process. Many research results have not yet been synthesised to form a suitable package for acid soil management. Lack of sufficient funds to continue particular aspects of research presents serious problems. At present, recommendations on cultural practices generally include the conservation of organic matter in the soils, split application of fertiliser, using green manuring crops and cover crops, cropping system practices, using compost and mulching. There has not been a specific study to develop a management practice package for any particular crop grown on acid soils. One of the most serious problems may be due to the lack of proper site characterisation for field trials (Moncharoen et al. 1987). Without this, correlation of results seems to be impossible. At the present stage, research and development on acid soil management for food crop production certainly needs much more input from the government.

Conclusion

Because acid soils are generally highly leached their fertility status is mostly low. Crop production on them needs certain management practices to obtain satisfactory yields. Sustainable agriculture on these soils has always been difficult worldwide.

In Thailand, the situation is no different. Research to improve the productivity of these soils has been continuing for many years. Some findings have been passed on to the farmers. Nevertheless, the situation on cultural practices at present does not seem to have changed either to cope satisfactorily with soil degradation or to slow the yield decline of many crops. However, the farmers' practices appear to have evolved slowly, to be in line with government recommendations on cropping. Fertiliser recommendations for broad categories of soils based on soil colour and texture with respect to kind and types of certain economic crops have been established in Thailand. However, management of acid soils for food crop production, from the point of view of both researchers and farmers, is still far from satisfactory. Only the high-input management of acid soils for fruit tree cultivation appears to be successful.

From extensive literature review based on technical reports, unpublished papers and scientific papers written by staff of Department of Agriculture, Department of Land Development, Department of Agricultural Extension, and faculty members of universities involved in teaching agriculture, few facts appear to substantiate the existing condition on management of acid soils for food crop production in Thailand. Firstly, past research on this topic emphasised crops more than soil management practices. Secondly, many studies on improving soil productivity have been short-lived and concrete recommendations could not be developed and passed on to the farmers. Environmental conditions for cropping practices on acid soils have not been well understood. Thirdly, there is the lack of proper site character-isation in field trials. Without proper knowledge of the site and its intrinsic characteristics, including its homogeneity and variability, specific recommendations cannot be made from research findings. Thus, agrotechnology transfer on soil management practices is impossible, because at the moment there is no specific acid soil management package to be used as a guideline for sustaining crop yields in Thailand.

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Management of Sloping Soils for Food Production in Vietnam

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Abstract

Sloping soils in Vietnam occupy three-quarters of the total land area. Soils are subject to serious erosion problems and leaching thus degrading the soil and reducing crop productivity. There is an urgent need to conserve and increase the soil fertility in Vietnam to improve food crop production. Recent research on terracing and intercropping has demonstrated improved yields of cassava and legumes in yellow-red soils of Nghe Tinh.

Introduction

Occupying three-quarters of the total natural land area of the country, sloping soils in Vietnam can be divided into:

- slight sloping soils (3–15°) – 4.5 million ha,
- moderate sloping soils (5–25°) – 3.5 million ha, and
- strong sloping soils (>25°) – 17.0 million ha.

Due to the natural conditions and inappropriate land use and management by humans, sloping soils in Vietnam are affected by many unfavourable soil processes such as erosion and leaching that lead to soil degradation. Consequently there is an urgent need to study appropriate methods of managing these soils to conserve and increase the soil fertility and to increase crop yield.

In recent years some work has been done in this field, and some highlights of results of management of sloping soils for food crop production are presented in this paper.

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Characteristics of Sloping Soils in Relation to Unfavourable Soil Processes

Most soils in the mountainous regions in Vietnam are yellow-red soils with the dominating ferralitic process of weathering expressed in the leaching bases and accumulation of iron and aluminium. Consequently, the soils are low in alkaline and alkali-earth cations, with low base saturation (25–40%), acid (pH (KCl) = 4.0–5.5, even lower) and low in available phosphorus (due to phosphorus fixation caused by high content of iron and aluminium).

The humid tropical climatic conditions with two distinct dry and wet seasons, with high and concentrated rainfall (averaging from 1700–2000 mm/year in the period from May to October) have accelerated the vertical leaching, and where the relief is sloping, caused strong soil erosion leading to plant nutrient loss.

The extent of soil erosion is very considerable. Erosion products have a nutrient content considerably higher than that in surface soil (Table 1).

Observations carried out in various yellow-red soils showed that on average 1 t of

Table 1. Nutrient content of eroded soil in receiver and in surface soil.

Soil	Organic matter %	N %	P_2O_5 %	K_2O %
Red-brown on limestone	4.8	0.01	0.13	0.28
Grey-brown on limestone	5.3	0.20	0.14	0.40
Eroded soil in receiver	11.0	0.48	0.23	0.84

Table 2. Potassium content in weathering layer and in soil under different methods of farming (K_2O).

Methods of farming	Parent rocks	
	Granite	Gneiss
Weathering layer	3.54	4.76
Soil under forest	2.28	1.76
Soil, with erosion control measures	1.73	1.86
Soil, without erosion control measures	0.47	0.55

lost soil contains 1.2–21.6 kg N, 1.0–1.5 kg P_2O_5 and 15.0–32.0 kg K_2O. By using inappropriate farming methods, annual soil loss can reach 350 t/ha and the surface soil can be eroded by 1–4 cm. That is the cause of skeletal eroded soil formation and nutrient exhaustion of the yellow-red soils on sandstone, shalestone and old alluvial, with a shallow surface soil layer in many mountainous regions in Vietnam.

Erosion has completely changed the characteristics of yellow-red soils on granite and gneiss which were high in potassium by origin. Due to farming practices on sloping soils without erosion control, these soils have become low in potassium like the yellow-red soils on basalt and porphyrite (Table 2).

Vertical leaching is also great, the leachate containing clay particles, organic matter, nitrogen and especially a high content of Ca, Mg and K. The decrease in alkaline and alkali-earth cations content can be seen through the results of analysis of the soil layers: their content in the lower layer is 3–4 times higher than that in the surface one (Table 3).

Apart from climate, parent rocks have an apparent influence on the chemical properties of soils, especially potassium. Yellow-red soils on

Table 3. Alkaline and alkali-earth content (NH_4^+ is included) in different soil layers (meq/100 g soil).

Soil	Depth (cm)			
	0–20	20–40	60–80	90–100
Yellow-red on shalestone	5.00	7.40	10.7	11.8
Yellow-red on gneiss	6.50	6.40	11.6	15.8
Yellow-red on basalt	5.10	6.30	9.70	12.5
Yellow-red on porphyrite	5.10	7.30	10.4	13.9
Yellow-red on limestone	6.00	8.50	11.5	14.2
Yellow-red on granite	7.30	8.60	11.8	13.9

acid magmatic rocks (liparite, granite) are the soils highest in potassium (about 2%) and the soils formed on neutral or basic magmatic rocks are the lowest ones (<0.5%). By contrast, the phosphorus content is higher in the soils on basic magmatic rocks compared with that in the soils on acid magmatic rocks (0.3–0.5%, compared with 0.02–0.1%, respectively). The specific limiting factor for the soils on acid magmatic rocks is phosphorus.

Regarding clay mineral composition, most of the sloping soils in Vietnam contain mainly kaolinite, therefore the soils are low in alkaline and alkali-earth cations by origin. Highly dispersed minerals often found in the soils are goethite and gibbsite. In the soil conditions in Vietnam, iron contained in these minerals possesses many positive aspects. It is the link of organomineral compounds which lead to the formation of granule structure, a good physical property of soils. Due to these minerals the phosphate ions have been chemically absorbed and consequently protected against leaching; besides, under reduction conditions, phosphorus is easily released.

Soil humus content varies greatly and is affected by the latitude and especially the presence of plant cover. Under humid tropical conditions, the intensity of the organic matter mineralisation process is very high. It is higher than that of humus formation. Besides, the sloping relief and the use of inappropriate ways of farming, like extensive cultivation, monoculture, burning and destroying of forests, etc., have promoted the soil erosion and leaching processes, thus the organic matter content decreases seriously. Methods of farming have a strong influence on the soil organic matter (Table 4).

After 3 years of continuous rice cultivation without fertiliser application, the content of soil organic matter decreases rapidly. Tilling and fallowing or plant cultivation without fertilisation rapidly decrease the soil organic matter; cultivation with fertilisation reduces the decrease in organic matter.

Organic matter is not only the crop nutrient source, but it also increases the moisture retention of the soils. All measures for returning organic matter into the soils or covering them increase the soil moisture content considerably.

So, it is essential to have appropriate methods of soil management in order to continuously supplement the soils with organic matter and to have the integrated effect of conserving and improving the fertility of sloping soils. To create a system of intercropping leguminous green manure plants, grain legumes with main crops will be a valuable measure in solving this problem.

Some Measures for Management of Sloping Soils for Food Crop Production

For utilisation, conservation and improvement of sloping soils in Vietnam there are three categories of measures: structural, biological and agrotechnical.

Structural measures are an essential prerequisite to the replacement of shifting cultivation and extensive farming by settled agriculture and intensive farming. Special attention has been paid by the government to the construction of water reservoirs, storage dams as well as irrigation and drainage systems.

Terracing, especially for rice cultivation, was carried out many years ago in the north and northwest regions. This measure gives the highest erosion control effect and at the same time maintains the soil fertility and ensures stable crop yields. Results of experiments on erosion control for upland maize and pineapple showed that terracing has minimised the loss caused by erosion to the lowest degree. Even intercropping of green manure plants cannot give such a high erosion control effect as that of terracing. Nevertheless, in the socioeconomic conditions of the country, this costly, expensive measure cannot be applied on large areas for all crops grown on sloping soils. Other measures, such as forming green shelter belts across the slope, making canals and ramps and growing green manure plant strips, have been effectively applied.

Agricultural measures, such as ploughing, tilling and sowing along the contour, have great economic effect because of their simplicity, low cost and low labour use. This practice is usually carried out in combination with intercropping of green manure plants.

Intercropping is highly effective for all crops grown on sloping soils. A sod of *Stylosanthes gracilis* between cassava rows effectively promoted accumulation of organic matter, nitrogen and available phosphorus, thereby resulting in an increase of cassava yield of 10–15% compared with cassava planted alone.

Grain legumes have been found suitable for intercropping. Vietnamese farmers like to grow these leguminous plants because apart from their soil conservation and improvement effect they can give grain for people and for animal feeding. Results of experiments conducted on yellow-red soil on sandystone in Nghe Tinh province are

Table 4. Soil organic matter under different methods of farming.

Soil	Method of farming	Organic matter (%)
Degraded yellow-red soil on basalt after 3 years improvement	After 3 years of improvement	4.8
	Ditto, 1 year of rice cultivation without fertilisation	3.7
	Ditto, 1 year of rice cultivation with fertilisation	4.3

Table 5. Yields of cassava and intercropped legumes (yellow-red soil on sandy stone, Nghe Tinh).

Treatment	Yield (t/ha)		
	Cassava tuber	Green manure	Legume grain
Cassava alone	11.3	0.0	0.00
Cassava with intercropped groundnut	12.0	12.0	0.52
Cassava with intercropped mungbean	14.0	7.6	0.14

given in Table 5. They showed that the yields of cassava with intercropped peanut and mungbean increased by 7–24% and still depend on the yields of grain legumes. Also, a gain of 7.6 and 12 t of green biomass is obtained for incorporation into the soil to increase the organic matter content and improve the soil physical properties. Similar results have been obtained in annual crop patterns, for example maize with intercropped peanut or other grain legumes.

At present, the introduction of leguminous plants, especially grain legumes, to the food crop patterns and cropping systems has become conventional in the mountainous regions of Vietnam.

Planting green manure plants in temporary or permanent strips on the countour not only breaks the velocity and volume of erosion and runoff, but also provides a considerable amount of bulk organic matter and the yield of the main crop is increased (by 7–24% for cassava).

Mulching the soil surface with dead vegetative materials or living cover is a good measure that increases soil moisture content by 3–6% and decreases soil temperature by 3–5°C.

The role of organic manures expresses itself foremost in the improvement of the physical properties of sloping soils. Incorporation of organic matter into the soil increases the soil moisture content and the percentage of water stable aggregates and, as a result, increases the capacity for soil erosion control. Regarding the chemical properties, the nitrogen regime is improved by decomposing organic matter incorporated into the soil; besides, available phosphorus is released in greater amounts due to the increase in intensity of reduction and complex formation processes limiting the fixation of phosphorus. Therefore application of organic and green manures for all crops on sloping soils markedly increases crop yields and at the same time the soil fertility is maintained and improved. Results of experiments on cassava conducted on different sloping soils in Vietnam are given in Tables 6–7.

Application of green manures, organic manures and mineral fertilisers in combination gives a higher effect (Table 8).

Provision of organic manures is solved by collecting crop residues as well as wild green manure materials for composting. Green

Table 6. Some chemical properties of red-brown soil on limestone after 1 year of cassava cultivation (soil depth 0–20 cm).

Criteria	Original soil	After 1 year of cultivation by using			
		Hole-making	Soil digging	Hole making + 20 t green manure	Ridging +20 t green manure
Organic matter (%)	4.20	2.90	2.70	4.00	4.20
pH (KCl)	4.80	4.20	4.10	4.40	4.50
Al_3 (mg/100g soil)	6.60	18.60	23.50	5.30	5.00
NH_4^+ (mg/100g soil)	2.70	2.20	2.50	4.60	3.30
P_2O_5 (mg/100g soil)	trace	trace	trace	0.73	1.25
Fresh tuber yield (t/ha)		10.30	8.90	18.90	17.40

Table 7. Soil chemical properties after 2 years of cassava cultivation (soil depth 0–20 cm) (yellow-red soil on basalt, Central High Plateau).

Treatments	pH (KCl)	Organic matter (%)	N (%)	P_2O_5 (%)	Available P (mg P_2O_5 /100g)
Cassava alone	3.8	3.42	0.14	0.24	5.35
Cassava with intercrop of *Stylosanthes gracilis*	3.8	5.72	0.16	0.23	12.25
Cassava mulched with 50 t of grasses	3.7	5.77	0.18	0.22	8.10

Table 8. Effect of combined application of organic manures and mineral fertilisers on dryland crop yields (100 kg/ha) (yellow-red soil on basalt, Central High Plateau).

Treatments	Maize	Cassava	Upland Rice
Without fertiliser application	15.0	60.0	5.0
Farmyard manure	28.4	100.4	10.2
NPK	32.5	132.0	14.6
NPK + FYM	45.6	186.0	18.2
NPK + FYM + Lime	50.0	198.0	20.7

manure plants can be planted alone or intercropped with the main crops, especially with thinly planted crops like cassava at an early stage. By this means 10–30 t of green biomass can be obtained annually for incorporating into the soil or mulching for main crops. In order to obtain a great amount of biomass, additional application of some chemical fertilisers (20 N, 30 P, 20 K) is needed.

The effect of different mineral fertilisers on crops grown on sloping soils is usually considerable, especially K for the soils formed on neutral or basic magmatic rocks and P for the soils on acid magmatic rocks (yield increase is 200–300%).

For cassava the factors limiting crop yield are N and K. Application of potassium for cassava increases the yield by 180%. For maize the limiting factors are N and P. Combined application of mineral fertilisers, lime and organic manures increases crop yields considerably.

Effect of phosphate fertilisers on legumes (grain legumes or leguminous green manure plants) is marked both for pure cultivation and intercropping with cereals (maize), especially for the last case the total yield of crops per area unit is high.

By contrast with paddy soils, efficiency of liming on sloping soils is quite obvious (maize yield is doubled by liming). Calcium cations are significant for the acid sloping soils because of their effect on the quality of CEC.

Liming provides the crops with Ca as a nutrient, helps promote the mineralisation of organic matter and changes the calcium percentage in cation exchange capacity, but does not reduce the soil acidity. Where lime is scarce due to difficulties in transportation in the sloping mountainous regions it is better to reserve lime for leguminous crops (the yield of soybean increases by 26% by application of 500 kg lime/ha).

Apart from fertilisation, the application of rotation and intercropping to determine the crop patterns suitable for each soil type is also being studied. There have been some advanced crop patterns/cropping systems for food crops grown on sloping soils. Usually these consist of combinations of different crops such as maize, upland rice, cassava, sweet potato, soybean, peanut and some other grain legumes, e.g. early maize and intercropping soybean, autumn maize with beans, summer soybean—summer autumn maize—autumn peanut, early upland rice—spring sweet potato—summer soybean—autumn peanut, etc. An advanced crop pattern should have one crop of legumes provided with a small amount of lime (less than 200 kg CaO/ha); crop residues from these legumes will enrich the soil organic matter, influence CEC and increase the soil buffer capacity.

Conclusion

From the above-mentioned results some conclusions can be drawn:

Unfavourable soil processes, such as erosion and leaching that lead to the degradation of soils, greatly affect the fertility of sloping soils. The appropriate measures for managing sloping soils should be those integrated to overcome these unfavourable processes, to conserve and improve soil fertility, and to increase crop yield.

Farming measures for solving on-site the source of organic matter by creating a system of intercropping leguminous green manure plants, grain legumes with main crops, planting green manure plant strips, mulching with green manure materials to continuously supplement organic matter to the soil are the most suitable measures for sloping soils.

The effect of fertilisers on crops grown on sloping soils is great. Much attention must be paid to the application of mineral fertilisers (especially phosphorus fertilisers for legumes) in combination with organic manures to ensure the increase of crop yield and soil fertility.

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