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NUTRIENT MANAGEMENT FOR FOOD CROP PRODUCTION IN TROPICAL FARMING SYSTEMS.

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EDITORS' NOTE.

All papers presented at the symposium, invited papers and voluntary papers, have been published in the Proceedings.
Most papers had to be edited in order to keep the total volume of the proceedings at a manageable size, although all effort has been made to maintain the authors' data and their interpretation.
Therefore, the papers in these Proceedings are being presented as the responsibility of the respective author(s).

J. van der Heide

NUTRIENT MANAGEMENT FOR SUSTAINED CROP PRODUCTION IN THE HUMID AND SUBHUMID TROPICS

Key Words: Alfisols Humid and subhumid Tropics Nutrient management Oxisols Ultisols

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SUMMARY

Food production in many developing countries in the humid and subhumid tropics need to be increased to meet food deficit of current and anticipated future population. This can be done by area expansion, intensification of production systems or both. For uplands dominated by Alfisols, acid Ultisols and Oxisols in the humid and subhumid tropics, sustainable, viable and environmentally sound technologies for food production are emerging slowly. Results of investigations conducted during the past few decades have given better understanding on the soil and nutrient management components needed for sustained crop production on these soils. Through appropriate surface soil management by proper tillage and organic residue retention, combined with fertilizer and other chemical amendments, high crop yield can be obtained. The various nutrient requirements and management problems for sustained crop production were discussed. Because of the high costs of chemical inputs needed to sustain crop production, and problems of their availability in many developing countries, an integrated soil fertility

management that can better recycle native and applied nutrients and incorporate biologically fixed nitrogen need to be promoted.

I. INTRODUCTION

Production of adequate food to meet the need of increasing population has become a major challenge for many developing countries, particularly those in tropical South America and Africa (Brown, 1985). Dudal (1982) has indicated, that the world as a whole has enough land to produce food for present and future generations, however, due to uneven distribution of land resources, population and production inputs, food production is still inadequate to meet current and anticipated future population in many developing countries in the tropics. To meet the deficit, food production need therefore be intensified and substantially increased, which can generally be done by either increasing cropping intensity on existing crop land, or by expansion and development of additional land or by combination of both (Ofori et al., 1986). Applicability of these options vary greatly between regions depending on local availability of suitable land for area expansion, viable soil management techniques and inputs, infrastructure and socio-economic conditions. Based on results of FAO studies, Ofori et al., (1986) also concluded, that the warm humid tropics offers the largest remaining land reserves for horizontal expansion where 92% of the total land reserve of 1,464 million hectares is still available. However, as cautioned by various authorities, future development of new land need to be adequately researched to prevent recurrent of past disasters observed in many areas of the tropics (Bentley, 1986; Ofori et al., 1986).

For the humid and sub-humid tropics many years of research and experience have produced various highly successful and stable management practices for perennial crop production. Similarly, based on many generations of traditional wisdom and practical experience, Asian farmers have developed stable and viable multistorey home garden production systems on the uplands (Soemarwoto, 1987) and rice based systems on the wetlands. The biggest challenge facing agricultural scientist working in the humid and subhumid tropics, is to develop sustainable, viable and environmentally sound food production systems for the uplands. Okigbo (1981) has listed the necessary ingredients for a sustained agricultural production system in the humid tropics which will include the following measures: (1) chemical lost during cultivation has to be continually replenished, (2) physical conditions of soil are to be maintained at a favourable level with adequate levels of organic matter, (3) soil has to be kept constantly covered and erosion controlled, (4) increase in soil acidity and presence of nutrient deficiencies and toxic constituents have to be continually corrected, and (5) build up of pests, weeds and diseases need to be prevented. The problem is, that the viable and acceptable know how needed to build the necessary soil and crop management practices for the major upland soils are still lacking, and the generation of alternative technologies is only emerging slowly.

This paper will attempt to highlight some of the important elements of nutrient management for sustained crop production on the uplands dominated by Alfisols, Ultisols and Oxisols in the humid and sub-humid tropics.

II. NUTRIENT CONSTRAINTS

Alfisols, Ultisols and Oxisols together dominate large parts of the uplands of the humid and subhumid tropics. Oxisols occupy 35% of the land area, followed by Ultisols with 28%, and Alfisols with 4% (NAP, 1982). In areas dominated by these soils, alternating cropping and bush fallowing is the traditional agriculture practiced for food crop production. The system is characterized by low nutrient inputs, low yields, short cropping cycles and relatively long fallow periods for soil fertility restoration. Since, the fallow plays an important role in regenerating soil fertility, shortening or eliminating of the fallow period resulting from population and land pressures has to be compensated for, as far as nutrient restoration is concerned, by use of fertilizers. These soils which are less extensively utilized compared to the more productive volcanic and alluvial soils, have been widely researched during the past few decades to determine their potential, nutrient constraints and management problems, as they offer the largest possibility for land expansion and intensification of food production. Results of soil fertility trials conducted at several institutions (Kang and Fox, 1981; McIntosh et al., 1981; Sanchez, 1981) in the humid and subhumid tropics have greatly increased the knowledge of nutrient constraints and management problems for sustained and high yield crop production.

The Oxisols and Ultisols commonly found in the humid region are highly weathered and leached. They are stripped of most of their primary minerals and have their clay mineralogy dominated by kaolinite and Oxides of iron and aluminium (Juo, 1981). They are characterized by strong acidity, low levels of exchangeable potassium, calcium and magnesium levels, and high proportion of the exchange complex is saturated by aluminium (Table 1). Deficiencies of nitrogen, phosphorus, potassium, calcium and magnesium are common on these soils (Sanchez, 1981; Kang and Juo, 1983). Liming is essential to reduce toxic aluminium and manganese levels in Oxisols and Ultisols (Fox et al., 1985). An additional constraint of these soils, is their medium to high phosphorus - fixation capacity (Juo and Fox, 1977; Sanchez and Uehara, 1980). Despite their low fertility and various nutritional constraints, however, with application of chemical fertilizers in combination with liming and mulching, sustained and reasonable high crop yields can be obtained on the Ultisol as demonstrated by McIntosh et al., (1981) (Figure 1). Nicholaides et al., (1984) was also able to sustain high crop yield on acid Ultisol with liming, multi nutrient (N,P,K, Mg, Cu, Zn, B and Mo) application and crop rotation.

The less leached Alfisols with low surface charge and kaolinitic mineralogy are mainly found in the subhumid tropics. These soils have moderate fertility (Table 1). Deficiencies of nitrogen and phosphorus are common (Kang, and Fox, 1981; Sanchez, 1981). With intensive and continuous cropping deficiency of potassium will also emerge. Sustained high crop yield can also be obtained on these soils with adequate fertilization and proper soil management (Figure 2 and 3). In Figure 2, the Alagba soil series derived from sedimentary parent material showed lower productivity than the Egbeda soil series derived from banded gneiss.

III. NUTRIENT MANAGEMENT FOR CONTINUOUS CROP PRODUCTION

The productivity of upland soils in the humid and subhumid tropics decline rapidly following forest or bush fallow clearing and cropping. The rate of fertility decline with cropping differs between soil types. With no fertilizer decline with cropping differs between soil types. With no fertilizer inputs fertility decline is faster on acid Ultisols and Oxisols than on Alfisols (Sanchez, 1976). Many researchers have attempted to quantify the factors responsible for rapid decline in soil productivity following land clearing. Decline in crop yield with traditional farming according to Jurion and Henry (1964) is more due to a build up of weeds and parasites than to decline in chemical fertility. Andriesse (1987) based on studies in Serawak and Sri Lanka also concluded, that there was no evidence of nutrient decline as being responsible for abandoning fields after one year of cropping. This is also illustrated in Figure 2, where no weeding contributed in faster decline in maize yield at both locations. Decline in soil organic matter levels, soil erosion and leaching of nutrients are listed as main factors affecting rapid decline in soil productivity following land clearing (Lal, 1986; Roose, 1986). Roose (1986) further stated, that the rate of soil degradation can be reduced with proper land clearing and advocated the use of manual clearing and light burning for opening new lands.

Although the transition from forest or bush fallow to cultivation resulted in degradation of the physical, chemical and biological environments, the rate of degradation is rapid only during the first few years, until the soil attains a new

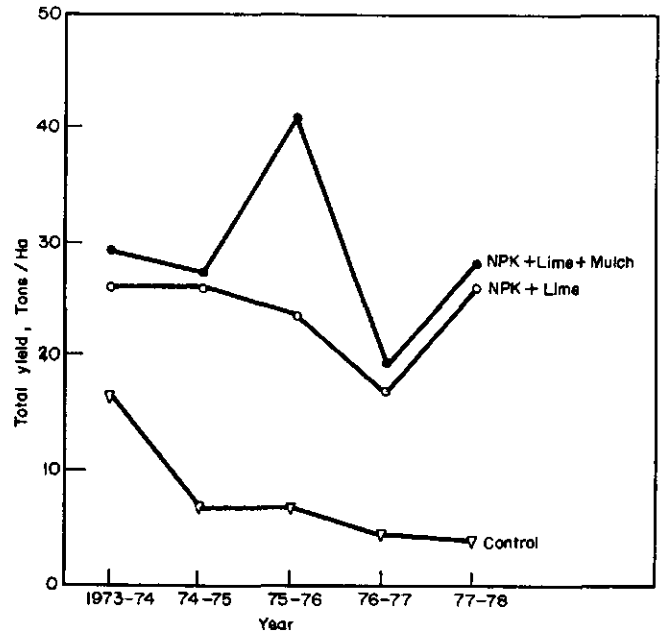

Figure 1. Effect of fertilizer application, liming and mulching on total dry grain yields of maize, upland rice, peanut, ricebean and fresh cassava tuber yield in cropping system on Ultisol in Central Lampung, (Adapted from McIntosh et al., 1981).

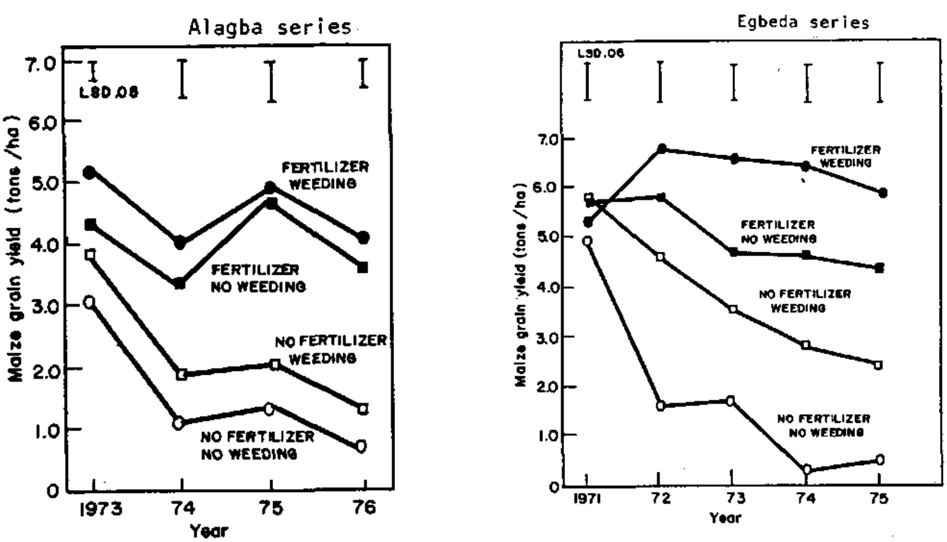

Figure 2. Effects of fertilizer application and weeding on yield sustainability of maize grown on Alfisols (Data from Egbeda soil series, Kang et al., 1977; Data from Alagba soil series, B.T. Kang unpublished).

TABLE 1. Properties of the Surface Layer (0-15 cm) of Four Soils under Tropical Rainforest (Kang and Juo, 1986).

pH (H_2O)	Org. C (%)	Exchangeable cations (me/100g) K	Ca	Mg	Al	H	Effective CEC (me/100g)	Al Satn. (%)
		Alfisol (Paleustalf), Ibadan, Nigeria						
6.2	1.4	0.3	4.6	1.5	0	0.1	6.3	0
		Ultisol (Paleudult), Onne, Nigeria						
4.3	1.2	0.04	0.2	0.05	1.8	0.5	2.8	64
		Oxisol (Haplorthox), Yangambi, Zaire						
3.8	1.4	0.1	0.2	0.1	1.7	1.2	3.3	52
		Oxisol (Haplorthox), Itaitubi, Amazonian Brazil						
4.7	3.9	0.1	0.3	0.1	2.8	0.5	5.0	56

equilibrium depending on the type of cropping systems adopted (Roose 1986). With maintenance of adequate soil organic level and proper crop residue management (Lal and Kang, 1982), proper tillage system to maintain good seed bed and to minimize soil erosion (Lal, 1974; 1986), with adequate and balance fertilization (Manuelpillai et al., 1980; McIntosh et al., 1981; Kang and Juo, 1983; Nicholaides et al., 1984), soil productivity can be maintained at acceptable levels during the post clearing period.

III-1 NUTRIENT MANAGEMENT FOR ALFISOLS

a. Long Term Nutrient Responses

Benefits from fertilizer application on the Alfisols have been well documented, particularly with high yielding cultivars at high population densities and with improved management practices (Kang et al., 1977). However, information on nutrient management practices for continuous crop production is still lacking. Reliable information on nutrient requirement for continuous crop production can best be formulated based on results obtained from long term fertility trials and supplemented by soil testing as

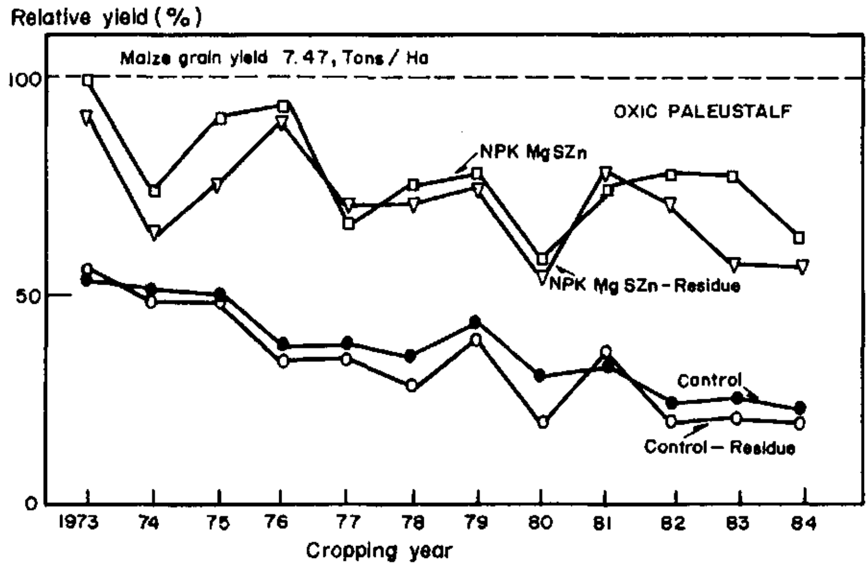

Figure 3. Relative maize yield as affected by fertilizer application and crop residue management (B.T. Kang, unpublished data).

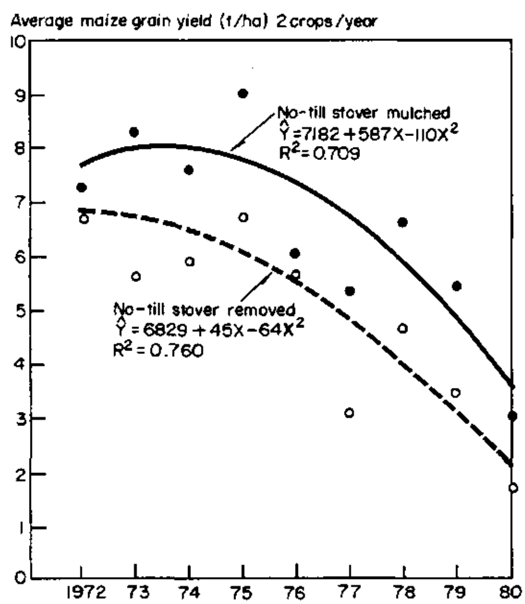

Figure 4. Long-term effect no-tillage system on grain yield of maize (cv TZB) under continuous maize monoculture with and without stover mulch on a kaolinitic Alfisol (Oxic Paleustalf) manually cleared from secondary forest at Ibadan (Kang and Juo, 1986).

illustrated in the example below.

To determine the nutrient requirement of an Alfisols (Oxic palustalf) in the forest zone of southern Nigeria for continuous crop production, a long term fertility trial was established in 1972. The trial was carried out for 14 years. The plot was manually cleared and subsequently lightly burned. Maize was planted during the major rainy season and rotated with sweet potato or cowpeas during the minor season. Soil erosion was minimal. On the sandy loam soil with fertilizer application high maize yield was obtained (Figure 3). During the first five years of cropping (first year yield was not shown, yield was low due to late planting) maize grain yield was sustained at higher level than in subsequent years where it stabilized at lower level. Although the maize yield recorded in 1984 was still high for the area, however, compared to the 1973 yield it has declined by 35%. Similarly, maize yield in the control plot has declined with continuous cropping. During the first three years following land clearing from secondary forest, there was only a small nitrogen response (Kang and Fox, 1981). Obvious nitrogen response was observed in fourth and subsequent cropping years. Large and significant phosphorus response was already observed in first cropping year following land clearing (Kang and Fox, 1981). This large and early phosphorus response was partly due to removal of vegetational biomass after land clearing. Result of other trial conducted in the same area where biomass was burnt as practiced by traditional farmers, showed no significant phosphorus response of the maize crop. A significant response to potassium in this trial was observed only in the ninth cropping year. During the fourteen years of cropping only small responses to sulphur and zinc were observed.

Continuous cultivation and fertilizer application also significantly effected soil properties (Table 2). Cropping and particularly continuous fertilizer application reduced soil pH, soil organic level and extractable cations. Repeated phosphorus application also significantly increased the extractable

TABLE 2. Chemical Composition of Surface Soil (Oxic Paleustalf) from Long Term Trial Plots Following 11 Years of Continuous Cropping with and without Fertilizer Application Compared to Plot Under Natural Regrowth (B.T. Kang unpublished data).

Treatment	$pH-H_2O$	Org C (%)	IN Am. K	Acetate Ca (me/100g)	Extractable Mg	Extr. P (ppm)
Control	5.83	1.03	0.21	6.04	0.78	2.1
NPKMgSZn	5.40	1.34	0.18	5.19	0.68	40.2
Fallow (regrowth)	6.63	2.04	0.53	10.39	1.87	7.8
LSD .05)	0.32	0.31	0.08	2.29	0.34	13.1

phosphorus status.

In this trial where erosion was kept to a minimum and the plots were annually tilled, retention of crop residue has only a small effect on crop yield (Figure 3). In no tillage system, retention of crop residue can have more dramatic effect on crop yield as shown in Figure 4. Removal of crop residue resulted in higher degree of soil compaction, chemical degradation and lower soil biological activity (Kang and Juo, 1986). In no tillage system with addition of adequate crop residue, Lal (1986) was able to maintain crop yield for 22 crops.

b. Nitrogen Management

Nitrogen is the most mobile and also the most easily exhausted nutrient in the soil. It is generally recognized as the key element for crop production, since crop yield level to a large extend depend on soil nitrogen status.

Traditional farmers relies on the fallow period and use of leguminous crops to restore soil nitrogen status. Through the use of intercropping systems, they can also better utilize native soil nitrogen (Kang, 1987). For sustain and high crop yield in intensive and continuous crop production system, nitrogen fertilizer input is required. As nitrogen is the most costly nutrient and its availability can also be a problem for small holder farmers, efforts should be made to: (1) increase efficiency of fertilizer nitrogen use, and (2) develop integrated nitrogen management systems that can fully exploit biologically fixed N_2 in the production system.

The amount of nitrogen fertilizer required to maintain high crop yield depend on soil type, land history, tillage system, cropping system and a great deal on the crop species and variety. The requirement on sandy soil and cropped land is higher than on newly cleared land (Kang and Fox, 1981). Split application of nitrogen can improve its use efficiency (Fayemi, 1966; Mughogho et al., 1986). Recent efforts to use new nitrogen fertilizer sources, such as urea supergranules has not resulted in improvement of nitrogen use efficiency (Mughogho et al., 1986).

Continuous nitrogen use is knwon to result in rapid soil acidification on the low buffered soils (Jones, 1976; Nnadi and Arora, 1985). Similar result is also shown in Table 2. Jones (1976) reported drastic changes in pH of two Alfisol profiles with application of high rates of ammonium sulfate in only three years. Changes are minimal with application of nitrogen as urea or calcium ammonium nitrate. The choice of the proper fertilizer source is therefore important in continuous cultivation. It also appears, that with continuous nitrogen fertilizer application even on the non acid soils liming may be required in the long run to reduce soil acidity.

The potential nitrogen contribution from biologically fixed N_2 can be significant (Dommergues and Ganry, 1986). In multiple cropping system non legumes can benefit from inclusions of legumes in the production system. The beneficial effect mostly coming from nitrogen left in the crop residue. Inclusion of legumes usually give small residual nitrogen as most part is removed in the grain harvest. The nitrogen contribution is usually also higher from sole than from intercropped gain legumes. Sole cropped grain legumes can contribute between 40 to 70 kg N/ha to the succeeding crop (Kang, 1987). Woody leguminous species can also contribute large quantitives of N in intercropping systems (Kang et. al., 1984; Dommergues and Ganry, 1986).

Inclusion of cover crops in the tropics can provide; (1) green manure, (2) mulch, (3) weed suppression and (4) erosion control. By far the most important role is organic matter contribution and soil structure improvement (Wilson et al., 1982). On the non acid soil, inclusion of leguminous cover crops can contribute significantly to the yield increase of subsequent crop such as maize grown in no-tillage system (Wilson et al., 1982). Since, the effect of cover crops is short lived (Faulkner, 1934), it can best be incorporated in a rotation system.

c. Phosphorus Management

On newly cleared land large quantities of phosphorus may be available from organic form (Mueller-Harvey et al., 1985) or from plant ash following burning of vegetation (Kang and Juo, 1986). This amount may be adequate for initial cropping, but have to be supplemented for continuous cropping.

The Alfisols derived from acidic rocks, due to their low phosphate fixing capacity (Juo and Fox, 1977) have low phosphorus requirement for crop production and high residual effect of applied phosphorus (Kang and Osiname, 1979; Bationo et al., 1986). For continuous cropping on phosphorus deficient soil, an intial dressing of 30 kg P/ha followed by maintenance dressings of 15-20 kg P/ha seems to be adequate. Slightly higher dressing is required on soils derived from basic rocks (Table 3), because of their higher phosphate fixing capacity. Due to the low phosphate fixing capacity of the soils, phosphorus placement is only advantageous at very low rates of phosphorus application (Fox and Kang, 1978). Recent studies with low cost partially acidulated rock phosphate sources have given inconsistent results and no obvious advantage over conventional sources (Bationo et al., 1986).

The low phoshorus requirement for crop production on Alfisols, may in part be due to the abundance of mycorrhizal

TABLE 3. Standard Phosphate Requirement Surface Soil of Selected West African Soils (Juo and Fox, 1977).

Soils	Sample number	Phosphate sorbed at 0.2 ppm soil solution	
		Range	Mean
		(ppm)	
Alfisols from acidic rocks	9	0-85	32
Ultisols from acidic rocks	9	15-110	55
Alfisols and Ultisols from basic rocks	6	190-420	253

infections of crops grown on the Alfisols, which is known to assist in phosphorus uptake by the crops (Ayanaba and Sanders, 1981).

d. Potassium Management

The potassium status of Alfisols as illustrated by examples from west and central Africa (Juo and Grimme, 1980; Juo, 1981), showed large differences depending on soil mineralogy and parent material. Those derived from basement complex rocks, mainly granitic gneisses, have moderate potassium status. Because of the low potential buffering capacity of the soil, there is also rapid decline of exchangeable potassium when fallow land is converted into crop land (Grimme, 1985). Juo (1981) also indicated, that soil organic matter form an important source of exchangeable potassium. Decline in soil organic level with cropping, will thus effect potassium availability to the crop. Under traditional system, crop residue and burning of fallow vegetation form important sources of potassium for crop production (Andriesse, 1987).

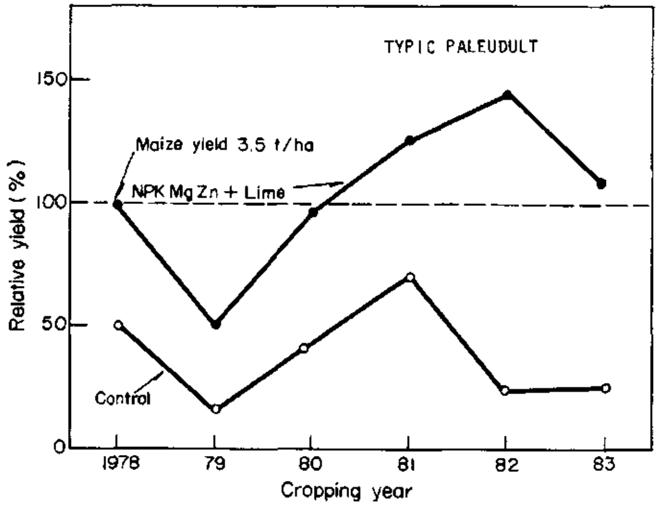

Figure 5. Relative maize grain yield as affected by fertilizer application and liming (B.T. Kang unpublished data).

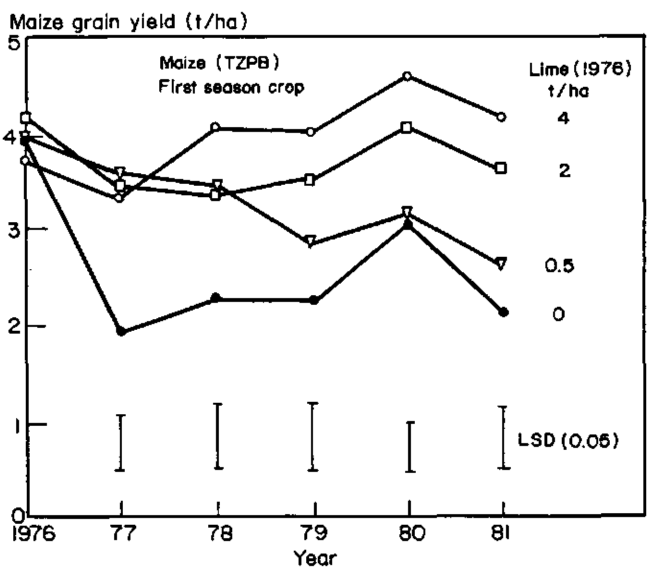

Figure 6. Residual effect of lime on maize yield grown on coarse - textured Ultisol (Typic Paleudult) (IITA, 1971).

Published data have shown, that potassium deficiency and responses increased with intensive and continuous cropping (Anderson, 1973; IPI, 1980). Retention and addition of crop residue and mulch maintains higher soil potassium status (Pichot et al., 1974); Bigot, 1977). Deficiency of potassium can be corrected by fertilizer application, and rates between 30-60 kg K/ha appears to be adequate for maintenance dressing (IPI, 1980).

Since, neither potassium fixation nor non-exchangeable potassium reserve plays an important role in controlling potassium supply to crop on the Alfisols (Juo, 1985), the level of exchangeable potassium can be adequately used to predict crop potassium requirement. Levels between 0.15-0.20 me/100g of exchangeable potassium for surface soils with sandy to loamy texture appear to be adequate (Juo, 1985).

III-2 NUTRIENT MANAGEMENT FOR ULTISOLS AND OXISOLS

a. Liming and Nutrient Responses

On the acid Ultisols and Oxisols soil productivity declines rapidly without chemical inputs (Sanchez, 1976). Traditional farmers rely on the use of plant ash from burning of vegetation as source of lime and plant nutrients. Addition of plant ash have more pronounced effect on the soil chemical properties of acid Ultisols than on Alfisols (Kang and Juo, 1986). On these soils, high maize yield can only be obtained with combined application of N, P, K, M, lime and manure (Force and Okigbo, 1974). Sanchez (1986) also mentioned, that with chemical inputs the fertility of the acid soils can be maintained at higher level in continuous production system than the original soil. Similar trend was also observed in ivestigation carried out in eastern Nigeria (Figure 5).

To deal with soil acidity problems of these soils, Sanchez (1981) suggested: (1) liming to pH 5.5 to neutralize exchangeable aluminium, and (2) using crop species that are tolerant to high levels of exchangeable aluminium. Low lime rates added serve primary to satisfy the calcium and magnesium requirements of the crops. On these soils even application of low lime rates to neutralize exchangeable aluminium have a considerable residual effect (Sanchez, 1981; IITA, 1981).

Results of liming and crop rotation experiment conducted by Dr. A.S.R. Juo on acid Ultisol in southeastern Nigeria showed, that relatively low rates of lime would be adequate to sustain crop yields under a continuous maize/cowpea rotation (IITA, 1981). With adequate supply of N,P,K, and Mg, liming at a rate of 0.5 t/ha can maintained maize yield at over 3 t/ha during first three years after liming (Figure 6). Sustained maize yields for six years or more were possible with a lime rate of 2 t/ha. For maize the critical Al saturation required to obtain 90% maximum yield was about 35% and for cowpea about 50% (IITA, 1981). Cowpea according to Sanchez (1981) responded only to a low rate of lime application that lower aluminium saturation from 80 to 68%. Application of high lime rates on these soil is not recommended because: (1) it can induced nutrient imbalance (Edwards and Kang, 1978; Friessen et al., 1980), (2) applied lime leached readily, particularly at high rates of application (Sanchez, 1981; IITA, 1981); although according to Sanchez (1981) it has an ameliorating effect on subsoil acidity, observations by Juo (IITA, 1981) showed no significant effect; and (3) lime is a costly commodity in various parts of the tropics particularly in tropical Africa.

b. Nitrogen Management

Pronounced nitrogen responses are observed on acid soils in the humid region even on newly cleared land (van der Heide et al., 1985). Due to rapid decline in soil organic matter status and high rate of nitrogen leaching (Arora and Juo, 1982), soil nitrogen status decline rapidly with cropping. Under high rainfall conditions; efficiency of nitrogen fertilizer use is low and nitrogen recovery is higher with intercropping (van der Heide et al., 1985). Splitting of nitrogen fertilizer application can reduce losses and increase nitrogen use efficiency by the crop (Arora and Juo, 1982). Studies on use efficiency of various nitrogen sources including urea, urea supergranules and calcium ammonium nitrate did not show any differences for the acid soils under high rainfall conditions (IITA, 1983).

Although annual leguminous cover crops such as Mucuna pturiens and Pueraria phaseoloides can play a sigificant role as ground cover and as source of mulch and organic matter on acid soils, their roles for nutrient cycling and source of nitrogen is rather limited. Studies conducted by Hairiah and Noordwijk (1986) have shown, that they have shallow root systems when grown on acid soils. Observations by van der Heide et al., (1987) also showed small nitrogen contributions from Mucuna on succeeding maize crop.

c. Phoshorus Management

Oxisols and Ultisols with sandy topsoils have low phosphorus fixation, while on those with clay content higher than 35% phosphorus fixation is severe and increase with increasing clay content (Leon and Fenster, 1979, Sanchez, 1981). Sanchez (1981) has extensively discussed the phosphorus management for acid soils and suggested the following strategies to overcome the high phosphorus fixation problems: (1) increase efficiency of phosphorus applications by identifying the rates and proper placement methods which give the best long-term residual effects, (2) use cheaper phosphorus sources, (3) decrease the soil phosphorus fixation capacity by cheap amendments, and (4) use crop species and varieties that are tolerant to low levels of availablable soil phosphorus.

d. Potassium Management

Ultisols and Oxisols from the high rainfall zone, particularly those derived from sandstone and sedimentary materials are known to have low potassium status (Ritchey, 1979; Juo, 1981; Sudjadi et al., 1985). Potassium responses are therefore very common on these soils particularly with continuous and intensive cropping. Kang (1984) observed significant potassium response of cassava grown on sandy Ultisols already in the second cropping year.

Traditional farmers rely on the use of plant ash as source of potassium. However, as reported by Seubert et al. (1975) added as plant ash to the soil, potassium disappeared quickly mainly due to leaching under high rainfall conditions. For intensive and continuous cultivation addition of potassium fertilizer is therefore needed. For high potasium demanding crops such as cassava or upland rice maintainance dressing using 50-100 kg K/ha may be adequate (Kang, 1984; Juo, 1986; Sudjadi et al., 1986). Sudjadi et al., (1986) also reported, that incorporation of plant residue can reduce potassium requirement for upland rice. For predicting potassium requirement for crop production, reliable soil testing methods still need to be developed for the acid soils.

IV. LOW NUTRIENT INPUT MANAGEMENT IN ALLEY CROPPING SYSTEM

Alley cropping is an intercropping system in which arable crops are grown between hedgerows of planted shrubs and trees preferably leguminous species. The hedgerows are periodically pruned to prevent shading the companion crop(s) (Kang et al., 1984). The shrubs and trees grown in the hedgerows retain the same functions for recycling nutrients, suppressing weeds and controlling erosion on sloping land as those in the traditional bush fallow. Use of woody leguminous species also add biologically fixed nitrogen to the system.

For the non acid Alfisols and associated soils in the humid and subhumid tropics inclusion of woody legumes such as *Leucaena leucocephala* and *Gliricidia sepium* add substantial amount of organic matter, and recycle large amounts of plant nutrients and can sustain yield of intercrop (Kang et al., 1984). Inclusion of woody species particularly legumes sustain higher crop yield even with nitrogen application (Figure 7). Kang (1987) estimated the nitrogen contribution from *L. leucocephala* and *G. sepium* hedgerows to intercrop maize at about 40 kg N/ha. Although promising results have been obtained in alley cropping with *L. leucocephala* and *G. sepium* on non acid soils (Kang et al., 1984;

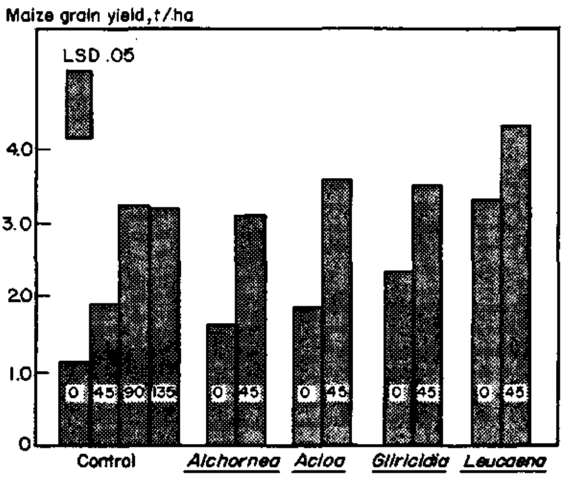

Figure 7. Grain yield of maize on eroded Alfisol (Oxic paleustalf) at Ibadan, Nigeria as affected by alley cropping with woody species (Acioa barterii, Alchornea cordifolia, Gliricidia sepium and Leucaena leucocephala) and nitrogen rates (Kg N/ha) (B.T. Kang, unpublished data).

Parera, 1986), however, both species do poorly on acid soils. On acidic Ultisols woody species such as Acioa barterii, Cassia siamea, Flemingia congesta and Inga edulis show more promise (Kang et al., 1968; Sanchez, 1987). Because of surface and subsoil infertility, addition of inputs is required for sustain alley cropping on the acid soils. Here the woody species can still play the important role of recyclying the added inputs.

CONCLUSIONS

The productivity of upland soils in the humid ans subhumid tropics declined rapidly during first few years following forest or bush fallow clearing and cropping. Productivity decline is faster with no inputs and poor crop husbandry. Research results have however shown, that sustain and high crop yields can be obtained on the Alfisols and on acid Ultisols/Oxisols. Key ingredients are; proper soil and organic residue management, balanced nutrient application and correction of toxic elements.

The less leached Alfisols require moderate nitrogen rates and low phosphorus rates for continuous cropping. Potassium is also required for intensive and continuous cropping. Since continuous application of nitrogen fertilizer particularly at high rates will acidify the soil, nitrogen fertilizers should be used judiciously. Incorporation of grain or cover leguminous crops in intercropping or rotation systems that can contribute biologically fixed N_2 to the production system should be encouraged, to reduce the requirement for nitrogen fertilizer.

On the less fertile and acid Ultisols/Oxisols, liming and multi-multinutrient (N, P, K, Ca, Mg, Zn, Cu) application are required for sustain crop production. On these soils, with balanced inputs and addition of organic residues, soil productivity can be maintained at higher level than in the original soil. The merit of inclusion of annual leguminous cover crops for nutrient cycling on acid soils need to be researched.

Long term fertility experiments are essential for the determination of nutrients needed and fertilizer rate requirements in continuous crop production systems. One season trials as pointed out by Kemmler (1982) is inadequate for making fertilizer recommendations. More long term fertility trials to increase our understanding on how best to manage the fertility requirements of the major soils in the humid and subhumid tropics for upland food crop production is needed.

Since, cost of chemical inputs (fertilizer and lime) and their availability can be prohibitive for small holder farmers, more efforts should be made in developing integrated soil fertility management systems that can reduce the requirement, and at the same time increase the use efficiency of added inputs. Considering the low activity and buffering capacity of these soils, development of nutrient management systems for sustain and high crop yields through better nutrient cycling such as in the alley cropping system need to be promoted.

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NUTRIENT MANAGEMENT THROUGH SHIFTING CULTIVATION
a comparative study on cycling of nutrients in traditional farming systems of Malaysia and Sri Lanka[1]

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Key words: shifting cultivation, soil fertility, recycling plant nutrients

SUMMARY

Nutrient changes during a shifting cultivation cycle were monitored in sites at Sri Lanka and Sarawak, representative for a poor leaching-prone soil medium combined with a semi-arid climate and a poorly drained nutritionally also poor soil with a wet equatorial climate, respectively.

The five year long study yielded a vast amount of factual data from which the following main conclusions are drawn:

(i) Monitoring of nutrient level changes in ecosystems involving both soils and biomass, and maintaining comparative conditions is complicated by great variability in actual situation, management and external factors. Quantitative studies are time-consuming, expensive and partly as a consequence of this, suffer from lack of replication.

(ii) Although the practice of shifting cultivation may universally be based on essentially the same processes of recycling nutrients through soil and regenerating biomass, there are considerable qualitative and quantitative differences in the recycling mechanisms operating in ecosystems due to dissimilarities in climate and soil. Two site conditions are important: the potential biomass production and the operating soil leaching regime. Climate plays a role in both. Therefore, each system has its own unique interplay of environmental factors which should be identified before innovations are to be introduced into the agricultural system.

(iii) "Burning", although generally recognized as common practice, is essentially only needed to accelerate the mineralization process to release sufficient nutrients from biomass to produce an adequate crop. Its role appears highly ambivalent depending on the site-specific factors. In a wet equatorial climate part- or unsuccessful burning is responsible for prolonged release of major nutrients inclusive of N and P even up to one year after burning through decomposition of felled biomass. But the initial levels may be too low for one adequate crop.
Intensive burning and piling of biomass can result in too high temperatures in topsoils causing volatilization of soil N and alkaline conditions and can

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therefore produce the opposite to the required effects. Probably too intensive burning in a semi-arid climate with neutral soils is not as justifiable as it may be in a wet-equatorial environment with acid soils, but much depends on the amounts of biomass involved.

(iv) No evidence was found for declining nutrient levels as being responsible for abandoning the fields after one year cropping. The results rather indicate the reverse situation, namely continuous increase in nutrients through presumably wash-out of accumulated ashes and decomposition of remaining biomass after burning. Enrichment of the topsoil in all sites could be followed up to four years after burning but particularly in soils below ash accumulations in Sri Lanka.

(v) Vegetation regeneration and soil nutrient levels indicate that the interplay of independent variables: climate and soil, and dependent variables: vegetation types and leaching regimes, are crucial to the mechanisms of nutrient cycling and the dynamics thereof.

Based on these conclusions it is considered that:

(i) In a **wet equatorial climate** nutrient residence times are essentially short because of fast and large biomass production, high litter fall, rapid decomposition and dense rooting in topsoils.
Small available amounts of P, K, Ca and Mg are frequently recycled. Production of N is closely related to that of biomass. Fast growing shallow rooting seedlings of adapted species are dominant in the secondary vegetation, and seem necessary to maintain the system.

(ii) Shifting cultivation in a **semi-arid climate** on a soil with a high leaching potential results in rapid depletion of active phosphorus, sulphur and potassium in the ecosystem involved.
Soils with a high clay content and relatively high CEC appear to offer a substantial buffer to losses in bases in a climate inducing high leaching.

Strategies aimed at halting soil or ecosystem degeneration should take note that:

Fast growing species with deep rooting systems are required for arresting the leaching down of nutrients in the early years of regeneration, or, isolated trees in the original vegetation should remain standing through abstaining from clear felling. It is highly probable that the tradition of only one cropping year is based on the desirability to maintain an adequate stand of still living stumps of deep rooting perennials capable of rapid recovery after the burn, to catch leached nutrients with their deep rooting systems. Too frequent burning destroys this essential capacity of the ecosystem to sustain itself. The role of perennial deep rooting species or, depending on climate and soil, adapted grass species, in maintaining this system cannot be too strongly emphasized. The conclusion is justified that strategies aimed to improve or sustain shifting cultivation by introducing adapted agroforestry systems are probably the most logical and effective ones. Choice of vegetation, however, remains very much dictated by climate and soil.

INTRODUCTION

Presently, an estimated 300 million people within the tropical belt depend for their daily food supply on shifting cultivation. The system is locally known by names such as ladang cultivation (Indonesia), berumah (Malaysia, Sarawak), chena (Sri Lanka), and kaingin (the Philippines), to mention some examples. In literature terms such as "swidden cultivation" and "slash and burn" are frequently used, the latter term probably being the most derogative one referring only to the most outstanding features of the system and which are reason why ecologists tend to view it with contempt because it would lead to large scale degradation of scarce tropical forest resources.

Although techniques and management vary locally, basic to all these systems is the employment of the natural recuperative power of the ecosystem to replenish fertility lost during a relatively short cropping period through a prolonged period of bush fallowing.

This traditional agricultural system has received considerable attention in anthropological and social studies (e.g. Freeman, 1955; Ruthenberg, 1976; Grandstaff, 1977; Sherman, 1980), but until recently relatively little fundamental work on agro-ecological aspects was carried out although the system depends primarily on the interaction among soil, biosystem and climate.

Pre-1970 agronomic studies were reviewed by Nye and Greenland (1960), mainly in Africa, and Conklin (1963) for Latin America and the Pacific. The Food and Agriculture Organization of the United Nations (FAO), urged by the need to revive interest in traditional low-input farming systems to combat the decreasing productivity of ecologically unstable land resources, contributed reviews of shifting cultivation in Latin America (FAO, 1971) and Africa (FAO, 1974). These revealed a paucity of fundamental studies concerning the interaction of soil and vegetation. Past studies, e.g. by Greenland and Kowal (1960), Zinke et al. (1970), and also those of more recent date, e.g. Lundgren (1978), Ewel et al. (1984), and Stromgaard (1984), which are within the context of the present study of specific interest, concentrated more on the factual, static situations than on the dynamics of systems supply. Notwithstanding their scientific value results often are incomparable because of differences in approach, climate, soil type, methodology of sampling and in analytical procedures. Extrapolation of results to other environments is thus very difficult, if not impossible.

To remedy this situation the Royal Tropical Institute in Amsterdam started observational studies in Malaysia (Andriesse, 1977). These showed that the great variability existing particularly in the level of available nutrients of individual fields, even belonging to the same soil series, is caused by many factors, and not only by the duration of fallow observed for the last shifting cultivation cycle. Contributing to this noted micro-variability are decay of the biomass and ant activity during the bush fallow period, incomplete burning, ash accumulation and erosion during the cropping period. Because of the generally low absolute nutrient contents of the soils, these variables have a relatively strong influence on the fertility level of each sampling point. Therefore, the precise action of bush fallow on soil fertility under different climatic conditions is still not completely understood. However, by obtaining reliable data from a series of standardized monitoring studies conducted under different soil and climatic conditions, it may be possible to formulate statements applicable to bush fallow systems generally.

Such studies were initiated in Sarawak (Malaysia), Sri Lanka, Thailand, the Philippines and Indonesia in 1980, but because of many problems of various nature it was not possible to complete these studies in all sites and only those in Sri Lanka and Sarawak yielded sufficient information for an adequate length of time to allow studying the obtained results in depth. Although the general research objective was to generate more detailed and reliable information on the changes in plant nutrient levels in soils caused by shifting cultivation practices, in order to gain more insight into the alleged sustainability of the system, the more specific aims were:

(i) to obtain statistically reliable quantitative information on nutrient level changes and related processes in locally adapted shifting cultivation systems,
(ii) to identify the roles played by the independent variables climate and soil in causing the changes noted,
(iii) to indicate how the knowledge acquired could be usefully applied to improve the efficiency of the relevant systems in terms of a sustainable increase in the carrying capacity of the land.

Interim and full results of this study have been reported in a series of internal reports by Koopmans and Andriesse (1982), Schelhaas et al. (1984), Andriesse and Schelhaas (1985) and Andriesse (1987). More scientific implications have been dealt with in separate papers dealing with specific issues (Andriesse, 1987, in press; Andriesse and Schelhaas, 1987 II and III). The present paper specifically aims at giving the complete results concerning the fertility aspects and it addresses the practical implications for farming activities, thereby highlighting the differences observed in the two contrasting agro-ecosystems studied.

METHODS

General

For comparative studies compatibility of methodology is essential and care was taken to ensure this. Since in this type of studies the methods employed are rather crucial in assessing the validity of results it is necessary to discuss them at some length. In practice, despite all efforts to follow a scientific methodology, deviations are difficult to avoid, particularly if infrastructural and physical conditions differ per site, and different field teams are responsible for the field investigations. It is therefore also necessary to review and evaluate the actual methods employed.

Field methods

(i) Lay-out of monitoring plots

The intention was to establish three plots of equal size positioned as a catenary sequence at upper-slope, mid-slope and lower-slope (Figure 1), so that the influence of erosion on fertility levels could be studied. This requirement frustrated the site selection in Sarawak because the correct combination of site parameters was difficult to find. Also the position of the biomass subplot had to be shifted to be of sufficient representative value for the whole site. This necessitated a lay-out and size of plots and biomass subplot slightly different from those originally intended (Figure 2). In Sri Lanka the prescribed lay-out could be adhered to because of homogeneity of terrain.

Sri Lanka plots each represent 1/8 hectare whereas those in Sarawak, as a consequence of changes in the basic lay-out, are about 1/20 hectare (0.054 ha). Since the prescribed number of samples was not changed, soil sampling density in the core sampling amounted to 400/ha for Sri Lanka and 925/ha for Sarawak, respectively.

(ii) The baseline study

This study consisted of two components, viz. a biomass study to assess the nutrients stored in the vegetative materials, and a soil study to determine the

Figure 1 Idealized situation of monitoring plots

This sketch reflects the factual situation in Sri Lanka (except for slope)

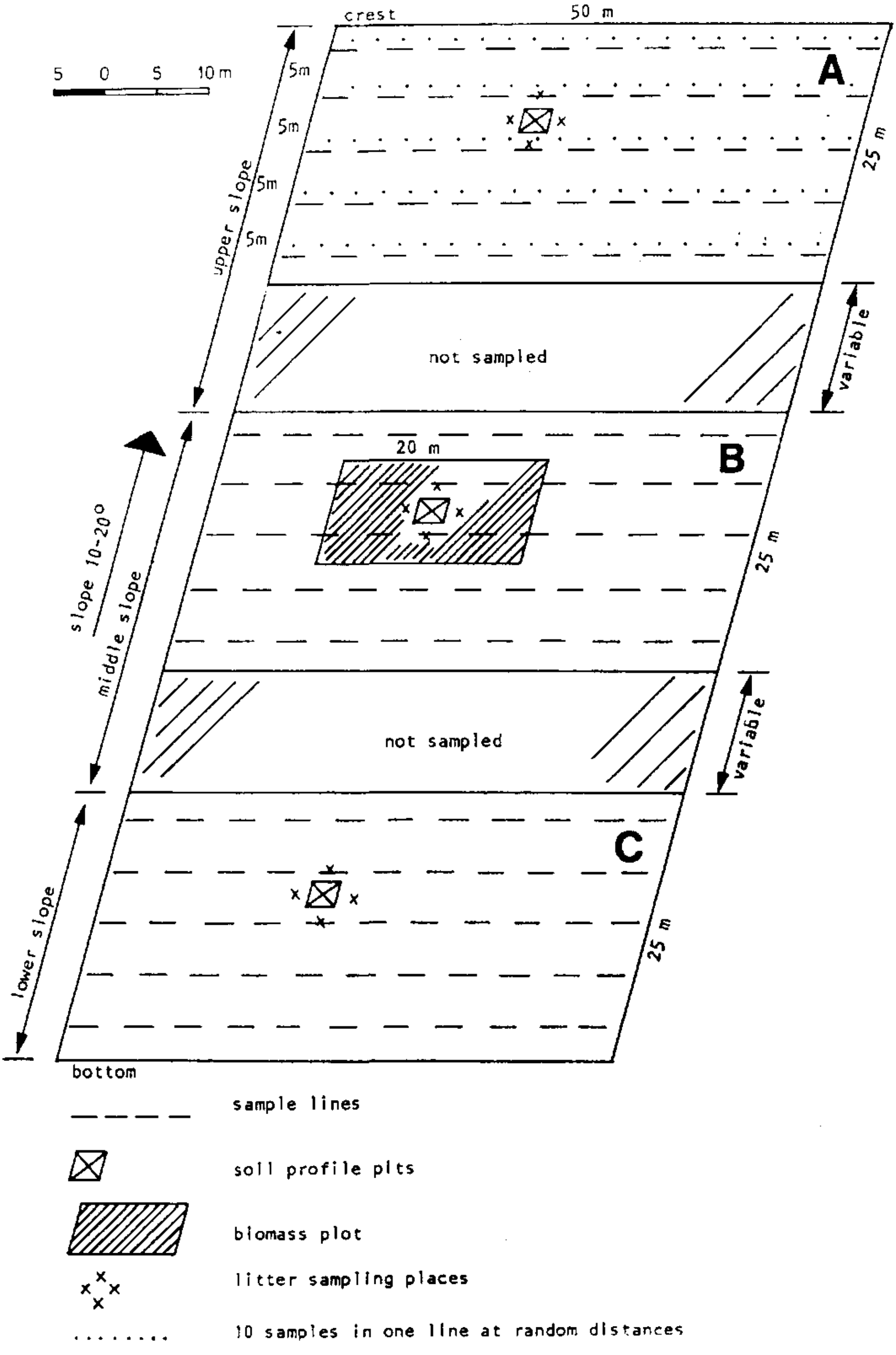
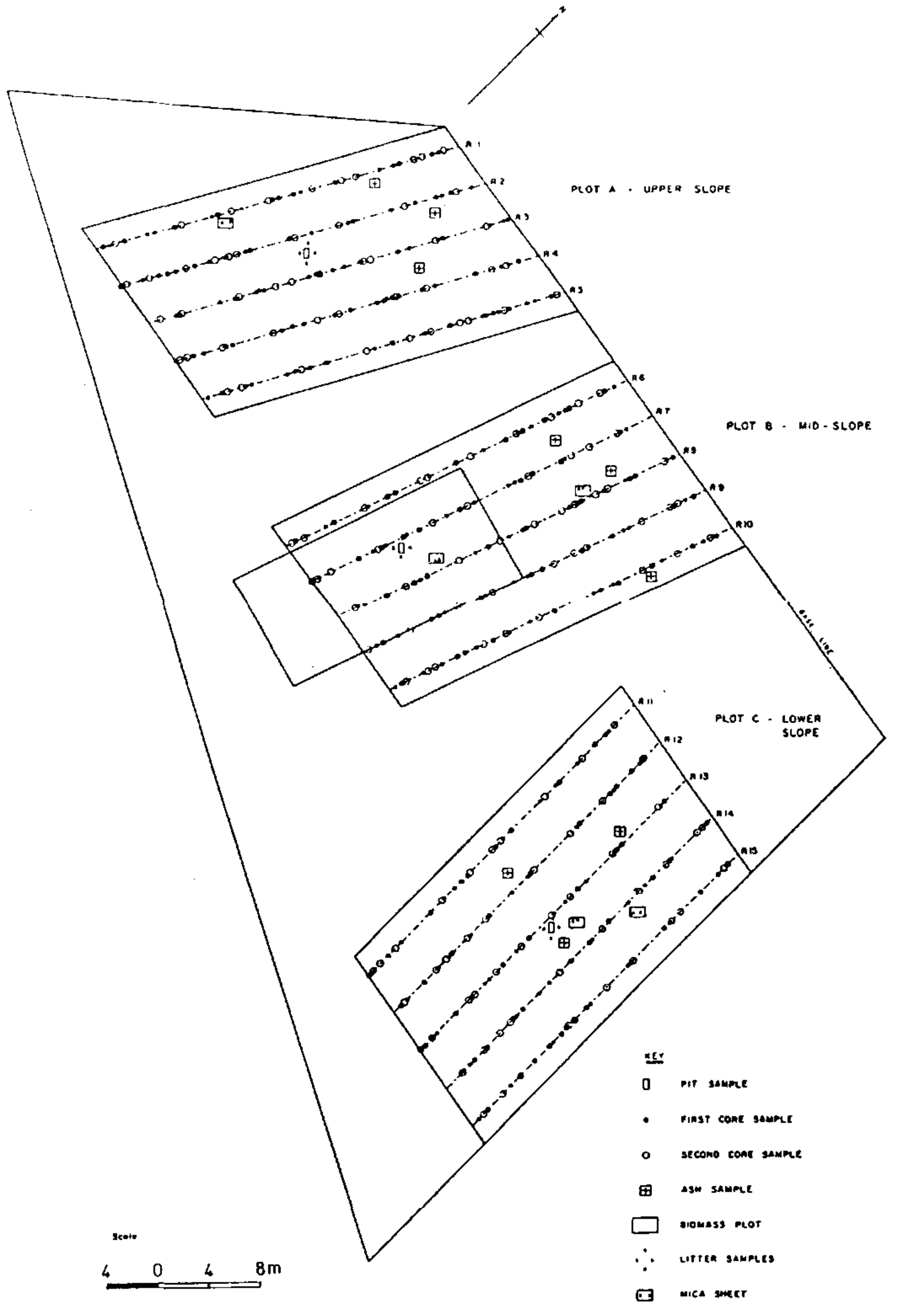


Figure 2 Sketch of nutrient-cycling plots in Sarawak, showing the location of samples taken



nutrients stored in the soil. The study was carried out during the least wet months in Sarawak, and in Sri Lanka at the height of the dry season.

Biomass studies

Methods used in estimating biomass of forest ecosystems followed those recommended in a review by Egunjobi and Bada (1976). They distinguished and compared four major methods:
a) conversion of volume to dry weight
b) total clear felling of a unit area followed by weighing and drying
c) harvesting of average sized trees
c) regression methods.

Each of the four methods has it merits. Method b) was favoured by the reviewers. Other researchers would use regression methods, particularly if disturbance of the forest is to be avoided.

Brunig (1979, pers. comm.) advocated the use of allometric methods for calculating a common "phytomass"-regression for parts which vary in density between species (wood, bark), and of weighing procedures, because "representative" plots are often of limited use.

After careful weighing the various alternatives method b) was finally adopted as being the best under the given circumstances. It is realized that the representative nature of the small biomass subplot is of crucial importance to approaching the real situation with some degree of reliability. The actual selection of the biomass subplot has been rather subjective in Sri Lanka, albeit done by experienced staff. At the Sri Lanka site large trees occurred with a density of about 10/ha and one individual tree was present in the biomass subplot (this fact was incorporated in the calculations).

An added difficulty in comparing results was that after clear felling Sri Lanka used "volume" to obtain proper conversion factors instead of "weighing". Sarawak used the prescribed weighing method.

Mentioned factors are probably the main sources of error in results obtained on the nutrient stores in biomass initially present.

In the baseline survey biomass assays were carried out on:

- living, above-ground vegetation using quantitative methods as described for the selected subplots of size 10 x 20 m;
- litter, collected on sample areas of 1 m^2 (4 in each of plots A, B and C); and
- roots, collected to a depth of 1.5 m in soils pits situated in plots A, B and C. Roots were handpicked and not sieved.

Above-ground vegetation was separated into trunk material (> 50 mm in diameter), small wood (50-20 mm), leaves and fruit, according to trees, lianas, shrubs and herbs (ferns and grasses) with leguminous and non-leguminous vegetation recorded separately. Fresh field weights were taken of each component (Sri Lanka volume/weight conversion) before drying at 105°C and subsequent total chemical analyses. Separate material was dried at 70°C for N-determination. Collected litter (leaves and twigs) present at time of sampling was weighed at the site and subsampled for moisture content and chemical analysis. Roots collected from the excavated soil were similarly treated for analysis.

After the assay of the biomass subplot and the soil characterization study (see soil studies) plots A, B and C were completely felled and left to dry for subsequent burning.

Soil studies

Soil studies prior to felling comprised two components:
- characterization of soil type in the three plots,
- assessment of initial fertility level.

For characterization and classification soil pits were dug in each plot. Profiles were described using US Soil Survey Manual (1951) procedures. Samples of each distinctive horizon were taken for analysis. To enable conversion of chemical values expressed in amounts per 100 g of dried soil on a kg/ha basis, undisturbed samples were taken in triplicate using sample rings of standard volume normally used for pF determinations at depth 0-5, 5-10, 10-25, 25-50 and 50-75 cm for bulk density determinations.

The initial fertility assessment required the implementation of a detailed core sampling programme. In each plot five parallel lines were individually sampled at ten randomly selected locations using tables of random permutations of 9. Sampling was carried out with Eykelkamp core samples at the same depths as those used for bulk density measurements.

Samples were bulked at the end of each line for each depth separately, thoroughly mixed, composite samples taken and sent to the Soil Laboratory of RTI at Amsterdam.

(iii) Felling, drying and burning

The period for drying the felled biomass in Sarawak amounted to only 25 days, which is one month shorter than usual, However, drying is always problematic in this country because there is no distinct dry season, and adverse weather conditions are normal for this agro-ecosystem and insufficient drying must be accepted as representative. The drying period in Sri Lanka amounted to two months which is locally considered adequate because of the intensely dry weather.

Temperatures in the burn were recorded by using glass slides covered by strips of temperature-indicating lacquers. Melting points of the lacquers used are accurate within margins of 25°C in the range 100-500°C, and 50°C above 500°C. Before the burn slides were placed randomly at five localities within the plots to be burned, on the surface, at 1, 2 and 5 cm depths (see Figure 2 for Sarawak).

As indicated, the burn in Sarawak was not complete and although litter, leaves, twigs and small branches were burnt, larger wood was only charred. No attempt was made to pile remaining wood for a second burn, as traditionally this is never practised. In Sri Lanka a heavy shower marking the onset of the wet season upset the plans for burning and the first burn was quite unsuccessful necessitating piling of remaining biomass which was burned a second time, leaving considerable accumulations of ash locally. Ash heaps were subsequently mapped out and treated as separate spots in all the randomized soil sampling rounds carried out after the burn in the monitoring programme. Termite hills were also mapped out at the same time, as they might also disturb fertility levels locally (Figure 3).

Ash samples were taken from each plot in both Sarawak and Sri Lanka, and forwarded to Amsterdam for analysis. Throughout this paper areas at Sri Lanka which were only burnt once are indicated as non ash-affected soil, whereas areas influenced by ash concentrations have been separately dealt with and are indicated as ash-affected soils (below wood piles).

After the burn the areas were seeded in by dibbling, in Sarawak with upland rice, in Sri Lanka with cowpea (Vigna unguiculata). The cropping was a failure in Sri Lanka because monkeys destroyed most of the crop before harvesting. In Sarawak the rice was harvested after six months (yield was the equivalent of 210 kg/ha, about one quarter of normal yields on this soil). No attention was further given to the fields and they were left to normal regeneration of vegetation (bush-fallow stage).

(iv) Monitoring of fertility levels

Monitoring comprised five sampling rounds, viz.:

a) before the burn (the burn is month 0)
b) after the burn (at month 0, immediately after the burn, in Sarawak; at month 4 in Sri Lanka)
c) after the harvest (at month 12, both sites)
d) two years after the burn (one year after the harvest, at month 24, both sites)
e) four years after the burn (three years after the harvest, at month 48, both sites).

Laboratory investigations

All vegetative materials comprising dried samples from the biomass assay (wood, twigs, roots, litter, leaves) were digested with H_2SO_4 and H_2O_2. N and P were determined colorimetrically; K, Ca and Mg by flame photometer.

Texture of soils was determined on the pit samples using the pipet method; pretreated with H_2O_2 and HCl to remove organic materials and Na-pyrophosphate to aid dispersion. Pit and core samples were analysed on pH-H_2O and pH-KCl by pH-meter, organic C by Walkley Black (using a factor 1.33 to convert obtained values in organic C), N by micro-Kjeldahl, available P by Kurtz and Bray II, total P by concentrated H_2SO_4 and HNO_3, organic P by the Saunders and Williams method. Available S was determined turbimetrically as $BaSO_4$ using Tween 80 as a stabilizer. CEC and exchangeable bases Ca, Mg, K and Na were determined at pH 7 using the AAS for Ca and Mg, and the flame photometer for K and Na.

Ash samples were analysed on their contents of total N, P, K, Ca and Mg using methods as indicated. In addition, water soluble salts were determined for the ash from both sites, and for micro-elements for the Sri Lanka site only.

All analyses were carried out in duplicate. When the difference between two duplicate values exceeded 10% of the mean value, the analyses were repeated. Analytical data therefore represent the average results of two or three values.

Measurements of soil bulk density and field moisture content (differences of fresh and dry weights) for the organic materials were the only ones performed by the local laboratories in Sri Lanka and Sarawak.

As indicated, bulk density was measured once for the Sarawak site, but measurements were repeated for the Sri Lanka soils after the burn. Throughout the study the original values were maintained as the second determination for Sri Lanka did not differ from the first. However, the considerable difference which appeared to exist between the BD's of the Sarawak and Sri Lanka soils could be an important source of error in the conversion of nutrient values from a dry weight to a volume weight basis. The relative importance of this possible error could not be further investigated because Sarawak failed to repeat the BD measurements.

Statistical evaluation

Overall error based on known coefficients of variation and the sampling density actually used, plus standard analytical error, was calculated to be 10%. Noted changes in nutrient levels exceeding 10% of the reference value can be ascribed to the multiple effects of the indicated changes in land use with a probability of 67% (Cox, 1958).

RESULTS AND DISCUSSION

For purposes of this paper attention is focused on pertinent results, i.e. those related to fertility changes only. For more details on other matters the reader is referred to listed reports and subject papers.

Baseline studies

The location of the two sites in Sri Lanka and Sarawak together with characteristics of the rainfall are shown in Figure 4. The semi-arid nature and bimodal rainfall distribution of the ecosystem in Sri Lanka contrast with the wet equatorial rainfall of the Sarawak site. This lacks a well-defined dry period, although the rainfall distribution shows the existence of a less wet season during the period July to September.

Table 1 summarizes the main characteristics of both sites. Of importance are the difference in relief and in soil type between the two sites.

Table 1 Major agro-ecological characteristics of the experimental sites

Location	Climate	Vegetation	Soil*	Relief	Crops
Sarawak (Malaysia) Semongok Agric. Research Station	Wet equatorial (Af Köppen) 4000 mm annual rainfall, every month >100 mm	12-15 year old secondary forest	Aquic Paleudult	10-15°	Hill rice (6 months)
Sri Lanka Vanathavillu Agr. Exp. Station	Semi-arid (Aw Köppen) 900-1200 mm annual rainfall, with 2 wet periods (>100 mm monthly) of 3 months and 1 month duration resp.	25-40 year old secondary forest (timber partly extracted)	Rhodic Oxic Paleustalf	2°	Cowpea: <u>Vigna unguiculata</u> (3 months)

* USDA - Soil Taxonomy (1975)

The Sarawak soil is a clay soil, imperfectly drained, with a relative high exchange capacity but low in nutrients. The Sri Lanka soil is more sandy with a clay content gradually increasing with depth. It is freely drained and has a low exchange capacity and is also low in nutrients.

Major parameters of the two sites are set out in Table 2.

Figure 4 Location and rainfall distribution of sites at Sri Lanka and Sarawak

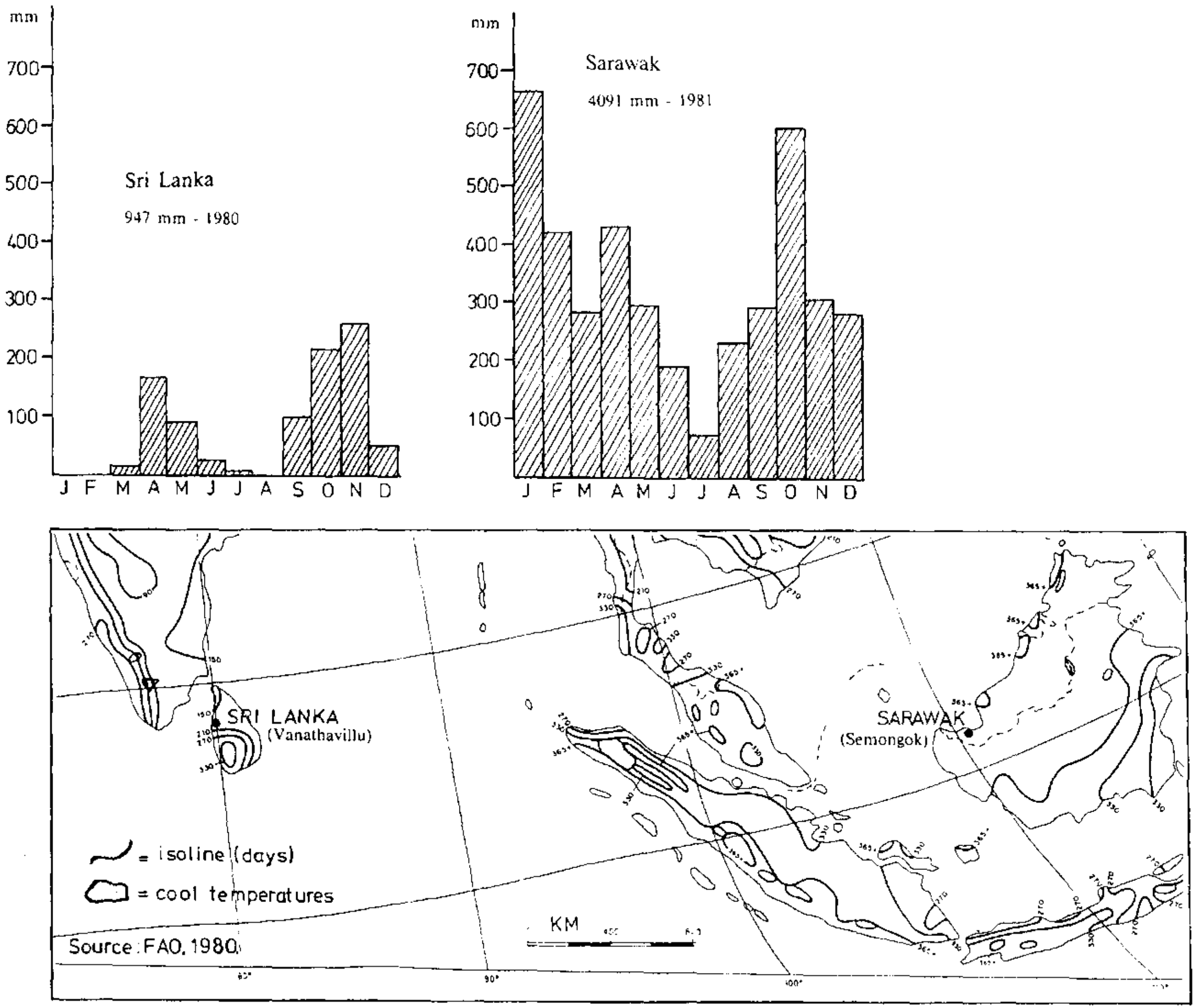


Table 2 **Major parameters of the vegetation/soil systems in Sarawak and Sri Lanka (means of plots A, B and C)**

	Sarawak	Sri Lanka
BIOMASS		
Living above-ground biomass		
weight dry matter	32 ton/ha^{-1}	81 ton/ha^{-1}
presence legumes	10% of individual trees	very few
fertility status (total macro nutrients Ca,Mg,K,P,N in % of total dry weight)	1.5	2.5
N-status (% of total nutrients)	27	26
Litter		
weight dry matter	9800 kg/ha^{-1}	3360 kg/ha^{-1}
fertility status	3.4	3.7
N-status	41	30
Roots		
distribution	shallow (0-25 cm)	deep (over 150 cm)
weight dry matter	6300 kg/ha^{-1}	17,200 kg/ha^{-1}
% of total biomass	13	17
fertility status	2.4	2.4
N-status	31	26
SOILS		
texture	clays	loamy sands to sandy clay loams
acidity ($pH-H_2O$) (top- to subsoil)	4.5 - 5.0	6.5 - 5.2
CEC meq/100g	40 - 30	4.5 - 2.5
sum bases meq/100g	9.2 - 0.85	2.4 - 1.5
base saturation %	23 - 3	65 - 37
% N	0.43 - 0.08	0.05 - 0.02
P-status in ppm ($P_{av} + P_{org}$)	209 - 128	72 - 79
P_{org} in % of P_{tot}	66 - 62	69 - 70
K-status meq/100 g		
absolute	0.5 - 0.24	0.2 - 0.18
relative (as % of sum bases)	6 - 28	8 - 12

This table illustrates the large amount of biomass initially present in Sri Lanka; also the almost non-existence of leguminous vegetation should be noted. The higher fertility status of the biomass in Sri Lanka because it contained relatively more Ca, Mg, K, P and N on a dry weight basis than the biomass in Sarawak is important. This indicates that burning of the same weight of dried biomass in Sri Lanka would release more nutrients than in Sarawak. The nitrogen value of both types of biomass is almost the same. In contrast with the living biomass the amount of litter is much higher in Sarawak than in Sri Lanka whereas the former has also a higher N-value. This would indicate the relatively high importance of litter as a source of nutrients in Sarawak. Rooting is very deep in Sri Lanka, whereas in Sarawak only shallow roots are found. Actual amounts are much higher in Sri Lanka, being of the same order as the difference found in dry weight of above-ground biomass.

The roots in Sarawak contain relatively more nitrogen than those in Sri Lanka. This must be a reflection of root type, those in Sri Lanka being more woody. The initial differences in soil fertility level are worth noting. High acidity in Sarawak contrasts with almost neutral and weak acid conditions in Sri Lanka. There are large differences in CEC indicating lack of storage capacity in the Sri Lanka soil. The very high P-status of the Sarawak surface soils coincides with also high nitrogen levels. The K-status of Sarawak soils is much higher than in Sri Lanka.

Figure 5 allows a comparison of the amounts of nutrients initially present in the various storage compartments of the Sri Lanka and Sarawak soil/biomass systems. This is based on values expressed in kg/ha and as indicated such values must be used with caution because of possible errors in B.D. values. Quite illustrative, however, is the relatively important role of litter in Sarawak in general, and the role of biomass plus litter in storing active phosphorus in particular (see column at extreme right in this figure).

Figures 6 and 7 show that there is a difference in fertility levels between the soils found at the top, mid- and lower slope positions. In Sri Lanka this is a more regular feature in most nutrients than it is in Sarawak, which might be explained by the fact that at the latter site the slope is quite irregular in shape. Because of such differences it appears essential that for studying changes in nutrient levels during the project period mean values calculated over the entire site should be used and it can be stated that in general for studies of this nature the exact positioning of a plot on a slope phase is important.

The effects of burning on fertility levels

The effects of burning on fertility levels of the soils are influenced by two factors:

- the effect of heating per se (this has been studied by Andriesse and Koopman in a simulated burning experiment under laboratory conditions, 1984);
- the addition of nutrients through ash.

Both are strongly influenced by the effectivity (intensity) of the burn. Leaching may have occurred in Sri Lanka between the burning time and the sampling.

(i) Effectivity of the burn

The intensity of the burn can firstly be gauged by temperatures reached at various soil depths, secondly by visual observation after the burn. In Sri Lanka, after the second burn, ash-accumulated areas were mapped out (Figure 3). Table 3 shows the temperatures reached at both localities. The studies indicate that high temperature values occur at the soil surface only when biomass is piled (range 200°-700°C), but at 1 cm depth they generally remain 175°C and at 2 cm depth

Figure 5 Relative distribution of active amounts of main nutrients over the soil-biomass- litter compartments in Sri Lanka and Sarawak

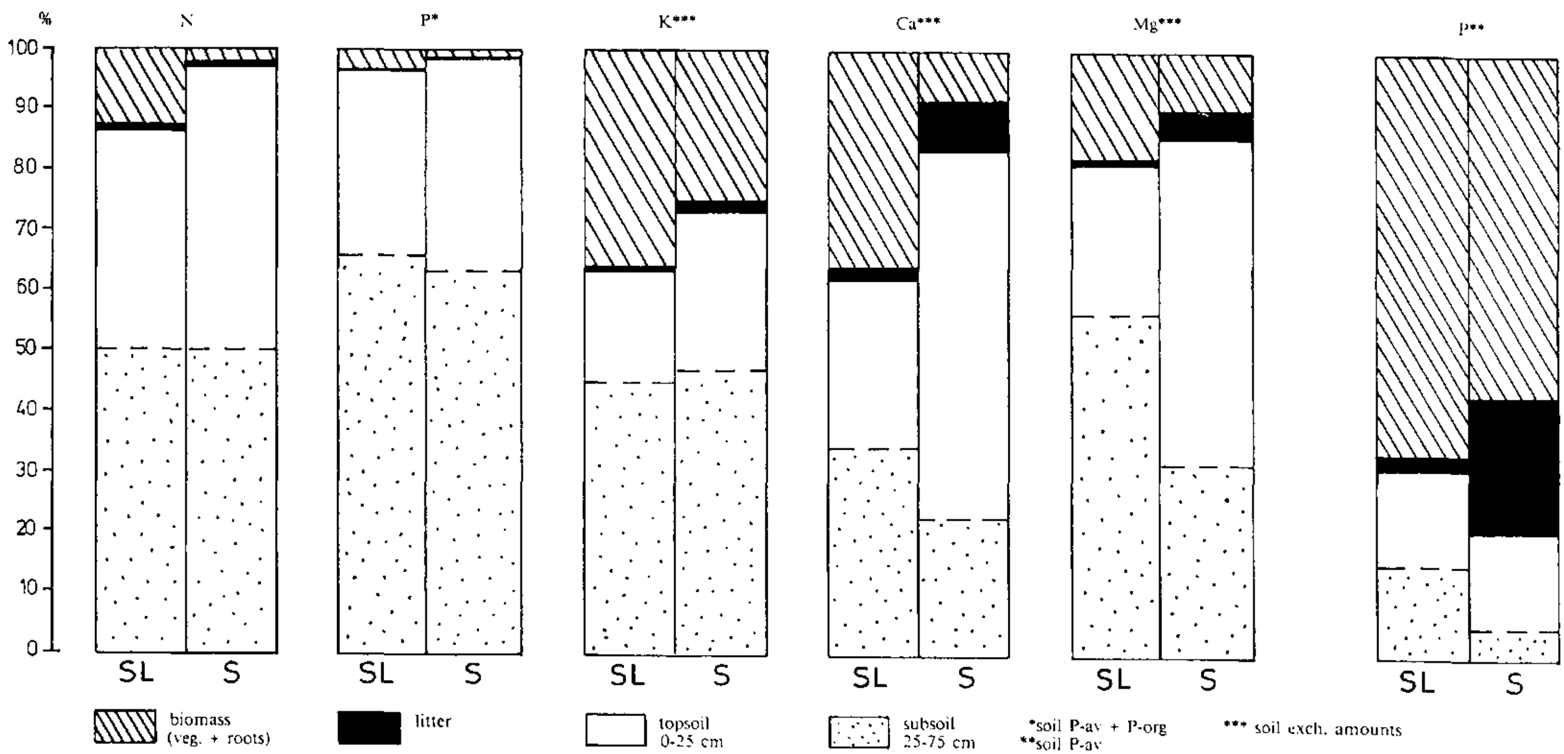
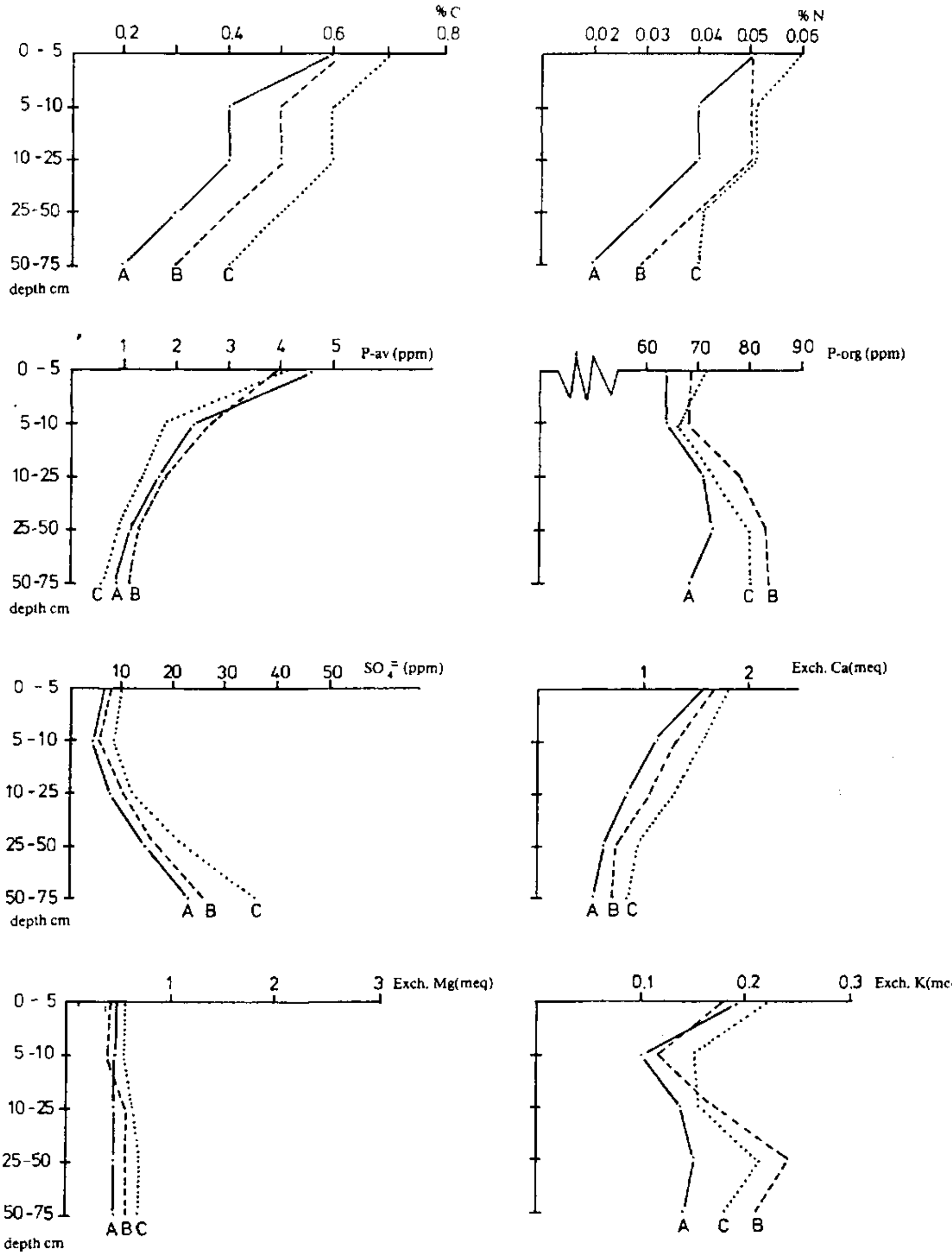
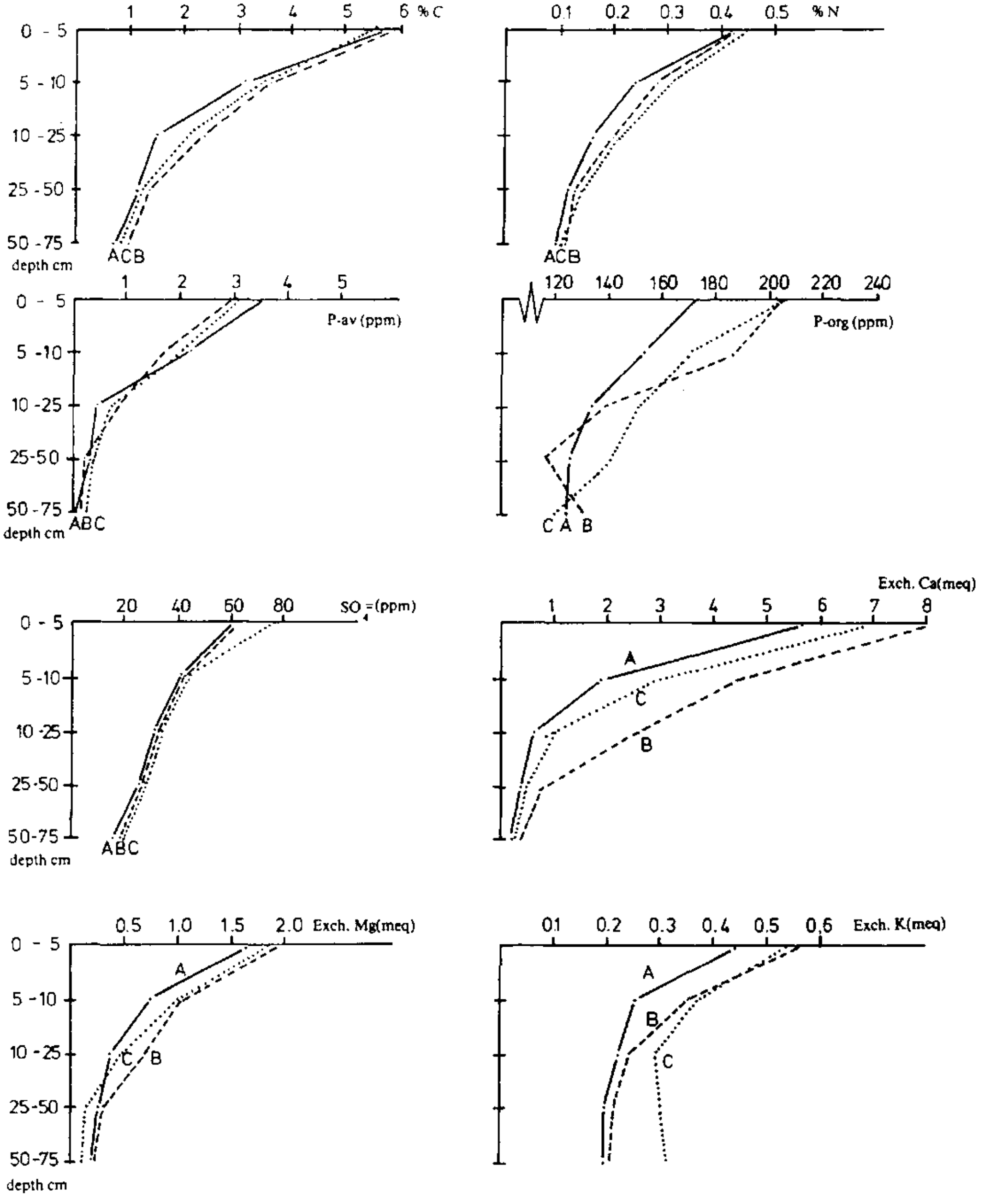


Figure 6 Relation between nutrient levels and position on slope-baseline situation - Sri Lanka



A = upper slope
B = middle slope
C = lower slope

Figure 7 Relation between nutrient levels and position on slope-baseline situation - Sarawak

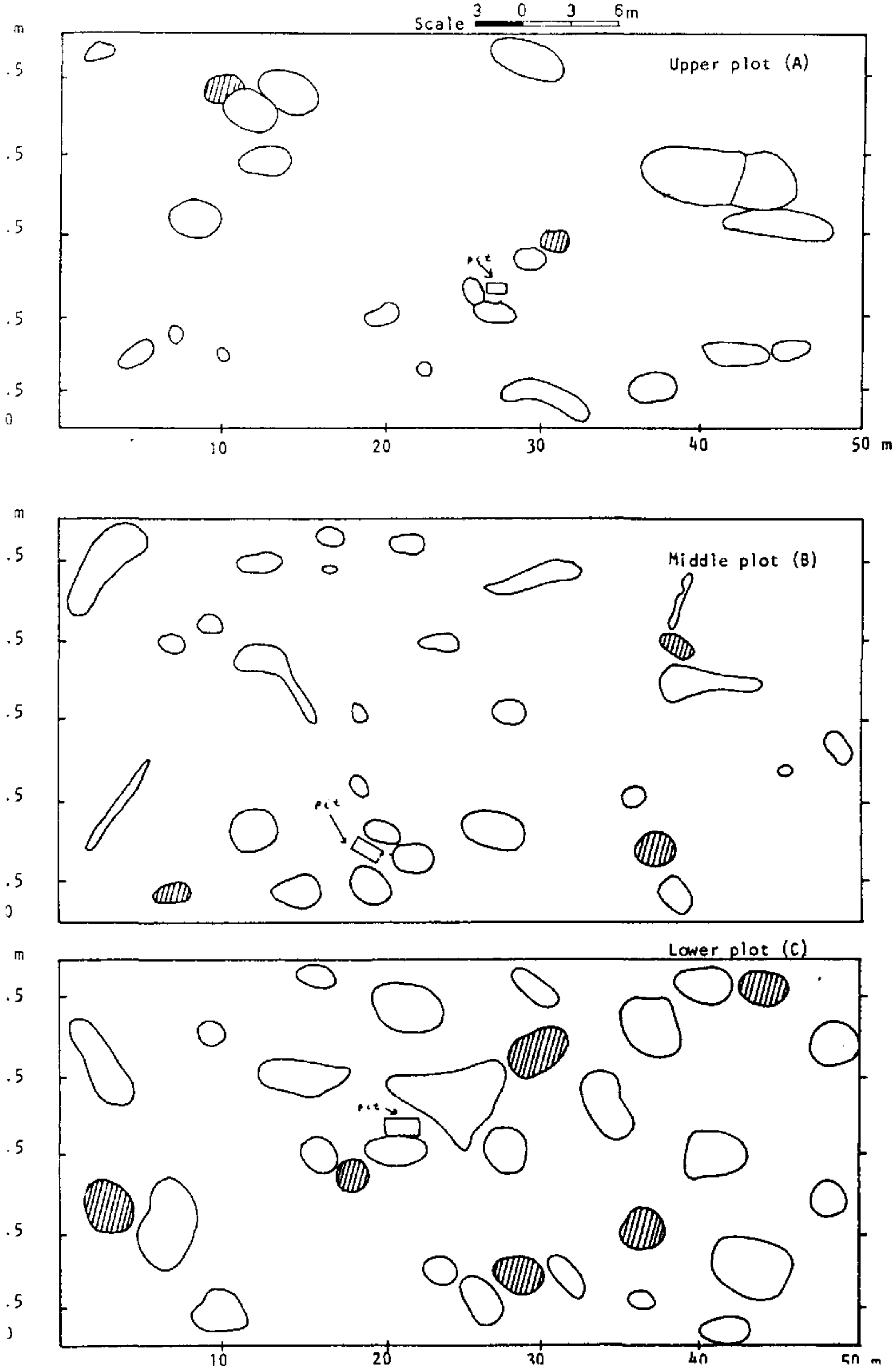


A = upper slope

B = middle slope

C = lower slope

Figure 3 Distribution of ash heaps (white) and ant hills (hatched) at the Sri Lanka site



they stay below 100°C. Temperatures reach values of 150° to 200°C at a depth of 5 cm only where much biomass has been piled up. Andriesse and Koopman (op.cit.) report that significant changes in soil properties would only occur when temperatures surpassed values of 150°C. The present field studies indicate that such temperatures are reached only in the 5 cm deep surface layer when biomass has been piled up. It can thus be safely assumed that over most of the area heating per se has not caused any significant changes in soil chemical properties, although heat sterilization of the soil will certainly have affected its microbiology.

Table 3 Temperatures and intensity of biomass burns at Sri Lanka and Sarawak sites as indicated by lacquered glass strips

Site	Plot	Biomass surface coverage	Intensity of burn	Temperatures recorded at indicated places and depths in °C				
					surface	1 cm	2 cm	5 cm
Sri Lanka	A	thin	medium		400	150	<100	<100
(1st burn)	A	moderate	low		300	<150	<100	<100
	B	moderate	medium		300	<175	<100	<100
	C	thin	low		350	<100	<100	<100
(after piling)	B	thick	high	below centre	350	300	300	250
	B	thick	high	below edge	450	350	300	250
	C	thick	high	below centre	450	350	300	250
	C	thick	high	below edge	350	150	150	150
Sarawak	A	moderate	bad		175-200	100	100	100
	B	very thin	low		<100	<100	<100	<100
	C	thick	moderate		200-250	<100	<100	<100

(ii) Ash-studies

Ash was sampled and analysed in the laboratory on total composition and water soluble salts. In Table 4 the chemical composition of the ash is compared with that of the original biomass at both sites. Concentration factors of the main elements were calculated by dividing the percentage for each element in the ash by the percentage found in the biomass.

Table 4 **Nutrient composition of above-ground biomass and related ash after burning, in percentage oven-dry material**

	N	P	K	Ca	Mg
a - **above ground biomass composition**					
Sri Lanka	0.69	0.037	0.47	1.25	0.17
Sarawak	0.64	0.024	0.54	0.64	0.10
b - **composition of ash samples**					
Sri Lanka	0.07	0.26	1.91	18.7	1.70
Sarawak	0.42	0.38	5.38	7.08	1.26
c - **concentration factor: composition ash/ above ground biomass**					
Sri Lanka	0.10	7.0	4.1	15.0	10.0
Sarawak	0.66	15.8	10.0	11.1	12.6

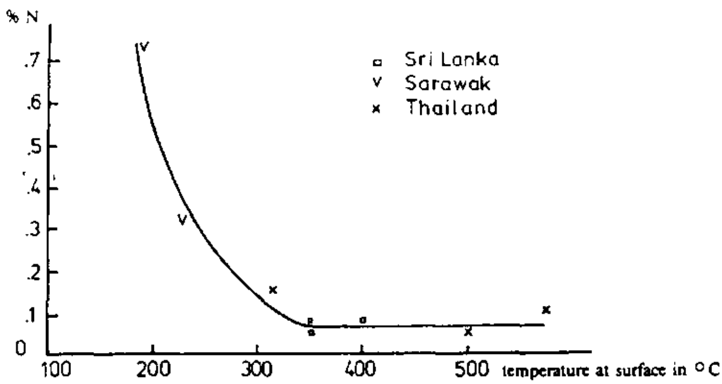
Table 4c would point to considerable losses in nitrogen (values should ideally approximate unity). There is considerable concentration in phosphorus (7 - 15 x), potassium (4 - 10 x), calcium (15 - 11 x) and magnesium (16 - 10 x). There are only losses to note in nitrogen (0.10 - 0.66 x). Sarawak experienced much higher concentrations of the various elements than Sri Lanka, despite the fact that the burning was not so effective. Presumably, quality of ash is not a measure for effectiveness of the burn. Burning has also destroyed the litter, which in Sarawak constituted an important qualitative and quantitative component of the total biomass, and therefore influenced the ash composition. It is interesting to observe the low concentration factor of nitrogen at both sites signifying large losses of nitrogen through volatilization (mostly so in Sri Lanka because of the much higher temperatures reached). Apparently burning and heating of organic materials result in rapid volatilization of N, the other elements becoming volatile only above 600°C (Jackson, 1958). Figure 8 shows the relationship between temperatures reached and N-content of the ash. In an experiment with rice straw, Nagarajah and Amarasiri (1977) showed that a temperature of 700°C is reached at the surface and 300° - 400°C in the centre of the heap. The residue had lost 93% of its original N and 20% of its original K. They concluded that in order to save most N from volatilization, temperatures should be kept as low as possible. The results of the present study corroborate these findings.

(iii) Soil changes

Changes in soil chemical properties were assessed by comparing the mean values obtained for the composite samples (n=5) per plot and per standard depth after burning with those obtained before burning.

In Sri Lanka it was necessary to distinguish between locations where biomass had been burned in piles and concentrated ash and those with normal accumulations. Table 5 gives a general review of main effects in comparison with those found in the simulated burning experiment by Andriesse and Koopman (1984). A

Figure 8 Relationship between burning-temperature and N-content in ash



number of soil properties and nutrient levels have changed considerably upon burning, particularly in ash-affected soils in Sri Lanka.

Table 5 General review of main effects of burning on values*

	Sri Lanka site				Sarawak site		Simulated burning lab.exp. 0-2 cm layer (Andriesse&Koopmans, 1984)
	non ash-affected soil		ash-affected soil				
	effect in %	depth zone in cm	effect in %	depth zone in cm	effect in %	depth zone in cm	effect in %
pH	+	0-50	++	0-50	nil	0- 25	+
EC	+	0-50	+	0-50	+	0- 50	+
C	- 25	0-75	- 50	0-75	+ 25	0- 50	- 80
N	nil		nil		+ 25	0- 25	- 50
P-tot.	+ 20	0-10	+ 200	0- 5	nil		nil
P-org.	- 10	0-10	- 50	0-10	- 15	0- 25	no observation
P-av.	+500	0-10	+1000	0-10	+100	0-100	+300
S-av.	+ 50	25-75	+ 100	0- 5 & 25-75	+100	0- 10	no observation
CEC	- 10	10-75	- 25	0-75	- 10	0-100	- 50
Ca-exch.	+150	0-10	+ 600	0- 5	+ 50	0- 25	- 25
Mg-exch.	+ 40	0-10	+ 100	0-25	+ 50	0- 25	- 25
K-exch.	- 40	0-10	+ 100	0-75	+100	0-100	+100
Ca-extr.	+200	0-10	+5000	0- 5	+ 45	0- 25	no observation
Mg-extr.	+ 50	0-10	+ 500	0- 5	+ 30	0- 25	no observation
K-extr.	- 35	0-10	+ 100	0-75	+ 75	0- 10	no observation
K-res.	- 20	0-10	+ 100	0-75	+100	0-100	no observation

+ = increase
- = decrease
* = effects of less than 10% are not shown

Changes are most pronounced in the topsoils (0-25 cm) and very significant *in the surface layer (0-5 cm)*, but subsoils appear to be also affected, probably because of mechanical wash-down of ash and leaching of soluble compounds. Similar general trends are found at all sites in all plots so that position on the slope appears to be unimportant; the differences which existed before the burn were largely maintained. There are, however, some distinctive differences in effect of burning among the sites.

Changes in subsoils are most pronounced in the Sri Lanka site for which two factors can be considered responsible. Firstly, the intensive burn and local concentrations of considerable amounts of ash and consequently nutrients. Secondly, the four months delay in sampling after burning coinciding with the wet season which apparently has caused considerable leaching.

Review of changes in soil parameters during the complete monitored cycle

(i) On acidity (see Figure 9)

Upon burning the soil pH increased considerably, especially in the topsoils. The intensity of the change and the duration of the effects are dependent on amount of biomass burned, the effectivity (intensity) of the burn and climate (leaching). In Sri Lanka pH was raised by 1 to 1.5 units and with piling of wood (intensive burning) this effect was still present four years after the burn (see Figure 9A).

In Sarawak the pH was raised only 0.5 unit because of an ineffective burn and the effect was erased after one year leaching. The differences in initial soil pH at both sites and those attained after the burn are of considerable agricultural consequence. In Sri Lanka the change from 6.8 to near 9 in some places resulted in the creation of unfavourable alkaline conditions; in Sarawak the change from 4.8 to 5.2 can only be regarded as beneficial, although the effect was only short-lived.

These findings emphasize that intensive burning of large amounts of biomass on initially almost neutral soils has a soil degrading effect manifested in the destruction of micro-biological activity, in creating toxic levels of certain chemical compounds and in general causing conditions detrimental to healthy root development necessary for seed germination. The same practice, however, on an acid soil may be very beneficial because it counteracts some of the negative effects of low acidity on nutrient availability and aluminium toxicity, whereas also microbiological activity is stimulated.

The results of the Sarawak site indicate that four years after the burn the acidity of the soil was higher than in the baseline (Figure 9B), which may point to an ultimately acidifying effect of the system employed.

(ii) On soil organic matter (see Figure 10)

Soil organic matter seems only slightly affected by the burn itself. Temperatures are seldom high enough to destroy soil organic matter present beyond a depth of a few centimetres. This does not imply that the effect of rising temperatures would have no effect at all. Generally speaking soil temperatures reach values of 150 degrees C to a depth of about 5 cm, which would destroy most of the soil flora and fauna down to that depth. This should have a confounded effect on the quantity and availability of soil nitrogen in relation to germinating seeds, thus in the early growth stages. Rate of mineralization of organic matter and the qualitative and quantitative aspects of mineral nitrogen formed during the monitored period were not part of this study and for this reason only the fate of the organic nitrogen can be followed.

From circumstantial evidence it is surmised that most probably there is a transport of organic materials from the surface through mechanical down-wash in the form of diminuted particles of organic origin present in the ash. It is not clear whether this is a simple down-wash or whether the particles are dispersed. Certain proven additions in the subsoil of e.g. sulphur, carbon and nitrogen, all of which are related to organic materials, can only be explained by assuming such a process. Inexplicable losses in CEC of the subsoil in Sri Lanka in particular would suggest that positively charged particles are (also) involved.

(iii) On soil nitrogen (see Figure 11)

With an intensive burn there are large losses of organic nitrogen in the 0-5 cm topsoil (Sri Lanka, ash-affected soils, Figure 11B). With a moderately effective to relatively ineffective burn the organic nitrogen content increases (Sarawak, Figure 11C). This is most probably caused by addition of partly decomposed (burned) diminuted organic materials washed down from the overlying mixture of ashes

Figure 9 Changes in pH-H_2O at various soil depths during the monitored shifting cultivation period in Sri Lanka and Sarawak

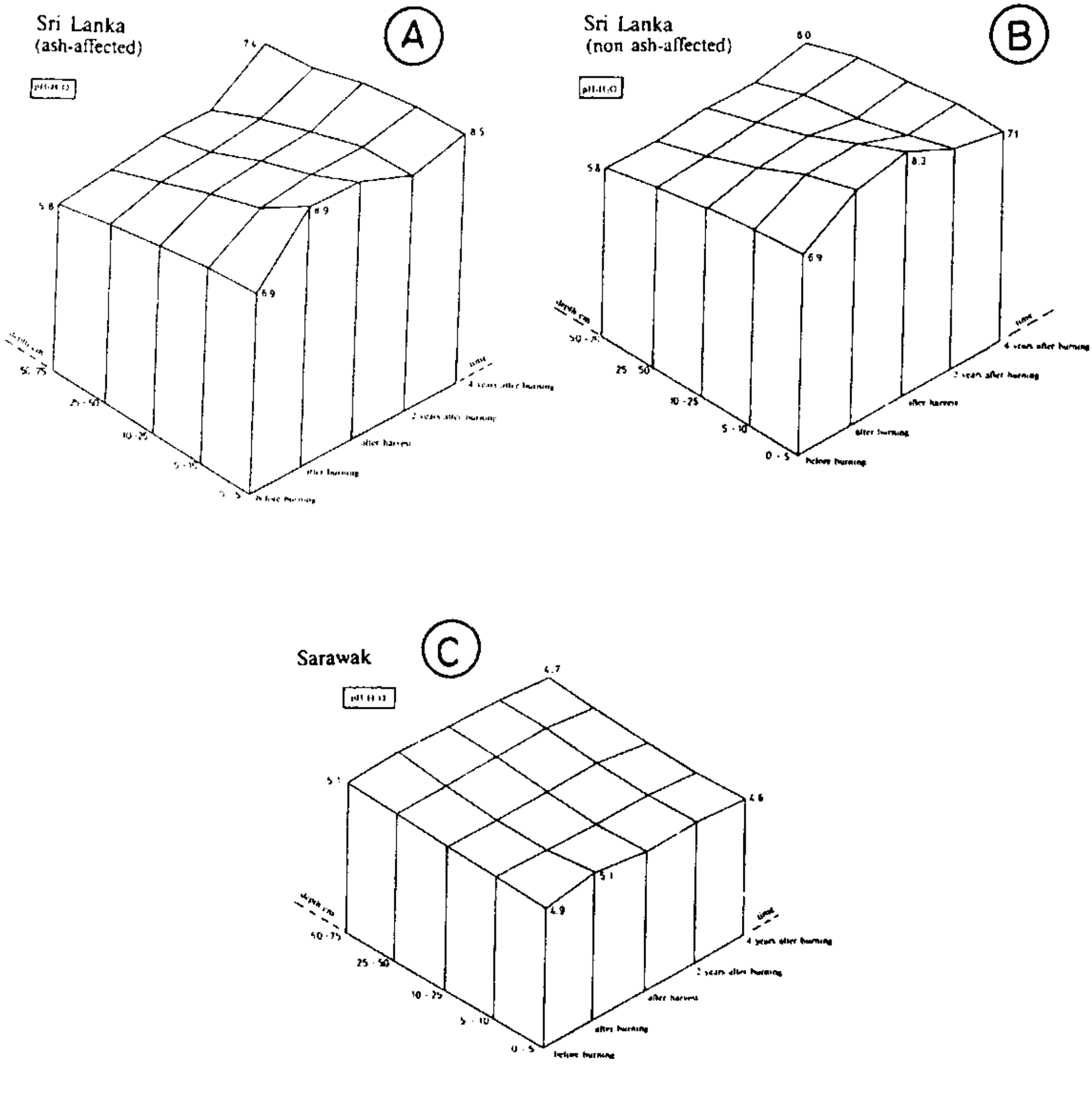


Figure 10 Changes in organic carbon at various depths during the monitored shifting cultivation period in Sri Lanka and Sarawak

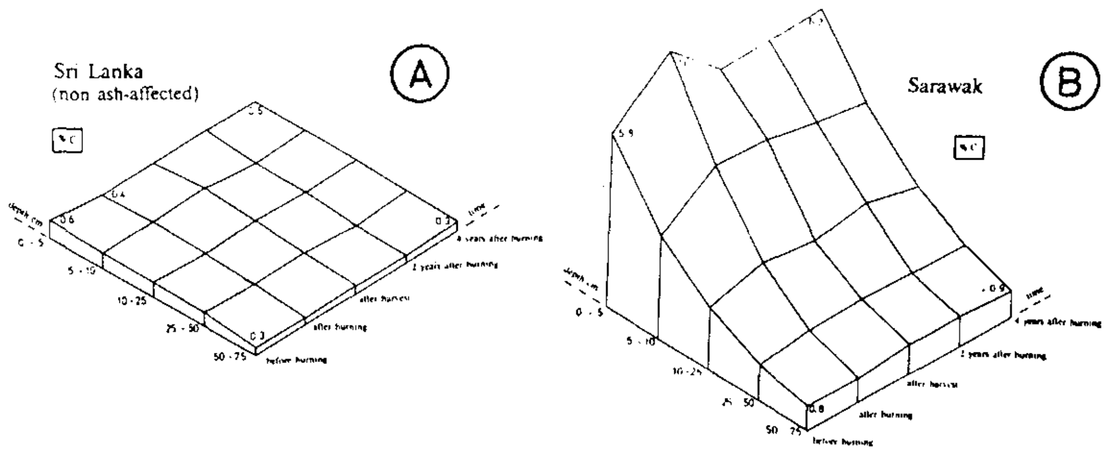
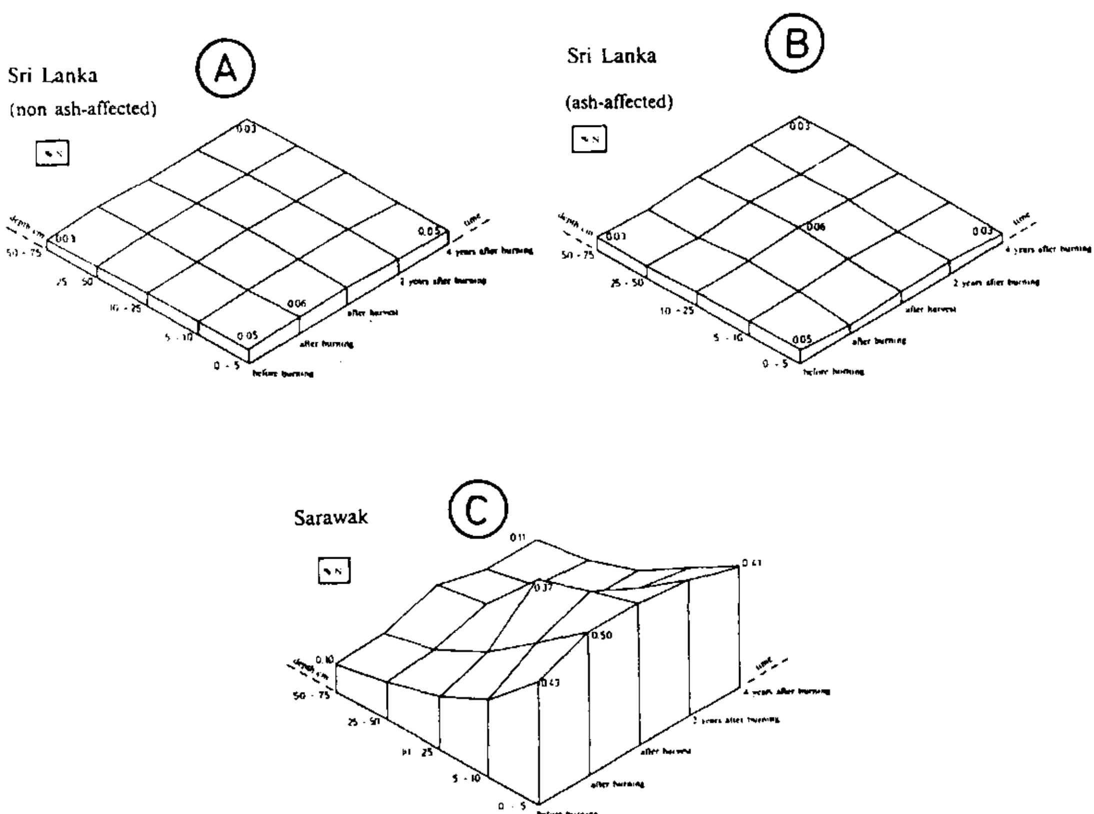


Figure 11 Changes in total nitrogen levels at various soil depths during the monitored shifting cultivation period in Sri Lanka and Sarawak



and organic debris. The overall effect of the shifting cultivation practices up to four years after the burn on soil organic nitrogen are neutral to positive, the total amount over the whole soil depth increased in both sites investigated. However, presumably because of the intensive burn the Sri Lanka site experienced a net loss in the 25 cm surface soil but a greater net gain in the 25-75 cm. In Sarawak there have been gains in both the top- and subsoil compartments, most likely because of the additions from the cut biomass as suggested. This increase is actually accomplished by a form of accelerated decomposition of the complete biomass through part burning, part normal decomposition and mineralization after felling and incomplete burning.

In fact gains in the complete soil have been more than all nitrogen present in the original biomass which is casting some doubt on the values obtained for the latter. The impossibility of finding a representative biomass plot measuring 10 x 20 m in this site may have played a role and has been commented upon.

(iv) On phosphorus (see Figure 12)

The changes in amounts of available phosphorus in the topsoils of both sites are the most dramatic ones of all recorded. There is a direct relation between the magnitude of increase and the actual amount of burned biomass. Both, a rise in temperature causing phosphorus to be liberated from the organic pool and wash-in of particles from the ash adding phosphorus originally present in the biomass, play a role in the large increase in available phosphorus of topsoils. The subsoils are hardly affected. The increase in availability of phosphorus is short-lived but relatively prolonged in ash-affected soil. After four years levels have again fallen significantly.

Levels of organic phosphorus (Figure 13) are quite rapidly restored and four years after the burn at both sites they are not much dissimilar to those recorded before the burn. The general impression is that overall losses of phosphorus from the system are relatively minor but that there are important shifts from one form to another during the various stages investigated. Upon burning the available pool receives relatively large fluxes from the organic pool present in both biomass and soil. Part of this is taken up by the crop or regenerating vegetation, all mostly within the surface 20 cm soil depth and therefore reverts back to organic bound phosphorus, part is taken up by the restoring soil micro-flora and -fauna replenishing the soil organic phosphorus pool. Apparently surplus available phosphorus is fixed as Al- and Fe-phosphates and may for a considerable part be taken out of roulation. This is illustrated by Table 6. It is by this process that losses occur during shifting cultivation - transition from active forms to relatively inactive and occluded forms. The values for total phosphorus appear to support this.

Figure 12 Changes in *available phosphorus at various soil depths during the monitored* shifting cultivation period in Sri Lanka and Sarawak

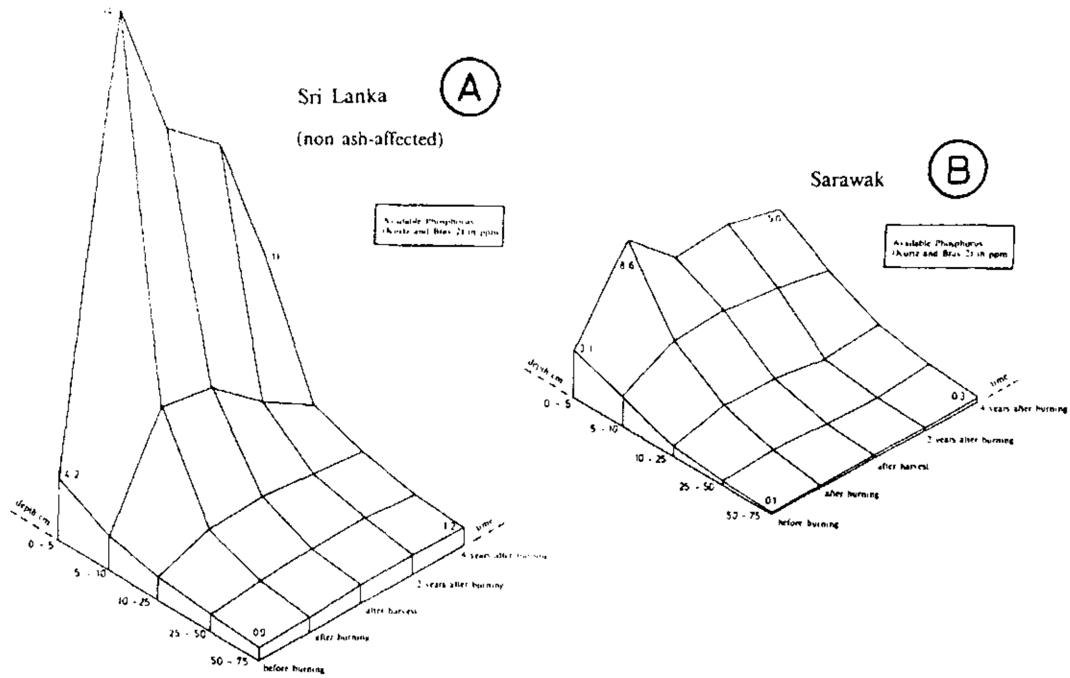


Figure 13 Changes in organic phosphorus at various soil depths during the monitored shifting cultivation period in Sri Lanka and Sarawak

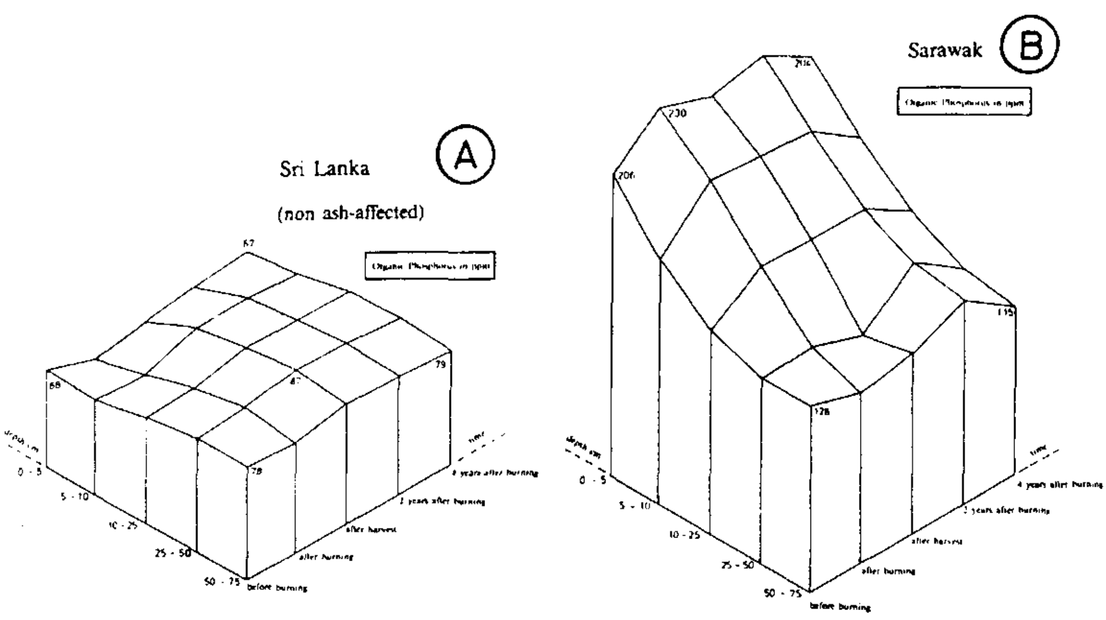


Table 6 **Calculated losses in ppm of active soil phosphorus through presumed fixation in one shifting cultivation cycle (average of plots A, B and C)**

	active P		fixed P		fixed P increase		
	$P_{av} + P_{org}$		$P_{tot} - (P_{av} + P_{org})$				
	a*	c**	a	c	c-a		
					ppm	% of initial P_{tot}	% of initial active P
Sri Lanka							
0 - 5	72	78	27	41	14	14	19
5 - 10	68	75	34	47	13	13	19
10 - 25	77	82	34	44	10	11	13
25 - 50	80	83	35	53	18	16	23
50 - 75	79	80	33	52	19	17	24
Sarawak							
0 - 5	209	209	104	119	15	5	7
5 - 10	172	173	93	118	25	9	15
10 - 25	142	142	87	118	31	14	22
25 - 50	128	122	78	99	21	15	16
50 - 75	128	116	69	97	28	14	22

* a = ppm baseline level
** c = ppm 4 years after burning

(v) On sulphur (see Figure 14)

In Sri Lanka large amounts of sulphur are added to the soil upon burning the biomass but the sulphur thus liberated is relatively rapidly leached. Although four years after the burn sulphur levels are almost at par with those before the burn, the small amount of biomass which had regenerated by that time could have incorporated only part of the sulphur present in the original biomass. The difference which most likely is appreciable was lost by the severe leaching regime during the four year cycle.

The Sarawak ecosystem contrasts strongly with this and shows gains in both top- and subsoils, most likely as a result of additions from the original biomass which was not burned entirely. The additions may therefore be delayed effects due to normal decomposition of organic materials. It is significant that leaching of sulphur in this ecosystem is not evident and the conclusion is justified that although the perhumid climate of Sarawak is much more inducive to leaching than that of Sri Lanka, rapid regeneration by the slowly permeable soil is responsible for the absence of losses under shifting cultivation practices.

(vi) On exchange characteristics (see Figure 15)

In Sri Lanka the CEC in the topsoil is almost entirely dependent on organic matter content, whereas in the subsoil clay content starts to play a role. Burning causes a decrease in CEC, particularly where much wood was piled. In the latter case subsoils also show a decrease. A temperature rise cannot be the cause of loss of organic matter at depth and it is hypothesized that positively charged particles originating from the ash are washed down and effectuate a net CEC

Figure 14 Changes in available sulphur at various soil depths during the monitored shifting cultivation period in Sri Lanka and Sarawak

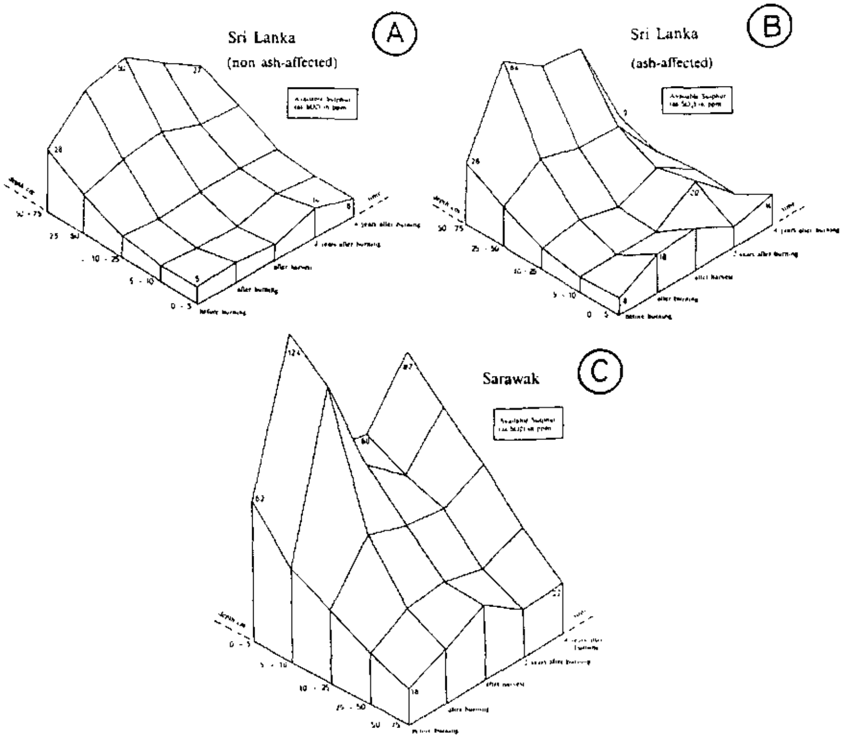
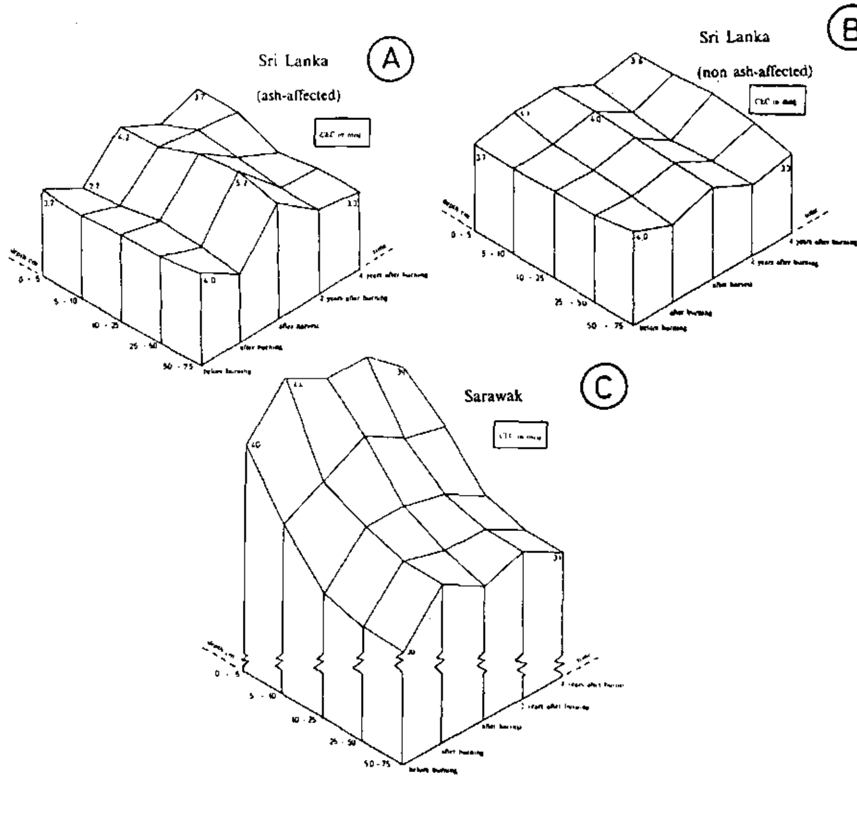


Figure 15 Changes in cation exchange capacity (CEC) at various soil depths during the monitored shifting cultivation period in Sri Lanka and Sarawak



decrease. Renewed increases after the harvest are responsible for the fact that four years after the burn the CEC levels have almost reverted to their initial levels existing before the burn. The overall lasting effect of a shifting cultivation cycle as studied on soil CEC is negligible. Also in the wet equatorial site of Sarawak the effects on soil CEC have been of no consequence.

Base saturation values increase dramatically after the burn in topsoils of ash-affected as well as non ash-affected soils. Leaching of soluble salts (cations) from the ash and lodging at lower depth is quite apparent, but mainly in the surface 25 cm. Such effects are directly related to the amount of biomass burned and intensity of the burn because the effects in base saturation of Sarawak soils where the burn was bad were comparatively minor. After four years bush-fallow base saturation values in Sri Lanka non ash-affected soils are almost similar to those found in the baseline, and it must be assumed that most of the base increase has been taken up by the regenerating vegetation or was lost by leaching. Base saturation increase, small as it was, was even shorter-lived in Sarawak and entirely consumed in the cropping period presumably mainly by the regenerating vegetation.

(vii) On exchangeable bases (see Figures 16, 17 and 18)

Calcium levels increase significantly after the burn but initially mainly in the topsoil. The effect in quantitative terms is dependent on the amount of biomass burned and the intensity of the burn. In both sites calcium is leached from the ash which can be a prolonged process. Also the leaching down to lower subsoil levels can be followed for quite some time after the burn. Even four years after the burn calcium levels are generally still somewhat higher than those originally present. Similar trends are found for the changes in magnesium levels. Apparently potassium is much more mobile than Ca and Mg and the difference in leaching regime has therefore a confounded effect on changes in levels at various soil depths in either Sri Lanka or Sarawak. Potassium losses in Sri Lanka even until after the harvest are considerable. Increases again four years after the burn may be due to the mulching effect of leaf drop from regenerating trees bringing the potassium back into the short cycle. Although there are losses in the complete soil-vegetation system, the subsoil system still had a 100% gain after four years compared with the initial values. In Sarawak following the initial increases after the burn, levels already declined after cropping. Also here there are net gains noticeable in top- and subsoil even four years after the burn. The impression is that also in this system potassium is more mobile than Ca and Mg but relatively less rapidly leached because of the greater adsorption power of the clays. Potassium therefore has a greater chance of remaining in the recycling system. New additions to the topsoil four years after the burn would indicate that short recycling through decomposition of litter from regenerating vegetation is already taking place.

CONCLUSIONS (general)

1 Monitoring of nutrient level changes in ecosystems involving both soil and biomass, and maintaining comparative conditions is complicated by great variability in actual situation, management and external factors. Quantitative studies are time-consuming, expensive and partly as a consequence of this, suffer from lack of replication.

2 Although the practice of shifting cultivation may universally be based on essentially the same processes of recycling nutrients through soil and regenerating biomass, there are considerable qualitative and quantitative differences in the recycling mechanisms operating in ecosystems due to dissimilarities in

Figure 16 Changes in available calcium at various soil depths during the monitored shifting cultivation period in Sri Lanka and Sarawak

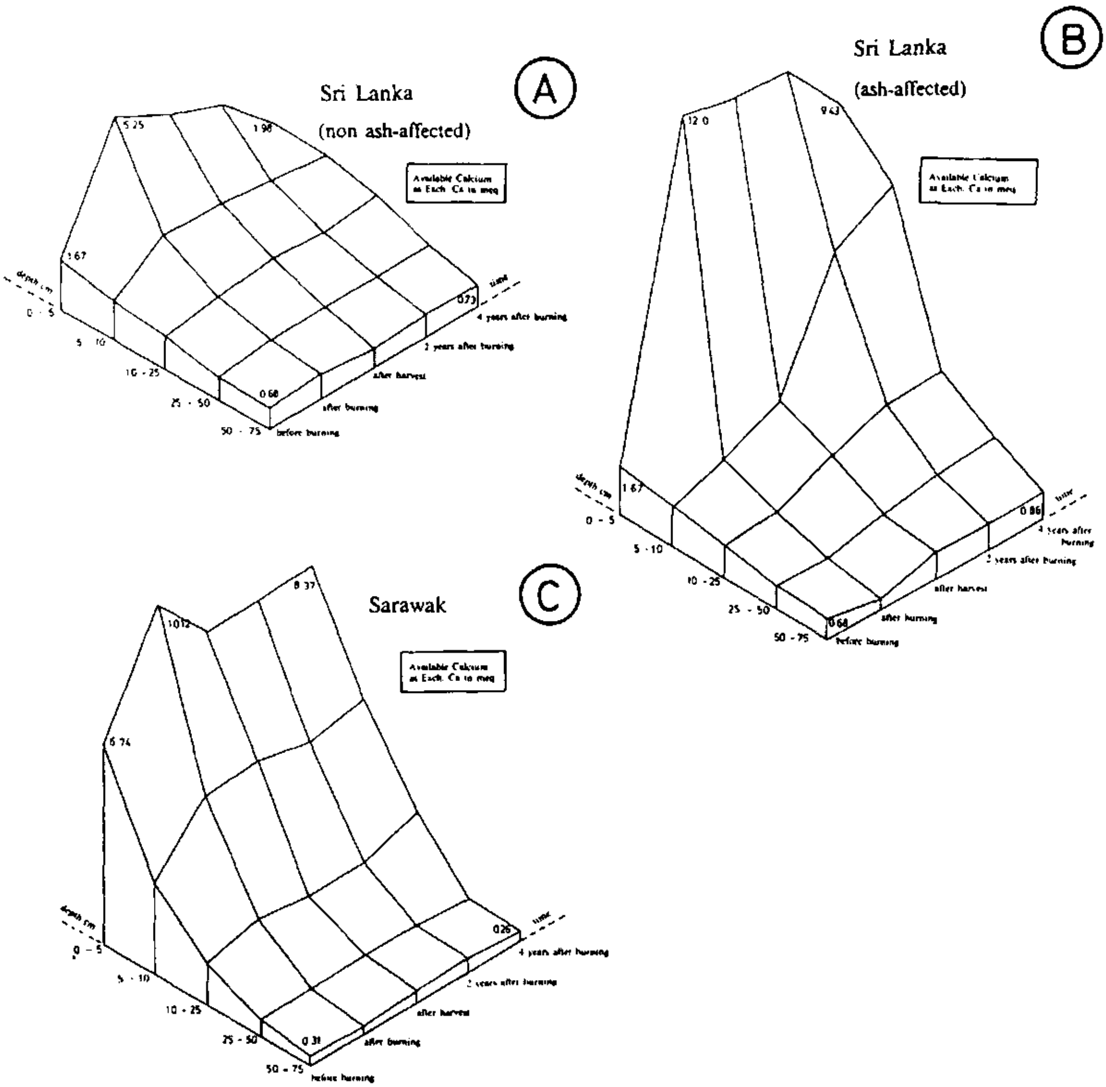


Figure 17 Changes in available magnesium at various soil depths during the monitored shifting cultivation period in Sri Lanka and Sarawak

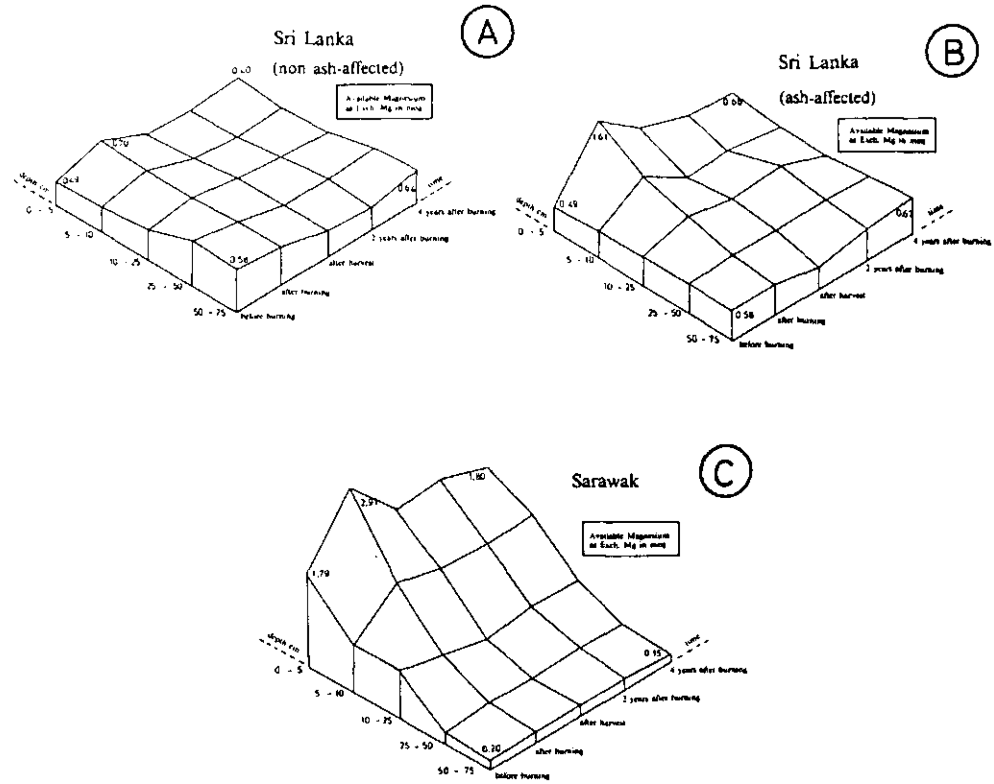
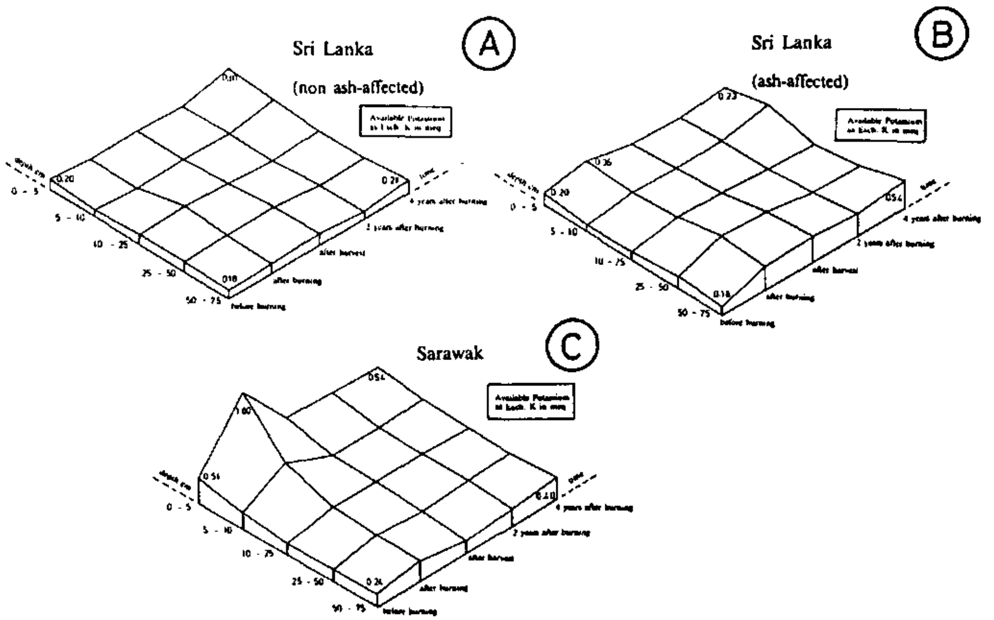


Figure 18 Changes in available potassium at various soil depths during the monitored shifting cultivation period in Sri Lanka and Sarawak



climate and soil. Two site conditions are important: the potential biomass production and the operating soil leaching regime. Climate plays a role in both. Therefore, each system has its own *unique* interplay of environmental factors which should be identified before innovations are to be introduced into the agricultural system.

3 "Burning", although generally recognized as common practice, is essentially only needed to accelerate the mineralization process to release sufficient nutrients from biomass to produce an adequate crop. Its role appears highly ambivalent depending on the site-specific factors. In a wet equatorial climate part- or unsuccessful burning is responsible for prolonged release of major nutrients inclusive of N and P even up to one year after burning through decomposition of felled biomass. But the initial levels may be too low for one adequate crop.
Intensive burning and piling of biomass can result in too high temperatures in topsoils causing volatilization of soil N and alkaline conditions and can therefore produce the opposite to the required effects. Probably too intensive burning in a semi-arid climate with neutral soils is not as justifiable as it may be in a wet-equatorial environment with acid soils, but much depends on the amounts of biomass involved.

4 No evidence was found for declining nutrient levels as being responsible for abandoning the fields after one year cropping. The results rather indicate the reverse situation, namely continuous increase in nutrients through presumably wash-out of accumulated ashes and decomposition of remaining biomass after burning. Enrichment of the topsoil in all sites could be followed up to four years after burning but particularly in soils below ash accumulations in Sri Lanka.

5 Vegetation regeneration and soil nutrient levels indicate that the interplay of independent variables: climate and soil, and the dependent variables: vegetation types and leaching regimes, are crucial to the mechanisms of nutrient cycling and the dynamics thereof.
In a wet equatorial climate nutrient residence times are essentially short because of fast and large biomass production, high litter fall, rapid decomposition and dense rooting in topsoils. Small available amounts of P, K, Ca and Mg are frequently recycled. Production of N is closely related to that of biomass. Fast growing shallow rooting seedlings of adapted seedling are dominant in the secondary vegetation, and seem necessary to maintain the system.

6 Shifting cultivation in a semi-arid climate on a soil with a high leaching potential results in rapid depletion of active phosphorus, sulphur and potassium in the ecosystem involved.

7 Soils with a high clay content and relatively high CEC appear to offer a substantial buffer to losses in bases in a climate inducing high leaching.

RECOMMENDATIONS

1 In a semi-arid climate intensive burning of piled or stacked biomass on neutral sandy soils with a low buffer leads to degradation of the topsoils because of developing alkalinity. Equal spreading of biomass should be advocated instead.

2 Clear felling, without subsequent burning may, particularly in wet equatorial climates, have a beneficial effect on the nitrogen balance, but probably supplementary fertilization with phosphorus and potassium may then be necessary.

3 Sulphur deficiency might rapidly accrue in sandy soils with a low buffer capacity which could be rectified by applying sulphur containing fertilizers. In particular nitrogen fertilizers, which are probably most needed, are likely the most efficient carriers.

4 High mobility of potassium and sulphur, particularly in sandy soils, and rapid immobilization of active phosphorus in clay soils with high active Al- and Fe-compounds would necessitate a continuous presence of adequate root systems to keep in particular surplus potassium, sulphur and phosphorus in the ecosystem through uptake in the biomass. Whereas in the wet tropics and with clay soils nutrients are essentially recycled through root systems present in the surface soil of 25 cm depth, in the more arid climates and with sandy soils rapid leaching of the mobile elements necessitates the maintenance of an adequate root system at depths beyond a depth of 25 cm to prevent leaching of the meagre resources in plant nutrients, and thereby permanent losses from the system. It is in this context where agro-forestry systems can play an important role: the interplanting of trees or in general crops with deep rooting systems to intercept the leached-down nutrients. This is essentially another function than the BNF function which is commonly more propagated in agro-forestry but which is then aimed at improving the nitrogen status of the soils. It should be recognized that nitrogen is not necessarily always the most limiting factor.

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A GEOGRAPHICAL MODEL OF SOIL NUTRIENT REGIMES

Key words: Fertility Inventory Simulation

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SUMMARY

A soil nutrient regime is a general indication of the soil nutrient supplying capacity, and an important element for soil resource inventories. The soil nutrient regime model is to simulate the natural nutrient status of soils which is the result of the interactions of nutrient gains, retention and losses and the constraining effects of soil stresses on nutrient bioavailability.

It is at the same time a geographical model as it was based on the principle of compensative relationships among the land components. These relationships were established using contingency matrices with rank entries. The computations were done by batch processing. Thus a value change was registered only if it involved a change in rank or quality class.

The case of East Java is presented as an illustration.

INTRODUCTION

A soil regime is a general indication of a soil condition which affects plant growth. Buringh (1979) has listed six main regimes: moisture, nutrient, biological, temperature, air, and mineral. These are soil qualities which together basically determine the total growing condition of plants. A regime is in fact an ecological imprint on the soil component of an ecosystem. In a certain aspect it is a product of the interrelationships of the soil with the other components of the ecosystem. As aspects are integrated within the system, soil regimes are closely interrelated and interdependent.

A single soil property means nothing by itself. Its meaning is determined by its relative significance to the other soil properties, and by its compensative relationships with the other land characteristics.

For example, we can only say about iron toxicity if the Ca and Mg contents are known. Whether the soil moisture supplying capacity of a sandy soil should be considered sufficient or deficient, depends on the rainfall characteristics and the topographic location.

This paper deals solely with the soil nutrient regime. It depicts in a general way the quality of soils in terms of their natural nutrient supplying capacity. In this sense it combines Buringh's nutrient and mineral regimes.

A GEOGRAPHICAL MODEL

A geographical model is based on the land systems concept. A land system is a unit of a terrestrial area where all production variables are so interrelated as to form a specific land quality. The essential point in defining a land system is not the additive characteristics of the land parameters, but the systemic interactions those parameters are performing. Consequently, any input is seen as an intervention in the interactions, and not merely a cause of change in one property or more.

Irrigation, for instance, is not just supplying water to the soil. It is an intervention in the moisture regime of the area. The whole hydrological cycle must be considered, as otherwise irrigation may lead to the disruption of the moisture regime with the grave consequences of waterlogging or salinization of the soil. A wetter moisture regime may increase the leaching potential of plant nutrients. Fertilizer application without due account for the nutrient cycles and balances may easily lead to an overdose or deficiency of certain elements.

Different from pure mathematical models, in which interactions are perceived by numerical relationships, geographical models work on the principle of compensative relationships. A compensation is positive when a capability surplus of one land component can alleviate a capability deficit of another land component. When the condition of a land component is apt to amplify the value decline of another land component, the compensation is negative or the relationship is anti-compensative. For example, the low water holding capacity of a sandy soil is positively compensated by a sufficient and well distributed rainfall. An erodible soil is negatively compensated by a steep slope and an erosive rainfall. Compensation has a space-time dimension as the magnitude of changes in the characteristics of the individual land components with place and time are non-parallel to each other.

Another significant difference between mathematical and geographical models is the registration of changes. Mathematical models register changes through the continuous processing of regressions. Geographical models register changes through the batch processing of decision matrices. Thus a geographical model will register a change only if it involves a shift in value catagory, hence a quality transition.

THE SOIL NUTRIENT REGIME MODEL

AN (available nutrients), ESV (effective soil volume), NR (nutrient reserves), and SFS (soil fertility stresses) are the four principal elements of the SNR (soil nutrient regime) model. There are three derivative elements, namely SF (soil fertility), SFa (actual soil fertility status), and SC (soil capability). One complementary element is LP (leaching potential).

SF is produced by AN-ESV compensation, SFa by the negative compensation of SFS for SF, and the positive SFa-NR compensation produces SC. The end result of SNR is obtained by the negative compensation of LP for SC (figure 1).

The leaching model LP has six principal elements, and four derivative elements. The principal elements are P (precipitation; rainfall), ETo (reference evapotranspiration), I (infiltration rate), R (runoff), SMHC (soil moisture holding capacity), and WP (water percolation rate). The four derivative elements are AWB (atmospheric water balance), WI (water intake rate), SMDA (soil moisture dynamic), and RP (soil moisture replenishing potential).

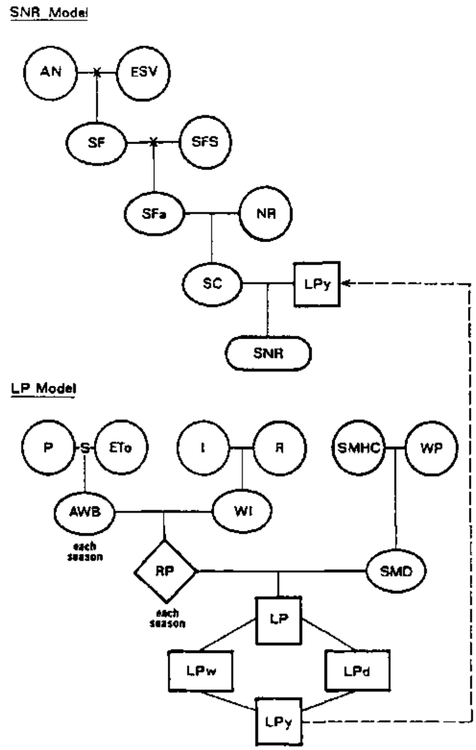

Fig. 1. The SNR and LP models showing the LPy link. Marks between the model elements: X = multiplication, S = subtraction. Without a mark means processing by decision matrix. See text for the letter symbols.

AWB is calculated by subtracting ETo from P. WI is the balance between I and R. SMD is the result of the two opposing forces of SMHC and WP. RP is determined by AWB as the capacity factor and WI as the conditioning factor. AWB is season dependent, so it was calculated for each season separately. Consequently, each season has its own RP. Since LP was derived from RP, its simulation was done by season. The seasonal pair of LP determines the yearly LP, which represents the potential intensity of leaching throughout the year (figure 1).

METHODS

The soil and soil-related data for the systems simulation of the SNR model were derived from existing soil maps. As the generally available soil maps of Indonesia are on a reconnaissance scale of 1:250,000 the soil data were estimated from the subgroup differentiae. AN and SFS were assessed on the basis of the general agricultural value of each subgroup. ESV was assessed by the general morphology of the subgroup. NR was interpreted from the description of the soil parent material of the corresponding subgroup. Whenever possible it was complemented by geological maps. The kind of soil parent material was also considered when assessing AN. The soil maps were prepared using the soil classification system developed by Dudal and Soepraptohardjo (1957).

The approximated values were classified into a number of classes by scoring. The number of classes assigned to a certain variable was to indicate the importance of that variable relative to another one in a compensative relationship. This was done, as small changes in the more important variable may result in significant changes in a particular soil quality, while greater changes are required in the less important variable before it can produce changes of similar magnitude.

SFa	NR				
	1	2	3	4	5
E	P	P	P	p	p
D	P	p	p	m	m
C	P	p	m	g	G
B	p	m	g	G	G
A	m	g	G	G	G

SC	LP						
	1	2	3	4	5	6	7
P	P	P	P	P	P	P	P
p	p	p	P	P	P	P	P
m	m	m	m	p	p	p	P
g	g	g	g	m	m	m	p
G	G	G	G	g	g	g	m

Fig. 2. The decision matrix NR x SFa to determine the five classes of SC: P = very poor, p = poor, m = medium, g = good, G = very good.

Fig. 3. The decision matrix LP x SC to determine the five classes of SNR: P = very poor, p = poor, m = medium, g = good, G = very good.

AN was considered more important than ESV in determining the soil quality SF. Hence five classes were assigned to AN, increasing from 1 to 5, but only three to ESV, increasing from 1 to 3. The scores of SF were obtained by multiplying the score of AN by the corresponding score of ESV. Thus SF got scores ranging from 1 to 15.

The scoring of SFS was proportional to normal soil conditions without any stress. SFS included toxicity, salinity, sodicity, extreme acidity, and oxygen deficiency. Four degrees of SFS were recognized, namely 0.3 (most impairing), 0.5, 0.7, and 1 (stressless). To obtain SFa, SF was multiplied by SFS, producing the five classes of SFa:

< 3 : very low (E)
4 - 6 : low (D)
7 - 9 : medium (C)
10 - 12 : high (B)
13 - 15 : very high (A)

SC was determined by the matrix NR x SFa. It was grouped into five classes (figure 2). The matrix LP x SC was used to determine SNR which has five classes also (figure 3).

To run the LP model, a year is divided into periods because P and ETo are time dependent. A period is a time interval within which P and ETo behave in manner distinct from their behaviour in the other periods. In a monsoonal region like Indonesia, it is convenient to divide a year into one rainy and one dry season. The mean monthly rainfall in the rainy season is 100 mm or more, while in the dry season it is less than 100 mm. For general purposes in the case of Indonesia, each season can be assumed to last six months.

ETo is the reference evapotranspiration of Penman. The balance between the season P and the season ETo is the season AWB. For the present study it would be sufficient to have three classes of AWB:

1. > 0; there is a surplus of P over ETo
2. = 0; P and ETo are balanced
3. < 0; there is a deficit of P

One may wish to subdivide further class 1 and class 3 to give more detail on surplus and deficit. A greater detail will present a better picture of the carry over effect of one season to the next.

The value of R (runoff) was derived from the local relief or slope. The five classes of R were:

1. Stagnant to very slow; in depressions or on level to nearly level terrain, slopes 0 - 3%
2. Slow to moderate; on gently undulating to undulating terrain, slopes 3 - 8%
3. Moderately rapid; on gently rolling to rolling terrain, slopes 8 - 16%
4. Rapid; on hilly terrain, slopes 16 - 30%
5. Very rapid; on steeply dissected to mountainous terrain, slopes > 30%

The infiltration rate I was derived from the soil texture. The four classes of I were:

1. Very slow to slow, < 0.8 cm h^{-1}; clays, silty clays
2. Moderately slow, 0.8 - 2.0 cm h^{-1}; sandy clays, silty clay loams, clay loams
3. Moderate, 2.0 - 8.0 cm h^{-1}; sandy clay loams, silts, silt loams, loams, sandy loams
4. Rapid to very rapid, > 8.0 cm h^{-1}; loamy sands, sands

I	R				
	1	2	3	4	5
1	1	4	4	3	3
2	2	5	4	3	3
3	6	5	5	4	4
4	6	6	6	4	4

AWB	WI					
	1	2	3	4	5	6
1	6	6	3	4	5	6
2	2	2	1	1	2	2
3	1	1	1	1	1	1

Fig. 4. The decision matrix R x I to determine the six classes of WI: 1 = strongly impeded; surface retention maximum, 2 = impeded, 3 = minumum; runoff maximum, 4 = limited, 5 = normal, 6 = maximum.

Fig. 5. The decision matrix WI x AWB to determine the six classes of RP: 1 = deficit, 2 = marginal, 3 = very low, 4 = low, 5 = normal, 6 = high.

The magnitiude of water intake WI was determined using the matrix R x I. It has six classes. See figure 4. The matrix AWB x WI determined the RP with six classes. See figure 5. As there is an AWB for each season, RP was determined for each season separately also.

SMD was defined as the capacity of the soil to retain water (SMHC) against the pulling force of gravity which causes water to percolate (WP). It was based on the combined action of soil texture, soil structure, and the effective depth of the soil. SMD was allocated in three classes:

1. Impeded; permeability very slow (< 0.8 cm h^{-1}), water retention high to very high; fine textured soils, massive to blocky structure, or soil effective depth less than 50 cm
2. Normal; permeability moderately slow to moderate (0.8 - 8.0 cm h^{-1}), water retention high to medium; medium textured soils, crumb to granular structure, soil effective depth around 100 cm
3. Excessive; permeability rapid to very rapid (> 8.0 cm h^{-1}), water retention low to very low; coarse textured soils, single grain to weak crumb structure, soil effective depth practically unlimited.

SMD	season RP					
	1	2	3	4	5	6
1	N	N	N	N	n	s
2	N	N	n	n	s	S
3	N	N	n	s	S	S

LPw	LPd			
	N	n	s	S
N	NN	-	-	-
n	nN	nn	-	-
s	sN	sn	ss	-
S	SN	Sn	Ss	SS

Fig. 6. The decision matrix RP x SMD to determine the four classes of LP: N = no leaching, n = some leaching, s = moderate leaching, S = strong leaching.

Fig. 7. The decision matrix LPd x LPw to determine the seven classes of LPy: NN = no leaching; leaching intensity 0, nN = some leaching in the wet season; leaching intensity 1, nn = some leaching throughout the year; leaching intensity 2, sN - SN = moderate to strong leaching in the wet season; leaching intensity 3, sn - Sn = moderate to strong leaching in the wet season, some leaching in the dry season; leaching intensity 4, ss = moderate leaching throughout the year; leaching intensity 5, Ss - SS = strong leaching in the wet season, moderate to strong leaching in the dry season; leaching intensity 6.

The intensity of LP was determined by the matrix RP x SMD. RP of a certain season produced the corresponding season LP. The LP was divided into four intensity classes. See figure 6. The wet and dry season LP were paired to obtain the yearly LP. The pairing was exercised using the matrix LPw x LPd (wet season x dry season). Seven classes were assigned to the yearly intensity LPy. See figure 7. As per definition LPd can never exceed LPw. At the most it may equal LPw. Therefore, the matrix contains boxes of non-existing pairs.

The pairing to imply the leaching characteristic during a year was inspired by Mohr's idea of water movement in the soil (Mohr, 1933). The product of the systems simulation is a map showing the geographical distribution of SNR. The mapping was done by a grid referencing system to assign each 1 cm^2 of the base map sheet a unique cell address. The values of the different elements of the model were recorded and stored for each grid cell. A digitized procedure for printer mapping was applied.

For the systems simulation of East Java the scale of the base map was 1:250,000, so the field measure of one grid cell was 6.25 km^2. This was the effective unit area of observation of soils, parent rock, and topography. The observation density of rainfall and evapotranspiration was much less due to the limited number of stations.

In areas of uniform topography at comparable elevations, Thiessen polygons were used to extrapolate station data of rainfall and evapotranspiration to grid cells. Since in Indonesia orographic rainfall is common, the reasonable distance of extrapolation along altitude sequences was decided empirically. As the local variations of rainfall and evapotranspiration were not so great as to significantly affect the simulation of AWB, the procedure of station data extrapolation seemed adequate. Besides, in regions where the land system units were large enough so that the percentage of grid cells covering border zones was small, the extrapolation error is expectedly small. The proportion of different conditions in border zone grid cells was visually estimated. The error can be kept small when sufficient terrain marks diagnostic of certain land systems are traceable on the base map. They may greatly help the proper setting of the boundaries of the mapping units, even with a limited number of observation points, provided that those points had been selected properly.

RESULTS AND DISCUSSION

Figure 8 exhibits the SNR map of East Java. For suitability reasons the scale of the map was reduced. The model permits revised criteria to be put in easily.

The SNR model, together with other models based on the land systems concept, provide the most logical basis for land resource inventories. Those models will produce pertinent baseline information upon which land development strategies can be defined, and imperatives for land use policies can be selected.

Most efforts to develop a land information system had at the outset the abstraction, storage, and direct retrieval of data as the main concern. The actual prediction of performance and suitability for use was considered a separate and distinct operation (Cline, 1981; Ridgway and Jayasinghe, 1986). Putman (1981), however, was of the opinion that masses of data are of little use without some means to manipulate them. Therefore, the Comprehensive Resource Inventory and Evaluation System (CRIES) has developed an Agriculture Resource Information System (ARIS) to store, retrieve, and manipulate mapped resource data. Cormack (1977) reported a manipulative extraction of area, point site, and profile data to generate information in a defined manner and the results were displayed in either map or tabulator form. Subroutines for data manipulation by correlation and regression relationships had been devised to facilitate the use of the National Soil Fertility Data Bank of Australia (Colwell, 1977).

The main purpose of the SNR model is to generate a specific information by manipulating mapped resource data and point site data altogether.

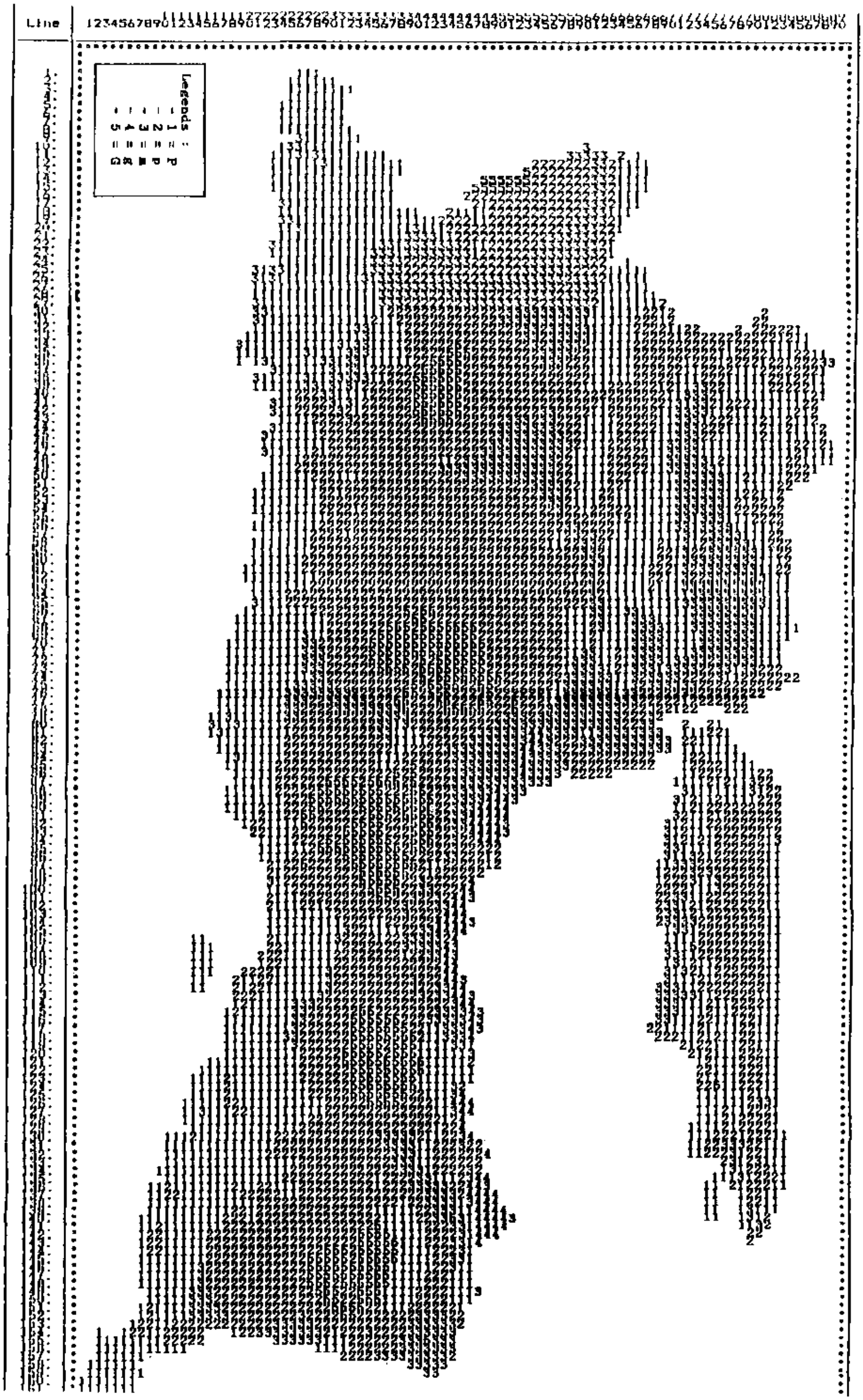

Fig. 8. Soil nutrient regime map of East Java. P = very poor, p = poor, m = medium, g = good, G = very good.

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LIMITATIONS TO FOOD CROP PRODUCTION IN TROPICAL ACID SOILS

Key Words: Aluminium Calcium Deficiency Legume Magnesium Manganese Molybdenum Nutrition pH Phosphorus Toxicity

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SUMMARY

Crop growth is often limited in tropical acid soils through a number of factors, including low pH per se, toxicities of aluminium (Al) and manganese (Mn), and deficiencies of phosphorus (P), calcium (Ca), magnesium (Mg) or molybdenum (Mo). These factors make it difficult to establish the cause of poor growth in each soil-plant situation; at a given site, different plant species may be growth-limited by different factors. The effect of soluble Al on root growth and on nodulation of legumes is accepted as the most important limitation to productivity. Results of recent studies have suggested the possibility of improved soil tests for toxic Al, based on soil solution chemistry. In particular, it is necessary to identify and measure the form or forms of Al responsible for poor root growth. Plant tissue analysis plays an important role in the identification and assessment of the other limitations to crop productivity in acid soils, viz. Mn toxicity and nutrient deficiencies. Failure to identify the cause of poor crop performance may result in inappropriate remedies (e.g. overliming) with adverse consequences.

INTRODUCTION

The climate of the tropics as well as the characteristics and distribution of soils in the tropics are not uniform. Also, parent materials and soil-forming processes in the tropics do not differ from those of temperate regions, but many soils of the tropics are older than those of temperate regions (Sanchez and Buol, 1975). The relatively old soils, high temperatures and high rainfall of many tropical regions have resulted in highly weathered soils of low base status. For example, many Oxisols, Inceptisols, Ultisols and Alfisols are acid (Kamprath, 1984), and acid soil infertility is a major constraint to food crop production. The acid Ultisols and Oxisols of the tropics comprise about 38% of the total land area of 4410 million ha (IBSRAM, 1987). Food crop production problems abound in the tropics, and the extent of acid soil infertility poses an important challenge to agricultural researchers (Sanchez and Buol, 1975).

In acid soils, plant growth and production are often poor as a result of the effects of (i) low pH per se; (ii) toxicities of aluminium (Al) and manganese (Mn); or (iii) deficiencies of calcium (Ca), magnesium (Mg), phosphorus (P), or molybdenum (Mo) (Foy, 1984). Additionally, nitrogen (N) fixation in legumes is often reduced in acid soils (Jackson and Reisenauer, 1984). It has been accepted that, in general, the adverse effect of soluble Al on root growth is the single, most important limitation to crop production in acid soils (Foy, 1984; Bell and Edwards, 1987). Nevertheless, acid soil infertility is a complex of factors that may reduce plant growth in a number of ways.

The extent of acid soils throughout the world has increased, and continues to increase, through human action. Agricultural practices of N fertilizer application, especially in the ammonium (NH_4^+) form, intensive irrigation and the removal of basic cations in harvested crops (Jackson and Reisenauer, 1984), and the growth of legumes (Haynes, 1983) decrease soil pH. Also, basic cations are lost through soil erosion, and air polluted by industry results in acid rain, the effects of which may be manifest at considerable distances from the sources of pollution.

The aim of this paper is to summarize recent developments in the understanding of acid soil infertility, with particular emphasis on Al toxicity.

COMPONENTS OF ACID SOIL INFERTILITY

Soil pH

There is general agreement that soil pH *per se* does not cause poor plant growth in acid soils. Nevertheless, soil pH, and its measurement, remain important in acid soils, since the solubility of Al and Mn increase and the availability of some essential nutrients decreases with decrease in pH.

Schofield and Taylor (1955) suggested that soil pH be measured in 0.01M $CaCl_2$ solution since the ionic strength of 0.01M $CaCl_2$ (30 mM) approximates that of the soil solution. However, Bruce (1986) found that the mean ionic strength of 48 surface soil and 48 subsoil samples from tropical and sub-tropical Queensland was 5.3 and 2.4 mM, respectively. Thus, the pH of the soil solution was more closely related to soil pH measured in H_2O than in 0.01M $CaCl_2$. Edmeades *et al*. (1985) also found pH measured in H_2O to best estimate soil solution pH, and suggested that high ionic strength of soil solutions might arise from the incubation of moist soil prior to extraction of the soil solution. The rewetting of air-dry soils to field capacity for 1 to 2 days prior to extraction of the soil solution allows cations and anions to reach equilibrium concentrations similar to those present in the field, but avoids greatly increased ionic strengths through mineralization of organic matter (N.W. Menzies, pers. comm.).

The increase in the incidence of Al toxicity with decrease in pH (H_2O) below 5.5 is related primarily to the increased solubility of solid forms of Al present in the soil. For a given soil, there is often a good relationship between soil pH and exch. Al or Al saturation, but there is no general relationship applicable to all soils. It appears that soil solution ionic strength is important in this regard (Bruce, 1986).

In individual soils, good relationships have been found between soil pH and crop growth (e.g. Blamey and Chapman, 1979) (Fig. 1). However, when data from a number of soils are combined, the association between soil pH and crop dry matter production is not as clear (Farina *et al*., 1980).

In spite of a poor direct relationship between soil pH and yield, soil pH plays an important role in nutrient availability. The availability of Mn, iron (Fe), copper (Cu) and zinc (Zn) increases as pH decreases, particularly below pH 5.0 (Lucas and Knezek, 1972). Boron (B) deficiency may be induced by liming acid soils (Gupta,

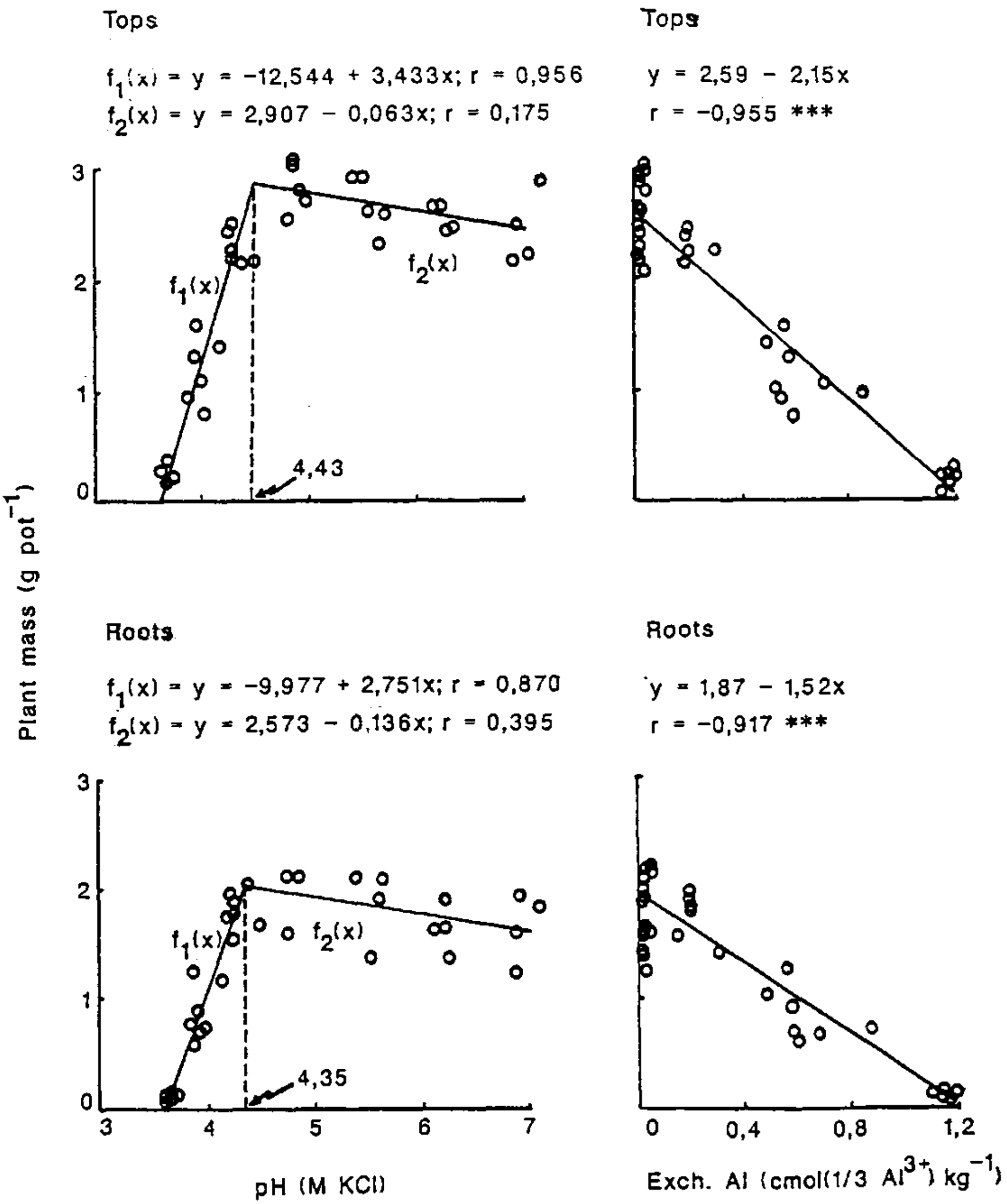

FIG. 1. Relationships between 1-month-old sunflower top and root mass and pH (M KCl) and exch. Al on an Avalon soil (Typic Plinthustult) (after Blamey and Chapman, 1982).

1972), but Mo availability increases with increased soil pH (Lindsay, 1972; Ellis and Knezek, 1972).

Because of the number of factors that change in the soil along with pH, studies on pH effects on plant growth generally have been conducted in solution culture. In a well-controlled flowing solution culture, Islam et al. (1980) found that crop species achieved maximum or near-maximum growth at pH 5.5 to 6.5, but there were substantial differences among species to grow outside this range. Ginger and cassava were the most tolerant species to low solution pH, but roots of all species were injured at pH 3.3. Free-living cowpea rhizobia have also been shown to differ in sensitivity to low pH, and reduction in growth of inoculated cowpea plants was attributed in most cases to a reduction in nodule number (Keyser et al., 1979). In soybean, the appearance of the first nodule was delayed and nodule number and mass decreased at pH 4.5, whereas there was no difference in total dry matter yield from pH 4.5 to 5.5 (Alva et al., 1987). Mayz de Manzi and Cartwright (1984) also found that nodulation of cowpea is more sensitive than host plant growth to low pH.

Toxic aluminium

Most of the Al present in the soil is in the solid phase as layer silicates, and as oxides and hydroxyoxides that may be either crystalline or amorphous (Thomas and Hargrove, 1984). Aluminium may also be present in the solid phase complexed with insoluble organic matter. Aluminium present in the solid phase is not toxic to plant roots, but plays an important role in soil acidity.

The assessment of soils for potential Al toxicity has been based on extraction of exch. Al with a neutral, unbuffered salt, usually 1M KCl (Barnhisel and Bertsch, 1982). In individual soils, good relationships have been found between plant growth and exch. Al (e.g. Blamey and Chapman, 1979) (Fig. 1). When data from a number of soils were combined, the relationship between relative yield and of maize plants and exch. Al was considerably better than that between relative yield and soil pH (Farina et al., 1980). However, Al saturation, the proportion of effective cation exchange capacity occupied by exch. Al, has often been found more useful in predicting Al toxicity than the absolute amount of exch. Al (Kamprath, 1984). In spite of an improvement in the prognosis of Al toxicity using Al saturation, no general relationship over all soils has been established (Adams and Lund, 1966; Adams and Hathcock, 1984).

To be toxic to plant roots, Al must be in solution. The chemistry of Al in solution is complex, but evidence from recent nutrient solution studies has thrown some light on the nature of toxic Al. When an Al-salt is dissolved in water, the released Al^{3+} co-ordinates with six OH groups. There is spontaneous hydrolysis of Al^{3+} to yield inorganic monomeric species, such as $Al(OH)^{2+}$, $Al(OH)_2^{+}$ through $Al(OH)_5^{2-}$ (disregarding waters of hydration) (Marion et al., 1976). At acid pH, the negatively charged monomers contribute little to the total Al in solution (Marion et al., 1976; Helliwell et al., 1983), only Al^{3+}, $Al(OH)^{2+}$, $Al(OH)_2^{+}$ and $Al(OH)_3^{o}$ being important. The presence of the inorganic anions, F^-, SO_4^{2-} and $H_2PO_4^-$, in solution results in the formation of various inorganic monomeric Al species (Lindsay, 1979; Cameron et al., 1986).

As the pH of a solution containing Al is increased (i.e. at high OH:Al ratios), Al may be precipitated and lost from solution. Additionally, Al polymers may form, e.g. $Al_2(OH_2)^{4+}$, $Al_6(OH)_{15}^{3+}$, $Al_{13}(OH)_{24}^{7+}$ (disregarding waters of hydration). Wada and Wada (1980) found that the proportion of polymeric Al in solution increased linearly from 2% without added OH to approximately 95% at an OH:Al ratio of 2.7. This result was obtained with a high Al concentration in solution (480 µM), but has been confirmed at lower Al concentrations (10-200 µM) (Blamey et al., 1983). The Al polymers that form on addition of OH, may be lost from solution at ionic strengths >910 µM, i.e. on the addition of nutrient salts (Blamey et al., 1983).

The equilibrium between monomeric and polymeric Al is slow (Hsu, 1963), allowing the development of analytical methods that discriminate between these forms of Al. For example, Bloom et al. (1978) used a 10s reaction with 8-hydroxyquinoline and Blamey et al. (1983) used a 30 min reaction with aluminon to measure monomeric Al. However, these methods do not discriminate between the inorganic, monomeric Al species and the Al present in solution complexed with organic acids. Kerven and Edwards (1987) described a 60s colorimetric procedure using pyrocatechol violet which discriminates between inorganic, monomeric Al and organically complexed Al present in solutions containing 0.2 to 25 µM total Al.

In spite of the many forms of Al in the soil, not all forms are toxic to plant roots. Solid forms of Al are not toxic. Indeed, the aim of liming has been to precipitate soluble forms of Al. Also, results of recent research have suggested that, of all the forms of

Al in solution, only the inorganic, monomeric species are toxic. Polymeric forms have been shown not to affect the growth of soybean roots (Blamey et al., 1983). Sulfate forms weak complexes with Al, and reduces slightly its toxic effects, while F^- complexes readily with Al, and is even more effective than SO_4^{2-} in reducing Al toxicity (Cameron et al., 1986). Furthermore, organic ligands form complexes of varying strength with Al, differences in which determine their effectiveness in detoxifying Al (Hue et al., 1986). In particular, the presence of humic and fulvic acids in solution, as occurs in soil solutions of many acid topsoils, reduces the toxicity of Al in solution to plant roots (Bartlett and Riego, 1972; S. Suthipradit, pers. comm.).

Adams and Lund (1966) suggested that the activity of ions in solution, rather than their concentration, better describes their effects, and used the activity of Al^{3+} in acid subsoils and nutrient solutions to describe the effect of Al on cotton roots. Blamey et al. (1983) suggested that the sum of activities of the inorganic monomeric species ($\Sigma a_{Al\ mono}$) best described the effect of Al in nutrient solutions on soybean root growth. Alva et al. (1986a) further explored this aspect, concluding that nominal Al concentration in solution (i.e. Al added) is of little value as an index of Al toxicity, as is total Al concentration in solution when considerable polymeric Al is present in solution. Also, where the effects of Al are studied in solutions of differing ionic strength, the concentration of monomeric Al is a poor index. The best and most robust index of Al toxicity, as measured by root growth of soybean, subterranean clover, lucerne and sunflower, proved to be $\Sigma a_{Al\ mono}$ which takes account of Al precipitation and polymerization as well as the effects of ionic strength in assessing toxic effects of Al.

In tropical and subtropical Queensland soils, Bruce (1986) found that monomeric Al concentrations ranged from 2.1 to 101 µM in 48 surface soil samples (mean soil solution pH 5.4) and from 0.05 to 378 µM in 48 subsoil samples (mean soil solution pH 5.3). The ranges in $\Sigma a_{Al\ mono}$ of the surface and subsoil samples were 2.1 to 67 and 0.05 to 143 µM, respectively. Edmeades et al. (1985) found that Al activities were < 50 µM in acid New Zealand soils. Bruce (1984) reported 90% relative root length of soybean corresponded with 4 µM Al^{3+} activity, while Edmeades et al. (1983) reported Al toxicity of white clover in two acid New Zealand soils was associated with soil solution Al activity >9 - 15 µM.

With the finding that it is the inorganic, monomeric Al species that are toxic to plant roots, considerable research effort is being expended in establishing which of the monomers might be toxic. This has proved possible with the development of techniques to discriminate between the different forms of Al present in solution. Also, computer programs, e.g. GEOCHEM (Sposito and Mattigod, 1980) and TITRATOR (Cabaniss, 1987), have assisted in the many computations necessary to calculate concentrations and activities of various Al species. However, Bertsch et al. (1986) warned that the programs need to be used with care, particularly in estimating concentrations of polymeric Al because of the slow equilibration between monomeric and polymeric Al.

A number of studies in nutrient solutions have attempted to establish which of the Al monomers is responsible for poor root growth. Kerridge (1969) suggested that a hydrolysis product of Al rather than Al^{3+} was responsible for poor root growth in wheat, and Moore (1974) concluded that $Al(OH)^{2+}$ was the monomer responsible for the toxicity. Blamey et al. (1983) suggested that either Al^{3+} or $Al(OH)_2^+$ might be the predominant ion responsible for decreased root elongation in soybean. Alva et al. (1986c), working with a number of species found that root length was most highly correlated with $Al(OH)^{2+}$ or $Al(OH)_2^+$. In the majority of cases, the relationship between root length and the activity of Al^{3+} was relatively poor.

When extending these concepts to the soil solution, care will need to be taken regarding soil storage time and temperature, extraction of the soil solution and filtration in view of their effects on Al in solution (Curtin and Smillie, 1983; Edmeades et al., 1985; Jardine et al., 1986). Also, properties of the bulk soil solution might not reflect conditions in the rhizosphere (Marschner et al., 1986; Romheld, 1986).

Differential tolerance to toxic Al among plant species and among cultivars of the same species has long been recognized (Foy, 1984). Recent research using dilute nutrient solution culture has emphasized the extent of these differences (Table 1). The $\Sigma a_{Al\ mono}$ associated with a 50% reduction in root length has ranged from 5 µM in sunflower to 102 µM in sugarcane cv. Q113.

The differential tolerance of plant species or cultivars to toxic Al has sometimes been ascribed to the differential ability of plants to alter the pH of the root environment (Foy, 1984). Other mechanisms may also be involved in the differential tolerance of plants to toxic Al, since Kim (1984) found differences in tolerance to toxic Al among subterranean clover cultivars grown in the same flowing nutrient solution units in which pH was continuously adjusted to 4.3.

TABLE 1

The Sum of Activities of Monomeric Al Species ($\Sigma a_{Al\ mono}$) associated with a 50% reduction in root length in a number of crops.

Crop	$\Sigma a_{Al\ mono}$ associated with 50% reduction in root length (μM)	Reference
Sunflower	5	Blamey <u>et al</u>. (1986)
Grain sorghum	7	"
Soybean	7-16	Alva <u>et al</u>. (1986)
Sunflower	11	"
Navybean	9	Hetherington <u>et al</u>. (1988)
Soybean	10	"
Maize	10	"
Sugarcane 'Q77'	47	"
Sugarcane 'Q117'	81	"
Sugarcane 'Q113'	102	"

Soluble Al in the root environment has detrimental effects on the survival of free-living rhizobia and on processes involved in N_2 fixation. Nodulation is particularly sensitive to Al, and in many cases is more sensitive to Al in the root environment than is host growth (Bell and Edwards, 1987). Reduced nodulation due to Al toxicity has been reported in species in which rhizobia enter the root through the root hair (e.g. subterranean clover) (Kim, 1984) and in species in which rhizobia enter through spaces between epidermal cells and lateral root junctions (e.g. <u>Stylosanthes</u> spp.) (Carvalho <u>et al</u>., 1982). At solution concentrations that restrict nodulation, Al appears to have no effect on the functioning of nodules in N_2 fixation (Carvalho <u>et al</u>., 1982).

Toxic Manganese

The chemistry of Mn in soils is complex, since Mn exists in several oxidation states and forms oxides of mixed oxidation states which exist in different crystalline and amorphous forms (Lindsay, 1972). Nevertheless, Mn availability to plants increases at low pH, and Mn toxicity may reduce plant growth as soils with high concentrations of easily reducible Mn become acid (Kamprath, 1984). Also, plants growing on soils high in easily reducible Mn may suffer Mn toxicity on waterlogging (Graven et al., 1965). To be effective in the prognosis of Mn toxicity, soil analyses must take account of Mn^{2+} in the soil solution, the amount of easily reducible Mn, soil pH and possibly soil organic matter. Bromfield et al. (1983) showed that Mn extracted with 0.01M $CaCl_2$ provided a better index of available Mn than either soil solution Mn or neutral ammonium acetate extractable Mn.

Crop species have been shown to differ markedly in tolerance to high levels of available Mn in soils and nutrient solutions (Foy et al., 1978; Edwards and Asher, 1982). Three possible mechanisms have been suggested for the ability of some crop species to tolerate high levels of available Mn in the root environment: (i) roots may have low rates of Mn uptake; (ii) Mn may be retained in the roots and not translocated to the tops; and (iii) plant tops may be able to tolerate high tissue Mn concentrations. In the study of Edwards and Asher (1982), cowpea, French bean and maize were shown to be susceptible to Mn toxicity (Table 2). Moderate to high Mn concentrations in nutrient solution were tolerated by pigeonpea through a low rate of Mn absorption and through retention of Mn in the roots. Sweet potato and sunflower tolerated high Mn concentrations in plant tops. The ability of sunflower to tolerate a high concentration of Mn in the tops has been related to a compartmentation mechanism whereby Mn is localized in the trichomes in a metabolically inactive form (Blamey et al., 1986b).

Keyser and Munns (1979) found that a high Mn concentration (200 µM) slowed, but did not stop, the growth of some cowpea rhizobia strains. Based on this result and those from other studies, Keyser and Munns (1979) concluded that Al toxicity and low pH are probably more important in limiting rhizobial growth than is Mn toxicity. Munns (1978) concluded that most observed effects of Mn excess on nodulation and N_2 fixation could not be distinguished from the effects of Mn excess on host plant growth.

TABLE 2

Manganese Absorption Rate and Manganese Retention in Roots at 394 µM Mn in solution, and the Critical External and Tissue Mn Concentrations (Associated with 90% Maximum Yield) of Nine Crop Species (Edwards and Asher, 1982).

Species	Mn Absorption Rate (µMol g^{-1}FW d^{-1})	Mn Retained in Roots (%)	Critical External Conc. (µM)	Critical Tissue Conc. (µg g^{-1})
Cassava	9.99	12.1	4.0	300
Sweet potato	6.47	8.5	18	1380
Cotton	22.2	3.9	4.1	750
Sunflower	9.83	5.1	65	5300
Cowpea	6.21	9.7	1.9	720
French bean	6.84	6.1	2.2	280
Soybean	5.43	21.1	8.5	600
Pigeonpea	6.22	25.9	46	300
Maize	4.58	21.7	1.4	200

Nutrient Availability

Poor crop growth results from inadequate nutrient availability in many acid soils. Deficiencies of Ca and Mg would be expected since these elements are often in short supply in parent materials, and acid soils have resulted through loss of these elements by leaching, erosion and removal in harvested products.

In many acid soils, Ca deficiency has not been found to be the primary cause of poor growth since the addition of neutral Ca salts (e.g. $CaSO_4.2H_2O$, $CaCl_2$) has not improved crop growth. However, recent research has suggested that Ca deficiency is more widespread than previously expected (Bruce, 1986). The addition of neutral Ca salts results in the displacement by Ca ions of Al ions adsorbed to colloid surfaces. The increase in monomeric Al ions in solution over-rides the increased ionic strength of the soil solution, and no yield advantages result from alleviating Ca deficiency.

Nutrient solution studies (e.g. Munns, 1965; Rhue and Grogan, 1977) have demonstrated a beneficial effect of increasing solution Ca concentration in alleviating the adverse effects of toxic Al on root growth. However, many experiments have not distinguished between an indirect effect of added Ca salts increasing solution ionic strength (and, hence, reducing the activity of Al ions) and any direct effect of Ca^{2+} ions per se in alleviating Al toxicity. Studies by Alva et al. (1986a, b) confirmed both indirect and direct effects of Ca in alleviating Al toxicity.

In contrast with many other crop plants, Ca nutrition plays a central role in peanut nutrition (Walker, 1975). This results from the non-translocation of Ca from vegetative to reproductive parts of peanut. The relatively high Ca requirement of the developing pod must be met by Ca uptake by the pod itself. Inadequate available Ca in the peg zone (0-5 cm), as a result of low Ca status, drought or competition for uptake by Mg and potassium (K), causes yield depression and reduced kernel quality.

Peanut crops are often fertilized with gypsum at flowering to ensure adequate Ca is available in the peg zone. Indeed, Adams and Hartzog (1979) found a good relationship between peanut yield and the level of Ca in soil extracted with 0.05 M HCl + 0.05 M H_2SO_4. Gypsum fertilization has decreased the nutritional disorders of unfilled ovarian cavities (pops) and black plumule, both symptoms of Ca deficiency. In addition, the B deficiency symptom, hollow heart, has been alleviated by gypsum applications (Morrill et al., 1977).

In contrast with these findings, Blamey and Chapman (1982) found little effect of gypsum on peanut yield and quality whereas lime improved kernel yield. This result was explained by the effects of these amendments on exch. Al levels in the soil (Table 3). The exch. Al levels, in turn, influenced nodulation with gypsum applications having a small detrimental effect while liming improved nodulation. As a result of improved nodulation, liming increased N_2 fixation as shown by the increased vegetative and kernel yields and the increased N concentrations in the leaf and protein concentrations in the kernel (Table 3). Chong et al. (1987) found that nodulation and N_2 fixation in peanut were inhibited when grown in soil at $pH \leq 3.9$, and Kamprath (1984) reported that nodulation of peanut was inhibited when Al saturation was > 30%.

TABLE 3

Effect of Lime or Gypsum on Soil Tests and Peanut Performance (1978/79) on an Avalon Soil (Typic Plinthustult) (after Blamey and Chapman, 1982).

Variable	Lime ($kg\ ha^{-1}$)				Gypsum ($kg\ ha^{-1}$)			
	0	800	1600	2400	0	800	1600	2400
pH (H_2O)	4.19	4.50	4.87	5.45	4.19	4.30	4.21	4.26
pH (M KCl)	3.74	4.01	4.33	4.83	3.74	3.84	3.76	3.80
Exch. Ca[1]	0.44	1.29	1.91	2.73	0.44	0.72	0.91	1.05
Exch. Al[2]	0.98	0.41	0.13	0.04	0.98	0.74	0.75	0.71
Al Saturation (%)	60.0	23.3	6.93	1.74	60.9	45.5	42.0	38.5
Hay Yield ($kg\ ha^{-1}$)	2143	3548	3802	3881	2143	2540	2095	2524
[N] in Leaf (%)	2.59	2.67	2.90	3.06	2.59	2.46	2.55	2.38
Pod Yield ($kg\ ha^{-1}$)	1590	3150	3072	3368	1590	1885	1505	1573
Kernel Yield ($kg\ ha^{-1}$)	1107	2334	2315	2534	1107	1363	1083	1119
Oil (%)	52.2	53.4	52.2	51.6	52.5	53.3	53.4	54.3
Protein (%)	20.1	23.2	23.6	25.1	20.1	21.0	19.6	19.0

[1] (cmol(1/2 Ca^{2+}) kg^{-1})
[2] (cmol(1/3 Al^{3+}) kg^{-1})

Phosphorus deficiency is a problem common to many acid soils. Increasing the pH of acid soils has increased P availability, improving crop growth and N_2 fixation (Jackson and Reisenauer, 1984). Whether or not P availability increases on liming an acid soil depends on the combination of pH and P factors (Adams, 1984). Also, P fertilization has the ability of reducing toxic Al in the soil solution.

The availability of the micronutrients, Fe, Mn, Cu and Zn, increases at low pH (Lindsay, 1972), and problems with deficiencies of these micronutrients are not likely to be encountered in acid soils. Problems with deficiencies may be encountered, however, when acid soils are limed.

Plant-available B in acid soils is mostly present as undissociated H_3BO_3, and to a lesser extent $H_2BO_3^-$ (Lindsay, 1972). The concentration of H_3BO_3 is not affected by soil pH, and the concentration of $H_2BO_3^-$ increases with increase in pH. It might be expected, therefore, that B availability to plants would increase with increased pH, but it has been well documented that liming acid soils increases the incidence of B deficiency (Gupta, 1972). It appears that liming decreases plant absorption of B through B adsorption on precipitated $Al(OH)_3$ (Hatcher et al., 1967). However, other studies (Hortenstine and Fiskell, 1961; Blamey and Chapman, 1979) have found no decline in B availability with increased pH. As a corollary to the increased adsorption of B at high pH, the available B in acid soils may be decreased through leaching of non-adsorbed B (Bradford, 1966).

Of the micronutrients, Mo is most likely to be deficient in acid soils, since the activities of molybdate ions decrease as soil pH declines (Lindsay, 1972). Also, the adsorption of molybdate ions by sesquioxides increases at low pH (Ellis and Knezek, 1972).

CORRECTION OF ACID SOIL INFERTILITY

Liming, to correct problems associated with acid soils, has been an agricultural practice for centuries. Nevertheless, it is still uncertain on which basis lime should be applied, and recommended rates of lime application have varied greatly.

On one hand, lime requirement has been estimated on the basis of 'a pH range most favourable for plant growth' (McLean and Brown, 1984). In the midwestern USA, this has ranged from pH 6.0-6.2 for maize and soybean to pH 6.5 for lucerne (McLean and Brown, 1984). Techniques of estimating lime requirement based on soil pH have used either one of the buffer methods (e.g. Shoemaker et al., 1961; McLean, 1978; Yuan, 1976) or soil pH in the field state and the expected increase in pH per unit of lime applied. In contrast with findings in midwestern USA, Farina et al. (1980) reported that the pH for maximum maize growth varied across soils from pH 4.2 to 7.0. Furthermore, severe yield depressions have been reported when liming tropical and temperate soils to near neutrality (Kamprath, 1972; Farina et al., 1980).

As an alternative to soil pH, Kamprath (1970) and Reeve and Sumner (1970) suggested the use of exch. Al as the basis of determining lime requirement. Alternatively, Al saturation has been used as a criterion for determining the lime requirement. The rates of lime recommended (t ha^{-1}) have ranged from 1.5 to 3.3 times the exch. Al (cmol(1/3 Al^{3+})kg^{-1}) (Kamprath, 1984). As with soil pH, however, there is no single relationship between Al saturation and the yield of a crop (Bouldin et al., 1987). Many reasons may account for this, but the understanding and use of soil solution properties, especially the activities of inorganic, monomeric Al, holds particular promise in the prognosis od Al toxicity.

Since crop species and cultivars within species have been shown to differ in sensitivity to acid soil factors (Foy, 1984), crop cultivars may be bred specifically for tolerance to acid soils. Care needs to be taken in such an exercise, since acid soil infertility consists of a complex of factors. The breeding of crops adapted to acid soil conditions may be conducted on very acid soils or on soils to which moderate lime rates have been applied. Breeding holds particular promise in overcoming problems of acid subsoils, where the application of lime is both difficult and expensive. However, crops will need to be selected on sites where there is a know reason for poor growth. Alternatively, rapid screening techniques in nutrient solution culture may be used. Screening for Al toxicity tolerance, however, needs cognisance of soil solution chemistry. Failure to consider the significance of ionic strength or the precipitation of Al from solution on addition of OH or P makes it unlikely that the genotypes selected will be well adapted to acid tropical soils.

CONCLUSIONS

Acid soil infertility results from a complex of factors, not one of which is responsible for poor crop production in all situations. The toxicity factors (H, Al or Mn) and the deficiency factors (Ca, Mg, P or Mo), and their interactions, make it difficult to identify the specific cause of poor crop growth in acid soils. However, it is necessary that the cause of poor crop growth be established in order that the appropriate remedial strategy be implemented.

One method of identifying the specific cause of poor crop growth is the growth of indicator crops. For example, sunflower is most sensitive to Al toxicity, yet is one of the most tolerant species to Mn toxicity. Additionally, toxicities and deficiencies produce characteristic symptoms on many crop species. Another method of identifying the specific cause of poor crop growth is the use of soil analyses. Many techniques, developed to estimate levels of plant-available nutrients in the soil, can be used to advantage in identifying acid soil problems. With regard to Al toxicity, recent studies have suggested the possibility of improved soil tests based on solution chemistry. A third method of identifying the specific cause of poor crop growth is the use of plant tissue analyses. Potential problems of nutrient deficiencies and Mn toxicity can be established by tissue analysis, but the identification of Al toxicity by tissue analysis has not proved satisfactory. Methods of overcoming acid soil problems remain the application of liming materials to the soil, and the breeding of crop plants better adapted to one or more of the acid soil factors.

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MANAGEMENT OF NITROGEN TO IMPROVE ITS USE EFFICIENCY IN LOWLAND AND UPLAND SOILS OF INDONESIA

Key words: Lowland soils Maize response Rice Status Supplying capacity Upland soils Use efficiency

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SUMMARY

An improved nitrogen management will be an important tool in reaching the target of self sufficiency in food crops and increasing the production of exportable crop commodities is certainly to require progressively greater increases in nitrogen use. It will pose a greater challenge to research and extension workers in the efficient use of nitrogen.

Research results in many lowland rice areas in Java have consistently shown that deep placement of USG is more efficient than broadcast urea in respect of fertilizer rate, yield and net benefit for farmers.

Every season incorporation of rice straw continously increased use efficiency of nitrogen from less than 20 kg grain/kg N to more than 40 kg grain/kg N, which was reached in the fourth season. Proper rate and time of application and organic matter incorporation greatly increased yield and use efficiency of nitrogen.

INTRODUCTION

Nitrogen use in the food crop production, especially rice, has considerably increased in Indonesia since 1977 (Fig. 1) reflecting a national effort in attaining self sufficiency in rice. However, after 1980 lowland rice productivity levelled-off, as the rate of production increase went down from 10.3 per cent in 1980 to 0.6 per cent in 1986 (Sihombing and Rusadhi, 1986; Bimas, 1987). Imbalanced fertilization and improper soil management were regarded as the main cause.

To maintain self sufficiency in rice, to reach self sufficiency in other food crops, and to increase the production of exportable crop commodities are the main targets of the Indonesian Government. To achieve these targets more land will have to be cultivated, and diversification and intensification to get greater productivity per unit cultivated land will be required. This effort is certain to require progressively larger increases in nitrogen use and will pose a great challenge to research and extension workers in the efficient use of nitrogen.

Adaptive research on fertilizer use has been started long before Pelita Program, but studies stressing the efficient use of fertilizers are only going on since a few years. These studies are collaborative efforts between the Agency for Agricultural Research and Development (AARD) and international institutions such as IFDC, IRRI and TROPSOILS.

This paper presents some results of studies on management of nitrogen in lowland and upland soils and also includes data on the nitrogen status of soils in Indonesia.

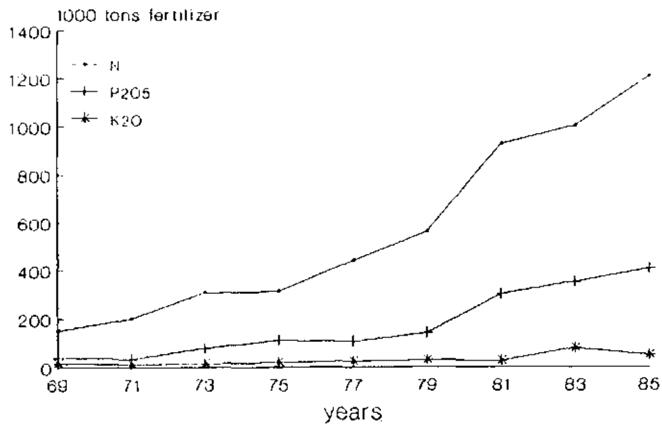

Figure 1. Trend of fertilizer consumption for food crops.
Source: Indonesian National Fertilizer Study

NITROGEN STATUS OF SOILS

Nitrogen is most likely to limit crop growth on almost all soils. Factors affecting the release and availability of nitrogen in soils are somewhat different than for the other essential elements, such as P and K, since nitrogen is mostly found in the soil organic matter. In some instances appropriate analyses for soil nitrogen and organic matter are helpful in giving proper rates of fertilizer nitrogen, especially for newly cleared woodlands. In the following paragraphs C-organic matter total nitrogen relationships and other soil properties and an assessment of nitrogen status of soils are described and discussed.

TABLE 1. Average and standard deviation of C, N and C/N ratio of North Sumatera topsoils within group of soil parent materials (Widjaja-Adhi, 1976).

No.	Kind/Group of parent material	Number of sample (n)	C-organic (%)		N-total (%)		C/N-ratio	
			x	S_x	x	S_x	x	S_x
1.	Ac,s(a)	17	2.27	.325	.185	.026	13.0	1.19
2.	Ac(a)	3	1.56	.413	.124	.014	12.7	3.28
3.	Ac,s(a-i)	17	1.80	.277	.163	0.017	10.6	.79
4.	Ta	60	3.89	.547	.270	.022	13.9	1.04
5.	Ta-i	17	4.18	.589	.336	.043	12.5	.97
6.	Ti	14	8.66	1.676	.658	.093	12.9	.75
7.	Sc,s/Ta	3	5.08	1.566	.364	.105	13.7	1.67
8.	Sc,s/	8	3.12	.859	.181	.019	17.6	5.18
9.	Ta/Ms	3	2.41	.477	.152	.017	17.0	5.50
10.	Sc	2	6.28	3.640	.327	.099	17.5	5.50
All samples		144	3.89	.332	.285	.018	13.4	.58

C-organic Matter and Total Nitrogen

Analyses of topsoils from North Sumatera were grouped according to soil parent materials. Average and standard deviation within each group for C, N and C/N ratio are presented in Table 1. Average percentage of organic C ranged from 1.56% in topsoils developed from the clayey acid Alluvium group, (Ac(a)), to 8.66% in topsoils developed from the intermediary tuff (Ti) group. Average total nitrogen ranged from 0.124 to 0.658, respectively, in the same soil parent material groups.

Within the three groups of tuff parent materials the average of organic C and total nitrogen decreased from intermediary (Ti) to acid (Ta) tuffs (Table 1). The C/N ratio was within the range of cultivated soils, demonstrating that the organic matter mineralization reaches "equilibrium" or "steady state" at higher levels of C- organic or of total nitrogen in the richer soils.

Relationship Between Total Nitrogen and Other Soil Properties

Total N and organic C percentages showed significant correlation coefficients, as expected, but it is interesting to note that the magnitude of the coefficients varied among the parent material groups (Table 2).

Total N significantly and positively correlated with clay percentages in clayey to sandy acid alluvium, AC,s(a), with P_2O_5 contents in acid tuff (Ta) and in a group of parent materials, but negatively with K_2O contents in acid tuff and with pH(KCl) in intermediary tuff (Ti).

TABLE 2. Correlation coefficient of the relationship between total N percentage and other soil properties of North Sumatera top soils within group of soil parent materials.

Kind/Group of parent material	% Clay	pH (H_2O)	pH (KCl)	% C	P_2O_5 mg/100g	K_2O	r .05	r .01
Ac,s(a)	-.779**	-.088	-.125	.891**	.331	-.274	.482	.606
Ac,s(a-i)	-.133	-.010	.358	.906**	-.171	.002	.482	.606
Ta	-.188	-.249	-.148	.640**	.312	-.296*	.253	.331
Ta-i	-.274	.096	.172	.881**	.470	.276	.482	.606
Ti	.216	-.298	-.715**	.943**	-.258	-.132	.532	.661
Group [1]	.532*	-.237	-.133	.732**	.757**	-.014	.456	.575
All samples	-.085	-.175*	-.096	.803**	.302**	-.189*	.164	.214

Source : Widjaja-Adhi (1976)

[1]) Notes : The group consist of af (Ac(a), Sc,s/Ms, Ta/Ms and Ss

For all samples total N showed positive, significant correlation coefficients with nitrogen and phosphorous content, and negative ones with pH(H_2O) (Table 2). This correlation study reveals that: (1) liming, that increases pH, and potassium application will reduce total N or will enhance organic matter decomposition, and (2) level of total N or soil organic matter increases by increasing P reserves in the soils through phosphate fertilization. The last conclusion is in accordance with the statement on the "equilibrium" level of soil N being higher in nutrient richer soils.

Soil Tests for Assessing Nitrogen Availability

Several test procedures have been developed to assess availability of soil nitrogen. Some are chemical extraction methods and reflect part of or total soil supply. Some are biological and measure mineralization or nitrogen supplying power of soils. All are arbitrary and to be useful they must be calibrated with crop use and crop needs.

A correlation study to select a method in assessing availability of soil nitrogen was conducted using results of pot experiments (Widjaja-Adhi, 1973). Among six test procedures compared, the two-week-anaerobic incubation procedure gave the highest correlation coefficient (r) of 0.902 and 0.927 with dry matter yield and N-uptake respectively (Table 3). Among the chemical tests studied, the alkaline permanganate oxidation method gave the lowest correlation coefficient of 0.659 and 0.642 respectively with dry matter yield and N-uptake.

TABLE 3. Correlation coefficient of the relationship between available-nitrogen indicates and dry-matter yield and N-uptake of lowland rice (Widjaja-Adhi, 1973).

No.	Method	Dry matter	N-uptake
1.	2 week-anaerobic incubation	.902**	.927**
2.	1 week-anaerobic incubation	.851**	.900**
3.	Alkaline hydrolysis	.780**	.837**
4.	Keeney - Bremmer's	.779**	.846**
5.	Acid hydrolysis	.766**	.805**
6.	Alkaline permangamate indication	.659**	.642**

NITROGEN MANAGEMENT IN LOWLAND SOILS

The efficient use of nitrogen results in greater crop yield and quality per unit of land and at less unit cost production, which means more profits to the farmer. To improve the use efficiency of nitrogen, proper rates of fertilizer should be made and proper application practices should be followed. Time of application, placement, kind of nitrogen carriers or sources, and the associated amendments applied with nitrogen all have some influence on the nitrogen use efficiency.

Response of Lowland Rice to Nitrogen Fertilizer

Figure 2 demonstrates contrasting responses of IR-5 lowland rice to nitrogen application at two sites in the wet season compared to the same sites in the dry season. Yield and responses were high in the dry season and low in the wet season. A lot of solar radiation during the dry season and less radiation during the wet season are usually the explanation of the above contrasting responses.

Yield responses to nitrogen application also vary because of site or soil conditions (Fig. 3). Yields and responses were high on a brown Latosol at Awirarangan and on a grey Regosol at Tegal Gondo, but were low on a Ground Water Laterite at Tulis and on a grey Alluvial at Lohbener. A low initial yield but with a high response to nitrogen application was observed on a dark grey Alluvial at Warujinggo and a medium initial yield and a low response was found on a dark grey Grumusol at Sumberrejo.

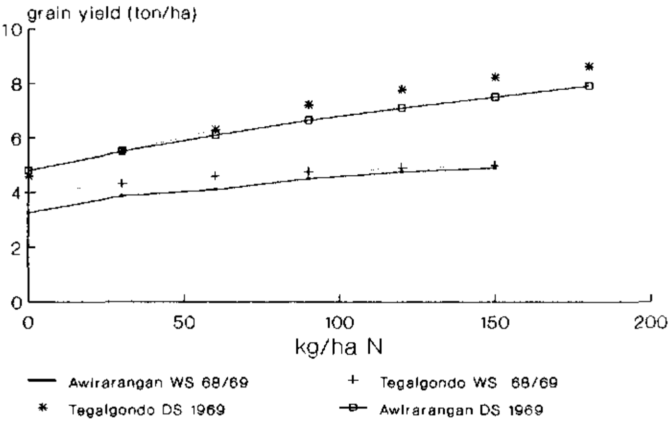

Figure 2. Nitrogen response of IR-5 lowland rice variety in Wet Season (WS) and Dry Season (DS) (Widjaja-Adhi, 1971).

<u>Lowland Types of Rice Response to Nitrogen</u>

Yield percentages at rate applications of 45 and 90 kg N/ha were calculated by deviding the yields of the respective application rates by the "maximum" or the highest yield of the nitrogen response curve and multiplied by one hundred. Based on yield percentages attained at these two rates of nitrogen application, fertilizer experiments conducted in the Wet Season of 1970/71 to 1972/73 and in the Dry Seasons 1971 and 1972 were classified in to three "lowland types" A, B, and C, using the criterium set up in Table 4 (Widjaja-Adhi <u>et al</u>, 1974).

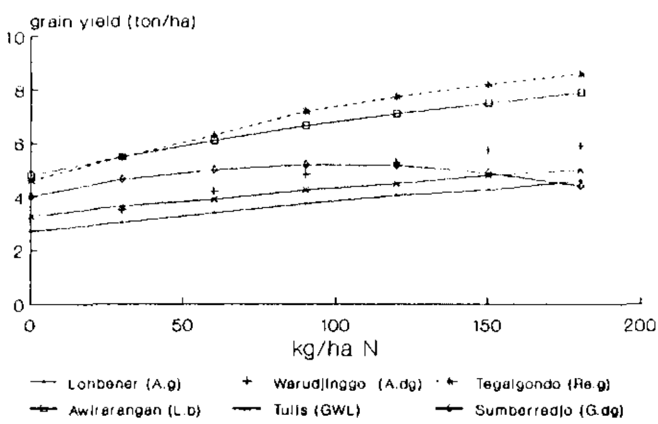

Figure 3. Nitrogen response of IR-5 lowland rice variety at no phosphate application on some soil types (Widjaja-Adhi, 1971).

TABLE 4. Lowland type criterium and nitrogen recommendation in wet and dry seasons for IR-5 rice variety (Widjaja-Adhi, 1974).

Lowland "type"	Percentage yield criterium				Recommended rate	
	Wet Season		Dry Season		Wet Season	Dry Season
	- - - - - (kg N/ha) - - - - -				- - - - (kg N/ha) - - - -	
	45	90	45	90		
	- - - - - - - % - - - - - - -					
A	>85	-	>80	-	30 (+0/15)	30 (+15/30)
B	75-85	>85	70-80	>85	45 (+0/15)	45 (+15/30)
C	>75	75-85	<70	75-85	60 (+0/15)	60 (+15/30)

Notes: Recommendations for lowland types A, B and C are 30, 45 and 60 kg N/ha 28 days after transplanting and at the primordia stage 0 - 15 kg N/ha for wet season crops and 15 - 30 kg N/ha for dry season crops the recommendation was aimed to reach 75 - 85% of maximum yield.

Soil and climatic conditions of sites in to each lowland type catagory reveal that the grouping has something to do with nitrogen supplying characteristics of the soil and the length of dry season. Initial yields were decreasing from A to C (Table 5). The traditional yields of long cultivated land reflect the magnitudes of nitrogen supply processes (Bartholomew, 1972).

TABLE 5. Average and standard deviation of initial and "maximum" yields of IR-5 lowland rice in three "lowland type" during Wet- and Dry-season. (Widjaja-Adhi, 1974)

Season "Lowland Type"	n	Initial Y	S_{n-1}	"Maximum" Y	S_{n-1}
		- - - - - - - - - ton/ha - - - - - - - - -			
<u>Wet Season</u>					
A	29	4.22	1.18	5.33	1.30
B	26	3.96	0.70	6.35	1.08
C	19	3.59	1.00	6.87	1.26
<u>Dry Season</u>					
A	13	3.88	0.89	5.87	0.86
B	8	3.94	0.45	6.78	0.82
C	15	2.95	0.66	6.79	0.99

"Initial": no nitrogen but with optimum P and K application
"Maximum": highest yield attained at optimum P and K application

The above grouping of lowland types was based on response to nitrogen application (Table 4). The lowland type A, B, and C showed low, medium and high nitrogen responses as reflected by the difference between initial and "maximum" yield (Table 5). One factor affecting nitrogen response is solar radiation (Fig. 2).

Improving Nitrogen Use Efficiency

Wetselaar (1985) studied surface broadcast, incorporated, deep broadcast or banded placement and deep point-placement of urea at Muara Bogor. Urea plus ammoniacal N in the floodwater was approximately 10% of urea applied broadcast compared to less than 2% when urea was incorporated. This was reflected in plant N, which was always higher with incorporated than with broadcast application (Fig. 4).

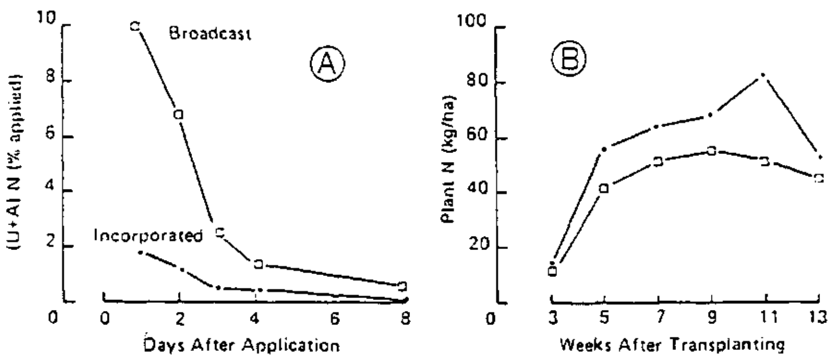

Figure 4. Urea Plus Ammonical N in the Floodwater (A) and Plant N Content (B) at different times for 87 kg N/ha of Urea either broadcast or incorporated at transplanting of IR-36, Muara, Wet Season 1983/84 (Wetselaar, 1985).

In another paper Wetselaar et al (1985) estimated the NH_3 loss at about 45% of N applied as broadcast urea, which was 10 times higher than that for urea supergranules (USG) over the 2.5-day period. In all four experiments, conducted at Sukamandi, Muara, Subang, and Dramaga, deep placement of USG resulted in very low N values in the water, with a maximum of 1.0% - 1.5% of N applied. This certainly reflected a proper placement of the granules and indicated that ammonia volatilization and run off losses were low. Plant N, apparent fertilizer N recovery (AFNR), and paddy yields at deep point-placement of USG were higher than those with broadcast prilled urea (Fig. 5; Wetselaar et al, 1985).

Further research to evaluate deep placement of USG has been initiated in a pilot area on Vertisol at Ngawi, East Java, since the wet season 1984/85. The results showed that deep placement of USG was more efficient compared to split broadcast prilled urea (PU). The advantage of deep placement of USG over split broadcast urea is greater at lower rates of application. The most significant implication of the study is that if deep placement of USG was used, about 70 to 90 kg urea per ha could be saved and 50 to 100 kg rice per ha could be gained while adding Rp. 40.000,- to Rp. 45.000,- per ha of net benefit for farmers (Diamond et al, 1986). Research results of two other pilot areas with different soil types, one at Klaten Central Java and the other at Subang West Java, confirmed these findings (Sri Adiningsih et al, 1987).

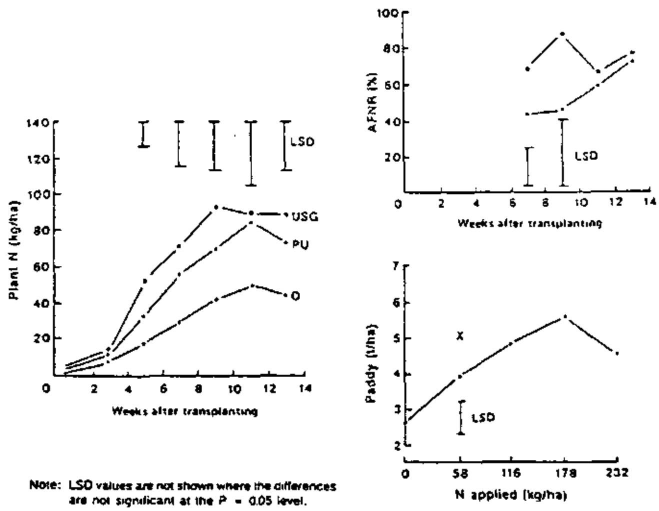

Figure 5. Plant N Uptake and Apparent Fertilizer N Recovery (AFNR) for 58 kg N/ha of Broadcast Prilled Urea (PU) and Urea Super Granules (USG), and Paddy Yield for Different Rates of PU and for 58 kg/ha USG, Sukamandi; dry season, 1983 (R. Wetselaar et al., 1985).

Simple trials to determine the level of farmer acceptance of deep placement technology have been conducted at 24 scattered farmer fields under the farmer's management level. Results of the first season trials indicated that at the same N-rate, the deep placement of USG gave higher yield (0.3 to 1.5 ton per ha) and a higher net benefit of the farmers compared with the split broadcast prilled urea (Sri Adiningsih et al, 1987).

Improvement Through Organic Matter Management

The application of 5 ton straw per hectare slightly decreased yield in the wet season, but increased it in the dry season (Table 6). In another study incorporation of 5 ton straw per hectare on a fine textured soil at Ngawi and a coarse textured soil at Klaten increased the efficiency of both deep placed USG and split broadcast urea (Sri Adiningsih et al, 1987). Seasonal incorporation of straw at a rate of 5 ton/ha/season, increased nitrogen use efficiency, which was below 20 kg grain/kg N in the first season, reached a plateau of more than 40 kg grain/kg N in the fourth, and kept on the plateau until the sixth season of the study (Sri Adiningsih, 1987). Straw incorporation has long been practiced as a "Walik jerami" system, especially in northern part of West Java.

TABLE 6. Yield and nitrogen use efficiency of lowland rice on Vertisols, Ngawi, East Java, during WS 1986/87 and DS 1987.

N	P_2O_5	K_2O	WS 1986/87		DS 1987	
			Yield (ton/ha)	Efficiency (kg/kg N)	Yield (ton/ha)	Efficiency (kg/kg N)
0	0	0	4.2	-	2.9	-
90/135	0	0	5.7	16.7	4.4	11.1
0	40/60	40/80	4.4	-	3.8	-
90/135	40/60	40/80	6.2	20.0	5.4	11.8
60	40/60	Straw*)	4.9	-	5.1	-
90/135	40/60	Straw*)	5.6	7.8	5.8	5.2
	LSD	.05	.4		.6	
		.01	.6		.9	

*) Notes : 5 ton/ha straw incorporated
Source: Sri Adiningsih et al (1987)

A study on the response of lowland rice to inorganic N and green manure (Sesbania Rostrata) was conducted on a Vertisol at Ngawi East Java and an Inceptisol (Latasol) at Cicurug West Java in the wet season 1986/87. Results from Ngawi showed that the response to S. rostrata at 45 days was higher than at 35 days (Table 7), which is probably due to higher N content and more biomass produced.

TABLE 7. Grain yield of lowland rice and use efficiency of urea applied in combination with S. rostrata on Vertisol, Ngawi, East Java during DS 1987. (Sri Adiningsih et al.,1987)

Treatment			Grain yield (ton/ha)	Use efficiency (kg grain/kg N)
N	P_2O_5	K_2O		
0	0	0	2.0	-
0	45	30	2.1	-
60	45	30	3.2	18.3
60*	45	30	3.7	26.7
120*	45	30	4.1	16.7/6.7
0	45	30 + SR 35	3.0	-
60	45	30 + SR 35	3.5	8.3
60*	45	30 + SR 35	4.0	16.7
0	45	30 + SR 45	3.1	-
60	45	30 + SR 45	3.7	10.0
60*	45	30 + SR 45	4.6	25.0
LSD .05			.6	
LSD .01			.8	

* Notes : Split application at 10 DAT and PI

It is interesting to note that split application of top dressed urea is better than one application at panicle initiation. The use efficiency of 60 kg N/ha urea increased from 18.3 to 26.7 kg grain/kg N by split application without, but from 10.0 to 25.0 kg grain/kg N with incorporation of 45-day old S. rostrata (Table 7). Proper time of application and green manure incorporation greatly increase yields and use efficiences of nitrogen.

NITROGEN MANAGEMENT IN UPLAND SOILS

The goal of nitrogen management in general and particularly in upland soils is to develop effective ways to manage nitrogen from both plants and fertilizers, so as to make and to sustain high crop productions. To achieve this goal, the nitrogen management is designed to improve the use of biologically fixed nitrogen, incorporating legume manures and crop residues into practical cropping systems.

Response of upland Crops to Nitrogen Fertilizers

Maize response to urea-N application was high for the first 45 kg N/ha increment at Nakau, but low and insignificant at Tarbanggi. Response to the second increment was low both at Nakau and at Terbangi (Table 8). There was no significantly different response to sources of N-fertilizer at the rate of 90 kg N/ha application except between nitrophosphate, that gave the lowest yield of 3.9 ton/ha and calcium-ammonium nitrate, which gave the highest yield of 5.3 ton/ha at Nakau.

TABLE 8. Grain yield of maize and nitrogen use efficiency of some nitrogen sources in dry season 1984.

No.	Treatment	Rate (kg N/ha)	Nakau		Terbangi	
			Yield (ton/ha)	Efficiency (kg/kg N)	Yield (ton/ha)	Efficiency (kg/kg N)
1.	Control		1.6		3.3	
2.	Urea	45	4.5	64.9	3.85	10.0
3.	Urea	90	4.6	33.8	4.0	7.6
4.	Urea	135	4.9	24.2	4.1	5.7
5.	Cal. Nitrate	90	4.1	27.7	4.2	9.7
6.	Am. Nitrate	90	4.3	30.3	4.1	9.3
7.	Cal. Am. Nitrate	90	5.3	41.3	3.9	6.2
8.	Nitrophosphate	90	3.9	26.3	3.8	6.1
9.	Am. Sulfate	90	4.8	35.8	3.8	7.1
	LSD .05		1.1		0.47	
	LSD .01		1.52		0.65	
	CV (%)		15		7	

Source: Sri Adiningsih S and Moersidi S. (1986)

Similar results were obtained in the experiments on response of upland rice to nitrogen application in wet season 1984/85 at the same sites as for maize. High response was attained in the first 45 kg N/ha increment at Nakau, but low response at Terbangi. At both sites maximum was reached at about 90 kg N/ha (Table 9).

TABLE 9. Grain yield of upland rice and nitrogen use efficiency of some nitrogen sources in the wet season 1984/85.

No.	Treatment	Rate (kg N/ha)	Nakau		Terbangi	
			Yield (ton/ha)	Efficiency (kg/kg N)	Yield (ton/ha)	Efficiency (kg/kg N)
1.	Control		1.89		2.45	
2.	Urea	45	3.1	27.1	3.3	19.1
3.	Urea	90	3.6	19.4	5.0	28.0
4.	Urea	135	2.7	6.4	3.8	10.2
5.	Cal. Nitrate	90	3.1	13.0	3.5	11.8
6.	Am. Nitrate	90	3.7	20.2	3.6	13.0
7.	Cal. Am. Nitrate	90	3.5	17.6	3.8	14.8
8.	Nitrophosphate	90	3.6	19.4	3.6	12.6
9.	Am. Sulfate	90	3.5	17.7	4.0	17.4
	LSD .05		0.71		tn	
	LSD .01		0.98		tn	
	CV (%)		12.9		21.7	

Source: Sri Adiningsih S. and Moersidi S. (1986)

Not all nitrogen sources differed significantly in yield. Ammonium nitrate gave the highest yield of 3.7 to/ha at Nakau and at Terbangi urea gave 5 ton/ha, which was quite a high level of yield for an upland rice crop.

The initial or traditional yields of maize at Terbangi were more than double those at Nakau, but for upland rice it was only about 1.5 times. It meant that the natural nitrogen supply processes (Bartholomew, 1972) were higher at Terbangi than at Nakau.

In one study conducted at Nakau in the wet season 1982/83, sulfur coated urea (SCU) 20% was markedly better than other nitrogen fertilizers, which were split and non-split urea, and SCU (40%), even though the rice crop did not give a significant response to applied nitrogen (Palmer and Sudjadi, 1984).

Use Efficiency of Nitrogen

At the application of 45 kg/ha urea maize showed a very high use efficiency of nitrogen, 64.9 kg grain/kg N, at Nakau (Table 8). To increase maize yield from 2.0 ton/ha to 4.0/ha, under average use efficiency, needs 83 kg N/ha (Bartholomew, 1972). On the other hand maize nitrogen utilization at Terbangi is very low, nitrogen use efficiency being only 10.0 kg grain/kg N.

To increase brown rice yield from 2.0 ton/ha to 3.0 ton/ha requires 41 kg N/ha under average use efficiency. So the use efficiency of 27.1 kg grain/kg N of upland rice at Nakau and 19.0 kg grain/kg N at Terbangi in WS 1984/85 belong to the average ranges of nitrogen use efficiency.

Role of Organic Matter

The effect of organic matter, incorporated or mulched, has long been recognized and practised, but recent research in Indonesia only deals with organic matter management in relation to Al-, P-, and K- behaviour (Sri Adiningsih et al, 1987), not with N- supply processes in soils. Several researchers reported that organic matter application, whether incorporated or applied as mulch or as part of alley cropping, increased crop yields and with a positive interaction with lime, P, or K. Higher yields require more nitrogen, so it can be concluded that the system releases more nitrogen to produce higher yields. But research with the objectives, i.e.: (1) to quantify the N supplied to the cropping system and (2) to evaluate the importance and availability of the organic matter N to crops, is of a great value.

CONCLUSION

It was noted that in order to increase the levels of nitrogen or organic matter in soils it is needed to increase P reserves through fertilizer application.

Research results consistently showed that deep placement of USG is more effecient than broadcast urea in researcher managed trials as well as under farmer's management.

Incorporation of rice straw continuously every season will increase use efficiency of nitrogen from below 20 kg grain/kg N to above 40 kg grain/kg N.

Proper rate and time of application of N-fertilizer and organic matter incorporation greatly increased yield and use efficiency of nitrogen.

Research on organic matter management, oriented to nitrogen dynamic and supply characteristics of the soils, is needed.

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NITROGEN MANAGEMENT OF RAINFED AGRICULTURE IN TROPICAL AND SUBTROPICAL REGIONS OF CHINA

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ABSTRACT

South China, with distinct tropical and subtropical climatic conditions, is rich in soil resources with various soil types. Hydrothermal conditions are suitable for food production. Because of excessive deforestation and improper land utilization in this region, upland soils are generally subject to erosion, leading to rather low soil fertility. Food production in this region, however, can be increased provided that adequate nutrients are applied and proper management measures are adopted. These include appropriate NPK ratio, application of manure, popularization of deep placement of supergranules of urea and ammonium bicarbonate, as well as the use of slow release fertilizers.

SOIL RESOURCES AND HYDROTHERMAL STATUS IN SOUTH CHINA

South China, with distinct tropical and subtropical climatic conditions, is an area of about 2.03 million square kolometers, and takes up 21% of the total area of the country. It is rich in soil resources with various soil types, which mainly belong to the red soils, including laterites, lateritic red earths, red earths and yellow earths. The topography of the region is varied: roughly speaking, it geographically consists of seven mountainous and two hilly areas and one plain.

The climatic conditions of the area are characterized by high temperatures and abundant rainfall. According to the hydrothermal conditions, South-China can, from north to south, be divided into subtropical south-subtropical and tropical zones. In the tropical region, e.g. on Hainan island, the mean annual temperature is over 24 ^{o}C, and the cumulative annual temperature for $\geq$ 10 ^{o}C amounts to over 8200 ^{o}C. Annual rainfall exceeds 1500 mm. In the subtropics, the mean annual temperature ranges from 15 to 22 ^{o}C, and the cumulative temperature for $\geq$ 10 ^{o}C from 4500 to 6500 ^{o}C. The annual rainfall amounts to 1200 mm.

In the south-subtropical zone the climatic conditions are in between those of the tropical and subtropical areas. These regions are important for food production in China. Rice is the main food crop planted on the plains and in the valleys, where irrigation and drainage ditches exist, whereas upland crops, such as corn, wheat, sweet potato, rape, soybean and peanut, are planted on the hillslopes where no irrigation systems are available, Crop yields of these rainfed crops are quite low and variable.

NITROGEN STATUS OF UPLAND SOIL IN TROPICAL AND SUBTROPICAL AREAS OF CHINA

Most soils in this region are highly weathered, and many of them are acid, with a low base saturation and a low cation exchange capacity (CEC). Apart from this, due to excessive deforestation and improper land utilization, upland soils are often subject to erosion, and generally rather poor in essential nutrient elements and organic matter. In most cases, the contents of total N and organic matter are below 0.1% and 2%, respectively (table 1).

Table 1. Total N and organic matter contents of upland red soils in tropical and subtropical regions of China.

Region	Total N (%)	O.M. (%)
Central China	0.090 ± 0.029 (118)	1.57 ± 0.61 (118)
Southwest China	0.109 ± 0.057 (71)	1.93 ± 1.28 (71)
South China & southern part of Yunnan Province	0.139 ± 0.077 (31)	2.68 ± 1.20 (31)
Middle & lower reaches of Yantze River	0.093 ± 0.033 (49)	1.58 ± 0.67 (49)

* Figures in parenthesis show the number of samples.
Data from Wen Qixiao & Lin Xinxiong.

Generally lower amounts of fertilizer are applied to upland soils than to wetland rice soils. There is, however, a relatively more rapid decomposition of organic matter and N mineralization in these soils; the total N and organic matter contents are, therefore, lower in upland soils than in paddy fields (Table 2).

Table 2. Total N content of the plowed layer of soils in different regions.

Region	Upland soil	Paddy soil
	--------%N--------	
Middle & lower reaches of Yantze River	0.093	0.134
Central China	0.090	0.143
South West China	0.109	0.149
South China & southern part of Yunnan	0.139	0.150

It will be clear that applications of N fertilizer and organic manure are of vital importance for increasing crop yields on the upland soils of the red earth region.

As land is more carefully utilized, with improvement of soil fertility, crop yields are increasing steadily. As long as adequate nutrients are applied and proper management measures adopted, higher yields of crops can be attained.

Of course, a substantial increase of food production is dependent on many factors such as proper irrigation systems, suitable crop varieties, excellent field management, etc. For upland red soils with a low fertility, the rational application of chemical fertilizer, however, is the most effective way to increase crop yields.

APPLICATION OF CHEMICAL FERTILIZER IN RELATION TO FOOD PRODUCTION IN TROPICAL AND SUBTROPICAL REGIONS OF CHINA

Rice, wheat and corn are the three main food crops in South China. A number of field experiments on the effect of chemical fertilizer on these three crops have been conducted in different soils of tropical and subtropical regions of China.

Figure 1 shows that the rate of chemical fertilizer application, particularly N fertilizer, has increased substantially during the last three decades. There was a clear positive correlation between food production and chemical fertilizer consumption. This shows that the application of N fertilizer on the infertile red soils plays an important role in food production in tropical and subtropical regions. Heavy applications of chemical nitrogen and relatively low use of phosphorus and potassium fertilizers have, however, resulted in rapid depletion of natural soil phosphorus and potassium. The phosphorus and potassium deficiencies in red earths limit the response of crops to N fertilizer.

The results in tables 3 and 4 show that the efficiency and recovery of N fertilizer have been declining as the N rate was increased without a corresponding increase in phosphorus and potassium application.

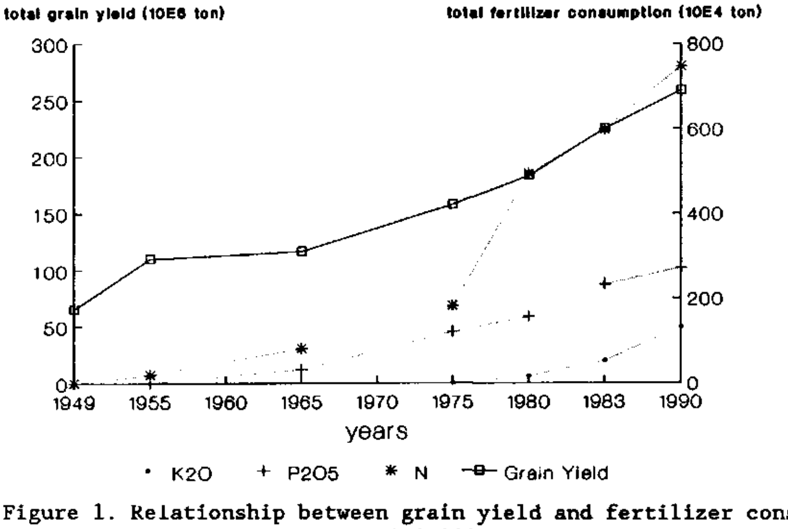

Figure 1. Relationship between grain yield and fertilizer consumption in South China during 1949-1990.

Table 3. Efficiency of N fertilizer applied to red earths during 1957-1983.

Years	N rate (kg N/ha)	Kg grain/Kg N applied	n*
1957-67	40	13.7	239
1973-77	47	12.8	109
1978-83	138	7.7	208

n* : number of experiments.

In order to improve the efficiency and utilization of N fertilizer applied to upland red soils, it is neccesary to determine an appropriate NPK-ratio. There is, however, a large shortage of phosphorus fertilizer, and especially potassium fertilizer; this is one of main problems in N management in South China.

Table 4. Recovery of applied N in different years as affected by N rates.

Years	N rate	N from soil	N from fertilizer	N recovery
	----------	kg N/ha	----------	---- % ---
1970	61	29.7	22.6	36.7
1974	72	32.6	26.2	36.4
1978	96	36.5	26.6	27.7
1982	144	78.5	33.9	23.5

APPLICATION OF ORGANIC MANURE

Large amounts of organic manure have been applied through centuries of agricultural production in China. With the increasing use of chemical fertilizer and the increasing consumption of plant materials for industrial and fuel purposes however, the use of organic manure has declined markedly (Table 5). Data from the Chemical Fertilizer Experimental Network show that since the late 1970s more N is derived from fertilizer than from organic manure. Correspondingly, the amounts of phosphorus and potassium derived from organic manure have decreased. The demand for phosphorus and potassium has become quite urgent in the red earth regions of China. It is neccesary to increase the use of organic manure in order to minimize the gap between demand and supply of P and K fertilizer.

Table 5. Input of chemical-N and manure-N in tropical and subtropical regions of China during 1949-1990.

Year	-----input (10^4 ton N)----- chemical-N	manure-N	% chemical-N	% manure-N
1949	0.33	97.3	0.1	99.9
1975	17.7	154.4	9.0	91.0
1965	84.4	188.3	19.3	80.7
1975	189.5	257.3	33.6	66.4
1980	490.4	262.8	52.9	47.1
1983	613.3	271.0	58.0	42.0
1990*	751.7	316.4	73.6	26.4

* Predicted data according to the Experimental Network of chemical Fertilizer in China

USE OF SUPERGRANULES

At present, ammonium bicarbonate and urea are the main types of N fertilizer in China. Table 6 shows that ammonium bicarbonate and urea account for about 55% and 34% of the total amount of N fertilizer produced in China, respectively.

These two types of N fertilizer easily volatilize when broadcasted on the soil surface, so that their efficiencies are quite low. According to a large number of experimental results, less than 30% of the ammonium bicarbonate and less than 35% of the urea is utilized by plants when surface-applied. The main causes are thought to be losses of N from the soil, caused by NH_3 volatilization, denitrification, leaching and runoff. A more efficient application of these two types of N fertilizer has been the aim of an important research project in South China.

Table 6. Types and production of N fertilizer in China in 1985 (10^4 TN).

Fertilizer	Productivity	%
Ammonium bicarbonate	642	54.8
Urea	396	33.8
Ammonium nitrate	53	4.5
Ammonium solution	48	4.1
Ammonium chloride	17	1.5
Ammonium sulphate	13	1.1

In order to improve the efficiencies of ammonium bicarbonate and urea, it is necessary to press powdered fertilizer into supergranules; these must be placed at some depth in the soil. ACSG (ammonium bicarbonate supergranule) and USG (urea supergranule) weigh about 1 gram, and are pressed by a double rolling machine.

Deep placement of ACSG and USG has been found to have much more effect on crop growth than surface-application of normal ammonium bicarbonate and urea. Some data are given in table 7.

Table 7. Effect of ACSG and USG on grain yield.

Crop	Treatment	Grain yield (t/ha)	Relative efficiency of fertilizer N (%)
Wheat	split application of NH_4HCO_3 powder	3.3	100
	Deep application of ACSG	3.8	115
	Split application of Urea	4.3	100
	Deep application of USG	4.7	109
Corn	Split application of $NH_4H\ CO_3$ powder	3.6	100
	Deep application of ACSG	4.2	117
	Split application of ACSG	4.6	100
	Deep application of USG	5.4	117

The ^{15}N tracer technique was used in field microplots to determine the fate and utilization rate of fertilizer N applied to the crop (tables 8 and 9). The experimental results in table 8 show that the utilization rate of deep-placed USG or ACSG was much higher than that of normal urea or powdered NH_4HCO_3 broadcasted or incorporated into the soil. Table 9 shows the recoveries of N from USG and common urea: Nitrogen recovered by wheat, 60-76% and 44-50%; residual N in soil, 9-20% and 27%; and deficit N, 5-30% and 23-29%, respectively.

Table 8. Utilization rate of ^{15}N-labelled fertilizer applied to red earths as affected by source and application method (wheat, 1980).

Treatment	Utilization rate (%)
Common urea, broadcast	44.2
Common urea, band application	49.8
USG, point-placed at 6 cm depth	76.0
Powdered NH_4HCO_3, broadcast	43.5
ACSG, point-placed at 6 cm	68.1
LSD 0.05	12.9
0.01	17.9

Table 9. Fate of ^{15}N-labelled USG and common urea applied to wheat.

Soil	Treatment	Recovered by plants (%)	Residual in soil (%)	Deficit (%)
Slightly acid loam	Common urea, split application	50.3	26.7	23.0
	USG, deep application	60.7	9.3	30.0
Strongly acid clay	Common urea, split application	44.2	27.3	28.5
	USG, deep application	76.0	19.5	4.5

Obviously, deep application of USG increased the uptake of fertilizer N by crops, reduced N loss, especially under the conditions of high temperature and abundant rainfall in tropical and subtropical regions. Deep placement of USG or ACSG is the most effective application method to reduce N losses due to volatilization, runoff and leaching. At present, however, because of some difficulties with the production of supergranules, USG and ACSG have only been used in limited areas, and are not yet commonly used. Improper application of supergranules resulted in a decrease in grain yield (Table 10).

Table 10. Wheat grain yield as affected by application method

Treatment	Grain yield (kg/ha)	
	Bleached soil	Permeable soil
Control	1508 c	2903 c
Common urea broadcast	2775 a	4748 a
USG, point-placed at 6 cm	2355 b	4208 b

Chen & Zhu (1982) reported that when supergranules were deeply placed at the same application rate as the normal urea, most of the N was taken up by the plants during the middle and later parts of the growing season, so that the N taken up by the plants could not be fully converted into grain in time, as a result of which the ripening of the crop was delayed and the rain yield decreased. This implies that ACSG and USG should be applied earlier and a lower rate than ammonium bicarbonate and urea.

Apart from the loss of NH_3 due to volatilization from urea and NH_4HCO_3, another problem in N fertilizer application is the effect of ammonium chloride on soil acidity. When NH_4Cl, a physiologically acid fertilizer, is applied to an acid red earth, soil acidity may increase, preventing root penetration and resulting in decreased crop growth. Experimental results in table 11 show that the response of millet to supergranules of NH_4Cl with urea applied to red earth was markedly higher than USG and AClSG (ammonium chloride supergranule). Application of (NH_4Cl+urea)SG could overcome both physiological acidity of NH_4Cl, and the toxic effects on roots resulting from excess NH_3 from urea.

Table 11. Millet grain yield as affected by N source.

Soil	Treatment	Grain yield (g/pot)
Red earth developed from red sandstone	Control	10.1 d
	AC1SG	38.2 c
	USG	41.9 b
	(1/2 AC1+1/2U)SG	45.5 a

USE OF SLOW-RELEASE FERTILIZER

In addition to supergranules, slow-release fertilizers have also been studied, because some nutrients, especially nitrogen and potassium, easily leach from the root zone due to rainfall under humid condition.

Research results of several years showed that fused Ca-Mg-phosphate is a good coating material. Phosphate-coated urea (PCU) and phosphate-coated ammonium bicarbonate (PCAC) were prepared and tested in pot and field experiments.

Table 12. Effect of PCAC on grain yields of wheat and corn.

Treatment	Wheat yield grain kg/ha	Increase %	Corn yield grain kg/ha	Increase %
Check, no N	5580 c	-	4545 c	-
Powdered NH_4HCO_3, broadcast	6375 ab	14.3	5070 ab	11.6
PCAC, point placed	6660 a	19.4	5430 a	19.5

The results in table 12 show that marked increases in wheat and corn yields were obtained in plots with N, in comparison with plots without N, but no significant differences in the grain yields of wheat and corn were observed after application of powdered NH_4HCO_3 or PCAC. However, field observations after the harvest of wheat and corn showed that most of the PCAC still held about 10-25% of the N within the coating shell. This residual N in the soil would be taken up by a following crop. According to the actual N uptake during the experimental period, the utilization rate of fertilizer N increased significantly.

Recovery of PCU by crops has also been studied in pot and field experiments. The results in table 13 show that the N recovery of PCU point-placed as basal fertilizer for middle rice on red earth under rainfed condition was the highest, amounting to 79%; the recovery rates of N from SCU and common urea were 42% and 34%, respectively. The recovery rates in pot experiments were higher than those in field experiments.

Table 13. Recovery rate of N as affected by N source and application method.

Treatment	Recovery rate of N (%)			
	Rice		Wheat	
	Pot experiment			
Common urea, broadcast	69.6		57.5	
PCU, point-placed	74.2		63.1	
SCU, incorporated	50.0		56.9	
	Field experiment*			
	Site 1	Site 2	Site 1	Site 2
Common urea, broadcast	27.3	34.3	34.4	-
PCU, point-placed	42.8	79.0	38.3	-
SCU, incorporated	22.5	42.3	29.0	-

* Site 1, Jiangsu Province, Site 2, Jiangxi Province

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EFFECT OF INCORPORATING PRUNINGS OF LEUCAENA LEUCOCEPHALA, CASSIA SIAMEA AND CAJANUS CAJAN ON YIELD OF MAIZE IN ALLEY CROPPING SYSTEM.

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SUMMARY

Experiments were conducted with maize, intercropped with Leuceana leucocephala, Cassia siamea and Cajanus cajan at several plant densities. The experimental results suggest that the incorporation of tree prunings had an ameliorating effect on the soil. The use Cajanus cajan in association with maize is not only promising as a source of nitrogen, but also for fuelwood supply.

INTRODUCTION

Smallholder farmers in the tropics have historically practised a system of bush fallow or shifting cultivation in which the land, rather than the crops, were rotated. In this type of system, the land was cleared and some trees felled, although often soil fertility restoring trees such as Acacia albida, Acacia bateri, Gliricidia sepium, Anthonatha macrophylla, Leucaena leucocephala were selectively retained (Wilson, 1981) mainly for their ameliorating effect on the soil.

Increases in world population have necessitated more intensive use of land land for food production, in particular in areas where shifting cultivation is the prevalent agricultural production system, with a view to warding off widespread hunger and famine.

It is noteworthy that increased food production has been achieved in most developed and developing countries through use of large amounts of inorganic fertilizers and pesticides. Yet while the use of inorganic fertilizers is obviously attractive, the cost of such fertilizers is escalating beyond the financial ability of many a smallholder farmer in the tropics. It is because of this escalating cost of inorganic fertilizers that agricultural scientists have turned to studying seriously the probable benefits of growing certain types of trees with crop plants, in the hope of cutting down on the amounts of inorganic fertilizers required to maintain current production levels.

Over the last ten years the cost of farm inputs, especially inorganic fertilizers, has more than doubled in Malawi (Manduwa, 1985). On the other hand, corresponding increases in prices paid to smallholder farmers for their crop products have significantly failed to keep pace with input cost increases, so that the smallholder farmer in Malawi, as in most other developing countries, is faced with declining fertility and productivity of his land in the face of fast-escalating input prices.

In order to help redress the problem of declining soil fertility and productivity which is exacerbated by the smallholder farmer's inability to pay for inorganic fertilizers, a medium to long-term experiment on alley cropping was initiated at Bunda College of Agriculture in Lilongwe, Malawi, in October 1983.

LITERATURE REVIEW

The recycling of nutrients to the surface soil is one of the basic assets of alley cropping and green manuring in general. If nitrogen-fixing leguminous trees or shrubs are used, some of the nitrogen fixed is eventually released to the companion crops through decomposition of prunings (leaves and twigs). Kang et al. (1981) have observed that Leucaena prunings are a more effective nitrogen source when incorporated in the soil than when applied as mulch. They suggest that the better results obtained with incorporation may be attributed to faster decomposition and mineralisation of prunings while the lower efficiency of surface applied prunings may be due to high losses from nitrogen volatilisation during decomposition.

Recent data indicate however, that crop utilisation of nitrogen derived from prunings is usually low and that supplementary nitrogen fertilizer is necessary for food crop production under alley cropping. By using the inorganic fertilizer equivalent method, nitrogen contribution of Leucaena leucocephala, Gliricidia sepium, Cassia siamea and Flemingia congesta was evaluated to be in the range of 38 to 78 kg/ha representing no more than 30% of nitrogen from the prunings (IITA, 1986).

On a sandy entisol at Ibadan, Nigeria, yields of maize in an alley cropped system has been maintained for six years at about 2000 kg/ha with the incorporation of Leucaena prunings only (Kang et al., 1984). Plots receiving prunings contained twice the amount of soil organic matter as plots where prunings were not incorporated.

Manduwa (1985) reported that incorporation of 20 tonnes/ha of Leucaena prunings as basal application on a ferric luvisol (FAO classification) at Bunda in Lilongwe, Malawi, produced 6443 kg/ha of maize grain as compared to 6885 kg/ha when 200 kg/ha of 20:7:8:0 (basal) and 200 kg/ha of calcium ammonium nitrate (side dressing) were applied. In this study, single application/incorporation of Leucaena prunings generally gave higher grain yields than split incorporation of the same amounts of prunings.

Although the association of maize with alleys of some woody leguminous perennials in an alley cropping experiment in Nigeria led to generally higher maize yields between the alleys as compared to the control plots, the improvement in soil physical properties and the subsequent improvement of root development was deemed more important than the supply of nutrients (Yamoah et al., 1986).

Kang et al. (1981) reported that an addition of Leucaena prunings from the full grown hedge rows of a maize-Leucaena alley cropping system on an N-deficient sandy Apomu soil series (Psammentic Usthorthent) at Ibadan, Nigeria, was able to sustain maize grain yields at about 3800 kg ha^{-1}/year for two consecutive years with no addition of inorganic nitrogen, whereas yields declined with no addition of prunings. Higher maize yields were, however, obtained with supplementation of low N rates of 20 to 80 kg/ha depending upon maize variety and season. In the same long-term experiment, Kang et al. (1984) reported a higher content of soil organic matter and reduced acidity on plots which had received prunings as compared to those where no prunings had been incorporated.

MATERIALS AND METHODS

The experiment discussed in this paper was conducted at Bunda College of Agriculture, Lilongwe, Malawi (altitude 1118 m, 33^{o} 46'S, 14^{o} 11'E) in 1983. Bunda College is located within the Lilongwe plain which is a gently undulating landscape with almost flat and gentle slopes. The area has a tropical continental climate characterised by a distinct wet and dry season. The mean annual rainfall varies from 850 to 875 mm and is evenly distributed throughout the growing season (November-April).

The aim of the experiment was to meet the following medium to long-term objectives:

i. To assess soil fertility maintenance capabilities of Cassia siamea, Leucaena leucocephala and Cajanus cajan under local environmental conditions;
ii. To determine the growth rate and biomass production of the three tree species;
iii. To determine the quantity of nutrients accumulated by the three tree species and their contribution to the soil;
iv. To assess the yield of maize grown with different tree species in alley cropping systems;
v. To determine suitable tree species for use in alley cropping systems in Malawi.

The results to be discussed in this paper will be relevant mainly to objectives (i), (ii), (iii) and (iv) above.

The soil used in this study is classified as a ferric luvisol by the FAO soil classification system (Lowole, 1985). Some characteristics of the soil are presented in table 1. This soil is a sandy clay loam, slightly acid with low CEC and exchangeable cations, except K.

TABLE 1. Some characteristics of Lilongwe 2 (Ferric luvisol) surface soil used in the study.

Mechanical composition			$pH-H_2O$	Org. C (%)	Total N (%)	Bray 1 P	Am Acetate Extr. (me $100g^{-1}$)				CEC (me $100g^{-1}$)
Sand	Silt	Clay					K	Ca	Mg	Na	
56	10	34	6.1	0.66	0.06	48.17	0.58	1.97	0.77	0.04	4.36

The experiment was laid out as a split-split-plot with three blocks. Main plot treatments consisted of three levels of nitrogen: 0 kg/ha, 50 kg/ha, and 100 kg/ha. Sub-plot treatments consisted of associated tree species: that is, maize alone, Leucaena leucocephala (with maize), Cassia siamea (with maize) and Cajanus cajan (with maize). Sub-sub-plot treatments were alley width for maize: 2.7 metres alley width (3 ridges maize), 5.4 metres (6 ridges maize) and 10.8 metres (12 ridges maize). Maize ridges were spaced 91 cm and maize and trees were planted on the ridge at a spacing of 91 cm between planting stations. Four maize seeds were planted per station initially and thinning to three plants per station was done a week after emergence. The maize variety Ukiriguru Composite A (UCA) was used in this trial.

It should be emphasised that in general the tree species were planted at the beginning of the investigation in 1983 but maize was planted annually in November/December, at the beginning of the crop season.

At the time of planting, all plots received 22 kg/ha of phosphorus. Treatments with 50 and 100 kg N/ha received N in split application, the first dose of half the rate at time of planting while the remainder was applied when the plants were 45-50 cm tall. At both times, the fertilizer was applied using the dollop method in which fertilizer is applied about 7.5 cm on both sides of a planting station at a depth of 5-7 cm. Tree species received no fertilizer.

Yield and yield components of maize were recorded as well as selected performance characteristics of the tree species. Data reported relate to the second year (1984/85) and third year (1985/86) after establishment of the tree species when it was possible to assess the probable effects of incorporating prunings from the trees on maize yield. Prunings were incorporated at least three weeks before maize was planted, at a time of ridging, in October each year.

Soil samples were taken before the experiment was established in 1983, and each year at the beginning and end of the crop season. Samples of prunings were also taken and analysed in order to determine the nutrient content of plants. The percentage values of organic carbon and total nitrogen were transformed using the arcsin transformation (Snedecor and Cochran, 1967) prior to carrying out an analysis of variance.

RESULTS AND DISCUSSION

Establishment and performance of trees

As indicated earlier, tree species were planted by direct seeding in October/November 1983 and results relating to their survival during three successive growing seasons are presented in table 2.

TABLE 2. Percentage survival of tree species during three growing seasons at different alley widths at Bunda.

Tree species	Alley Width (m)	Survival (%)		
		1983/84	1984/85	1985/86
L. leucocephala	2.7	73.7	72.4	72.4
	5.4	71.2	70.6	69.7
	10.8	73.3	72.5	70.5
Cassia siamea	2.7	39.9	68.8	87.0
	5.4	39.1	71.1	86.1
	10.8	46.5	80.3	84.2
Cajanus cajan	2.7	95.1	90.3	92.6**
	5.4	95.1	93.7	87.1
	10.8	94.2	92.4	90.7

* Value for each season is a mean of three replicates.

** All the Cajanus cajan was uprooted and replanted in 1985/86 because over 75% of the plants died from Fusarium wilt.

Survival records were taken at the end of each growing season and represent the proportion of trees alive relative to what was there at the end of the preceding season.

As is evident from table 2, the highest survival rate was observed in Cajanus cajan, followed by L. leucocephala and then Cassia siamea. Difficulties appeared in getting Cassia siamea established as indicated by the low survival rate between 39.1% and 46.5% in the first season, and by negligible biomass production for incorporation in the soil during the first and second year of establishment. While Cajanus cajan was the easiest to get established, it suffered seriously from attack by Fusarium wilt after the second season so that it had to be replanted at the beginning of the third season (1985/86).

The performance of the tree species, in terms of canopy height and canopy width, was recorded after maize harvest during the 1984/85 and 1985/86 seasons (table 3) while total biomass (dry weight basis) incorporated into the soil in the form of prunings is presented in table 4 for three consecutive seasons. The results in table 3 show that _Cajanus cajan_ performed best among the three tree species, followed by _L. leucocephala_ and then _Cassia siamea_. This is certainly consistent with the superior survival rate of _Cajanus cajan_ observed earlier relative to that of the other two species. It is also significant that because of the slow rate of establishment of _L. leucocephala_ and _Cassia siamea_, it was not possible to get enough biomass for incorporation into the soil until the third (1985/86) season. On the other hand, _Cajanus cajan_ was able to produce enough biomass for incorporation by the end of the first season of its establishment.

TABLE 3. Canopy height and canopy width (means) of tree species after maize harvest during the 1984/85 and 1985/86 seasons.

	Cajanus cajan		_L. leucocephala_		_Cassia siamea_	
	1984/85	1985/86	1984/85	1985/86	1984/85	1985/86
Canopy height (cm)	152.9	160.2	73.9	78.4	65.4	68.3
Canopy width (cm)	102.7	104.7	64.9	66.7	65.0	65.0

TABLE 4. Total biomass (dry weight, kg/ha) of prunings incorporated from different tree species alley cropped with maize.

Alley Width (m)	Tree species	Total biomass*		
		1983/84	1984/85	1985/86
2.7	_L. leucocephala_	-	-	1740
	Cassia siamea	-	-	5310
	Cajanus cajan	450	2250	1230
5.4	_L. leucocephala_	-	-	1980
	Cassia siamea	-	-	5520
	Cajanus cajan	390	1830	1590
10.8	_L. leucocephala_	-	-	1590
	Cassia siamea	-	-	6420
	Cajanus cajan	450	1800	1350

* Biomass entries are means of three replicates.- Biomass not available.

Contribution to soil carbon and nitrogen

Analysis of samples of prunings from the tree species for different nutrients gave the results presented in table 5. These results show that _L. leucocephala_ consistently had more nutrient content compared with the other two species, so that it might be expected that for equal quantities of incorporated biomass, _L. leucocephala_ would contribute more nutrients to the soil followed by _Cassia siamea_ and then _Cajanus cajan_.

On the other hand, the higher carbon content of Cassia would seem to suggest that the physical structure of the soil from incorporation would be greatest for Cassia followed by Cajanus cajan and then Leucaena.

By applying the results on mineral composition presented in table 5 to the quantities of biomass incorporated as given in table 4 the total amount of incorporated carbon and nitrogen can be estimated. As observed earlier, because of early establishment, it was possible to incorporate some prunings from Cajanus cajan in the first season but because of the relatively small quantity of the material, its contribution to soil carbon and nitrogen was small (table 6).

For each tree species, there are no significant differences in the estimated contribution to soil carbon and nitrogen among alley widths. This notwithstanding, it is significant that in absolute terms the greatest estimated contribution to soil carbon and nitrogen is observed for an alley width of 5.4 m except in Cassia siamea where this is observed for an alley of 10.8 m. This appears to suggest that an alley width of 5.4 m may be optimal for maximum contribution to soil carbon and nitrogen although there is no statistical evidence that this is necessarily superior to the other alley widths.

TABLE 5. Mineral composition of prunings of tree species grown on a Lilongwe 2 series (ferric luvisol) at Bunda*

Tree species	C	N	P	K	Ca	Mg	C:N Ratio
	%						
L. leucocephala	22.80a	1.92a	0.24a	1.24a	1.13a	0.17a	12:1
Cassia simea	58.48b	1.12b	0.18a	0.70b	1.22a	0.08b	52:1
Cajanus cajan	46.35b	1.03b	0.19a	0.17c	0.53b	0.11b	45:1

* Values for each nutrient element with different letters are significant. ($P < 0.05$).

Nitrogen and organic carbon were determined in samples of surface soil of the Lilongwe 2 series (ferric luvisol) on which the investigation was conducted after three seasons of alley cropping with maize (Table 7).

TABLE 6. Estimated contribution of total carbon and nitrogen (kg/ha) due to incorporation of prunings from different tree species grown in alley at Bunda.

Alley Width (m)	Tree species	1983/84		1984/85		1985/86	
		C	N	C	N	C	N
2.7	L. leucocephala	-	-	-	-	397	33
	Cassia siamea	-	-	-	-	3105	59
	Cajanus cajan	209	5	1043	23	570	13
5.4	L. leucocephala	-	-	-	-	451	38
	Cassia siamea	-	-	-	-	3228	62
	Cajanus cajan	181	4	848	19	737	16
10.8	L. leucocephala	-	-	-	-	363	31
	Cassia siamea	-	-	-	-	3754	72
	Cajanus cajan	209	5	834	19	626	14

TABLE 7. Total nitrogen and organic carbon of surface soil of Lilongwe 2 series (ferric luvisol) after three seasons of alley cropping with maize at Bunda.

Alley Width (m)	Crop System	Total N* %	Organic C %
2.7	Maize monocropped	0.05a	0.66a
	L. leucocephala + maize	0.08b	0.91b
	Cassia siamea + maize	0.08b	0.87b
	Cajanus cajan + maize	0.13c	1.12c
5.4	Maize monocropped	0.04a	0.65a
	L. leucocephala + maize	0.08b	0.83ab
	Cassia siamea + maize	0.07b	0.81ab
	Cajanus cajan + maize	0.08b	0.91bc
10.8	Maize monocropped	0.05a	0.64a
	L. leucocephala + maize	0.07b	0.72ab
	Cassia siamea + maize	0.08b	0.75ab
	Cajanus cajan + maize	0.07b	0.81ab

* Values for N or C with different letters are significant ($P<0.05$)

Analysis of variance for total nitrogen for the surface soil after three growing seasons showed significant differences among tree species. There was a significantly higher nitrogen content in the treatments which had received 100 kg/ha N during three years, the levels being 0.06%, 0.08% and 0.11% for 0, 50 and 100 kg/ha N, respectively. This may be due to the effect of residual N form annual application of fertilizer.

For the tree species, treatments with Cajanus cajan and maize had higher N contents of 0.06%, 0.06%, 0.07% and 0.93% for monocropped maize, Leucaena + maize, Cassia + maize and Cajanus cajan + maize in that order. The high N content in plots with Cajanus cajan + maize may be attributed to differences in mineralisation of material from the three species resulting in more additional organic nitrogen in Cajanus cajan + maize plots, thus increasing total N levels. Without empirical evidence on levels of mineralization, however, this is at best a conjecture.

Analysis of organic carbon showed significant differences among tree species and among alley widths. Again, Cajanus cajan + maize had significantly higher organic carbon than the other treatments while an alley width of 2.7 m generally gave the highest organic C content. The organic C content for maize alone, Leucaena + maize, Cassia + maize and Cajanus cajan + maize were 0.81%, 0.76%, 0.84% and 1.01% respectively. This could be explained by the fact that narrower alley widths had relatively more biomass added to them than was added to the wider ones.

Influence on maize yield

Results relating to the yield of maize during the seasons 1984/85 and 1985/86 are presented in table 8. No results are given for the 1983/84 season because the main objective here is to assess the effect on yield due to incorporation of prunings in the soil. No material was available for incorporation at the beginning of the 1983/84 season.

TABLE 8. Effect of alley cropping and fertilizer application on yield of maize (kg/ha at 12.5% M.C.) for two seasons.

Season	Crop System	Alley Width (m)	Nitrogen Rate (kg/ha)			Means	
			0	50	100	Alley	Crop System
1984/85	Maize monocropped	2.7	659	1455	2935	1683	
		5.4	1011	2538	3937	2495	2074
		10.8	411	1869	3819	2043	
		Mean	704	1954	3564		
	<u>L</u>. <u>leucocephala</u>	2.7	657	3485	3094	2412	
		5.4	737	1646	3730	2038	1957
		10.8	438	2246	1557	1420	
		Mean	617	2459	2794		
	<u>Cassia siamea</u>	2.7	515	2099	3378	1997	
		5.4	412	2137	2933	1827	1870
		10.8	473	1333	3549	1785	
		Mean	467	1856	3287		
	<u>Cajanus cajan</u>	2.7	482	1214	3154	1617	
		5.4	399	2011	2152	5121	1682
		10.8	522	1343	3857	1907	
		Mean	468	1523	3054		
1985/86	Maize monocropped	2.7	203	2389	3740	2111	
		5.4	141	2805	2973	1973	1901
		10.8	109	1758	2986	1618	
		Mean	151	2317	3233		
	<u>L</u>. <u>leucocephala</u>	2.7	45	1473	1581	559	
		5.4	151	2056	4975	2394	1411
		10.8	124	1465	2249	1279	
		Mean	107	1665	2935		
	<u>Cassia siamea</u>	2.7	-	420	900	440	
		5.4	20	1452	1294	992	915
		10.8	152	1274	2720	1382	
		Mean	57	1049	1638		
	<u>Cajanus cajan</u>	2.7	205	1440	2050	1231	
		5.4	407	2433	3870	2237	1681
		10.8	152	1882	2691	1575	
		Mean	255	1918	2870		

NOTE: Interactions were not significant.

Analysis of these results show that average grain yields of maize were significantly lower for the different treatments in the 1985/86 crop season compared to corresponding values for the 1984/85 season. The reduced grain yields during 1985/86 are probably due to a higher incidence of cob rot prior to harvesting thought to have been induced by prolonged rains compared to the previous season (MacColl, personal communication). However, despite the lower yields during the 1985/86 season, the overall trend in yields among treatments is quite consistent in each season.

During the 1984/85 crop season, alley cropping maize with L. leucocephala gave the highest maize grain yields from alley cropping followed by maize alley cropped with Cassia siamea. Yields of maize from alley cropping with Leucaena in the 1984/85 season compare favourably with the yields of maize to which 50 kg/ha inorganic N had been applied. Thus it would appear that incorporation of Leucaena prunings into the soil produces maize grain yields equivalent to those resulting from application of 50 kg/ha inorganic N.

During the 1985/86 crop season, alley cropping maize with Cajanus cajan produced highest grain yields of maize in alley cropping followed by maize in alley with Leucaena. In 1984/85, highest overall grain yields were observed for an alley width of 10.8 m while in 1985/86 the highest grain yields were observed for an alley width of 5.4 m. Since it was observed (table 6) that the largest absolute contribution to soil carbon and nitrogen occurred for an alley width of 5.4 m, the high maize grain yields at this alley width appear to be consistent with this. In addition, the large contribution to soil carbon presumably improved the physical properties of the soil, and increased nutrient availability.

On the other hand, one might expect slightly lower yields of maize at 2.7 m alley width due to shading of the maize by the trees and hence reduction in photosynthetic efficiency for maize. At 10.8 m alley width, it might be inferred that the same quantities of biomass available in the other alley widths was spread rather thinly over a relatively larger area thus reducing absolute nutrient contribution to the soil and, consequently, of available soil nitrogen.

It is also apparent from the data that Zea mais alone outyielded all maize-alley cropping species combinations, the differences being more pronounced in the 1985/86 season. While the 1985/86 results may have been influenced in part by climatic conditions during that season, as observed earlier, the overall reductions in yield in both years in the maize-tree species combinations may be attributed to probable shading effects of the trees on maize.

CONCLUDING REMARKS

On the basis of the two year post-establishment results presented in the foregoing analyses, there is evidence that incorporation of prunings form Leucaena leucocephala, Cassia siamea and Cajanus cajan into the soil has a definite ameliorating effect on the soil. Evidence from this study also suggests that incorporated material from such trees cannot be expected to provide the amounts of nitrogen that would be equivalent to those recommended when using inorganic fertilizers in order to get maximum yields of maize. While this is so, however, there is evidence that incorporation of prunings from these trees into the soil has an ameliorating effect on the soil without N fertilizer application.

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In view of the escalating costs of inorganic fertilizers already cited elsewhere in this paper, such a role for trees as a supplementary source of nitrogen cannot be ignored, especially as it would enable a smallholder farmer to trim his budget. Material from these trees has a tendency to improve the physical properties of the soils in which it is incorporated, especially if the soils are sandy with a low organic matter content.

Results from this study appear to suggest that Cajanus cajan may be one of the more promising soil improving tree species especially as it is considerably easy to establish and produces relatively large quantities of biomass over short periods of time. Its relatively high nitrogen content makes it suitable as a source of N. Since Cajanus cajan is capable of producing woody stems within two years, it can also serve as a source of much-needed firewood for rural farmers. Again, in view of the critical fuelwood problems facing rural households in many developing countries, such a dual role for trees must be appreciated.

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ROOTING DEPTH IN CROPPING SYSTEMS IN THE HUMID TROPICS IN RELATION TO NUTRIENT USE EFFICIENCY

key words alley cropping, leaching model, rooting depth, shifting cultivation, synchronization.

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ABSTRACT

A simple model is presented for calculating the rooting depth of a crop or crop combination required to intercept leaching nutrients for different climatic and soil conditions. Important parameters in this model are the amount of water moving through the soil, which depends on excess of rainfall over evapotranspiration, and the apparent adsorption constant, which depends on the nutrient and soil type involved. Calculations for three time patterns of nutrient supply in relation to nutrient demand show moderate effects of the degree of synchronization on rooting depth required if a high interception fraction is desired.

In shifting cultivation systems a deep-rooted fallow vegetation can recover nutrients leached to the subsoil during the cropping phase. The simple leaching model can indicate the combinations of climate zone and apparent adsorption constant for which such interception is possible. It appears that recovery of leached nitrate is only possible in the subhumid zone. In the humid tropics the continuous presence of a deep root system as part of the crop combination on the field is necessary to use nitrogen efficiently, except when acid soil conditions keep all nitrogen in the ammonium form or when an almost ideal synchronization exists of nitrogen supply and demand during the growing season.

Some data are discussed on the root distribution of food crops and on the possibilities to establish a "safety-net" under the crops grown in alleys between deep-rooted hedgerow trees.

INTRODUCTION

Methods to increase the often low nutrient use efficiencies obtained in the humid tropics should be based on an understanding of nutrient availability in the soil, nutrient demand by the crop and nutrient losses to the subsoil and to the atmosphere. Knowledge of the root distribution of all components of a cropping system is important in this context. A simple model of nutrient leaching, rooting depth and nutrient recovery by the crop will be discussed here for conditions in the humid tropics. Available data on root distribution of crops and hedgerow trees for alley cropping will be briefly reviewed.

Detailed models of nutrient transport in the immediate root environment (De Willigen and Van Noordwijk, 1987) suggest that effective transport rates of nutrients are dominated by the "apparent adsorption constant" and that for P, K and N different aspects of the root system are the most important. For P, with an apparent adsorption constant K_a in the range of 100 - 1 000 ml/cm^3, any increase in root length density (cm root length per cm^3 of soil) up to the high values found in a grass sod (10 - 20 cm/cm^3) will improve possibilities of using available resources in the soil. Mycorrhizal hyphae function as extension of the root length. Effective transport of P in the soil strongly depends on the water content of the root zone and on the degree of soil-root contact. For K, with an apparent adsorption constant K_a of 5 - 25 ml/cm^3, root length densities of agricultural crops in the topsoil (1 - 5 cm/cm^3) usually allow uptake of a considerable part of the available amount. Water content of the soil, root distribution pattern in coarse-structured soils and soil-root contact are important for K-uptake. Subsoil K can be only partial utilized at the root length densities normally found in the subsoil (< 1 cm/cm^3), even under wet conditions. For NO_3, with an apparent adsorption constant of 0 - 1 ml/cm^3, low root length densities of about 0.1 cm/cm^3 as found in the subsoil are sufficient for utilizing virtually all available supplies, if current crop demand is not satisfied by N-supply to other parts of the root system. For NH_4 a situation intermediate between NO_3 and K may be expected.

In the humid tropics, with a net downward movement of water through the root zone throughout the growing season, the leaching rate of nutrients depends on their apparent adsorption constant. The apparent adsorption constant thus influences the rooting depth required for interception of nutrients leached during the start of the growing season. Even under conditions of shallow rooting and a high leaching rate of water, no leaching of nutrients will occur if nutrient demand by the plants always exceeds the current nutrient supply. For tropical rain forests this appears to be the case (Jordan and Escalante, 1980). Under agricultural conditions supply usually exceeds demand at the start of the growing season. The degree of synchronization of supply and demand then determines the severity and time-pattern of leaching (figure 1).

A simple model description of this relation is possible by assuming "piston flow" of water through a column of soil, neglecting two-dimensional aspects of water flow on sloping land. In this description newly infiltrating water pushes the soil solution downwards, without mixing. The nutrients that are temporarily in excess in the first week of the growing season will be found at the greatest depth at the end of the growing season. The distribution of nutrients with depth at the end of the growing season thus is a reflection of the history (time-pattern) of the excess of supply over demand in the topsoil. Deep rooted crops may recover part of these nutrients in the second part of the growing season, when supply in the topsoil is smaller than current demand.

In the model the process is simplified by first distributing all available nutrients over the zone between the soil surface and the annual leaching depth and then considering uptake from the root zone. By assuming that all nutrients within the root zone will be taken up, we restrict the use of the model to nutrient-limited growth. When other factors are growth-limiting, nutrient use efficiencies will be lower than calculated here. Losses of nutrients from the soil other than by uptake and leaching are not considered here. Nutrients are considered separately, each with an "apparent adsorption constant" K_a; in fact interactions exist, especially between anion and cation movement, and absence of an-

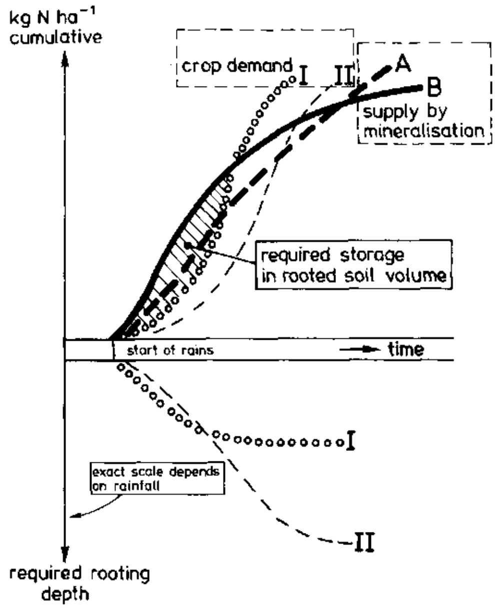

Figure 1. Schematic interaction between the rooting depth required for recovery of leached nitrogen and the (lack of) synchronization of supply of nitrogen by mineralization and crop demand; crop demand curves are typically S-shaped as shown by line I and II, while mineralisation of crop residues show a logarithmic decrease as shown by line A and B; for demand curve I and supply line A the temporary excess of nutrients in the top soil is indicated; depending on the amount of excess rainfall this temporary excess of nutrients will leach into the soil; recovery by the crop is possible if the roots have reached the leaching front by the time crop demand exceeds nitrogen supply in the top soil; for the later crop demand curve II thus a deeper root development is required.

ions may restrict cation leaching, for instance at low soil pH when most of the nitrogen is in the ammonium form. Such complications can be smoothed out by adjusting the parameter value for K_a to current conditions. A further major simplification in the model is that all soil layers are assumed to have the same soil physical and soil chemical characteristics.

REQUIRED ROOTING DEPTH FOR INTERCEPTION OF LEACHED NUTRIENTS

The depth, $Z_\ell(T)$, of the leaching front of a nutrient at time T is determined by the integral up to T of the flux density of leachate, $l_w(t)$, the saturated moisture content of the soil, θ_{sat}, and the retardation due to apparent adsorption:

$$Z_\ell(T) = \frac{\int_0^T l_w(t)\,dt}{(1 + K_a)\,\theta_{sat}} \qquad \text{[cm]} \qquad (1)$$

The notation and "standard" parameter values are given in table 1; $l_w(t)$ can be estimated from the amount of rainfall - evapotranspiration - run-off + run-on, all expressed in m/year. For the transport of nutrients we only consider convection and we do not consider the bypass of water occurring in cracked soils or dispersion and diffusion. A moderate degree of bypass, as described by Grimme and Juo (1985) as a two-phase transport, can be incorporated in the term K_a which should then be called retardation constant. Retardation due to immobilization-mineralization cycles can betreated in the same way.

The distribution of nutrients between $Z_\ell(1)$ and the soil surface depends on the degree of synchronization of supply and demand. We will consider three (linear) distributions here (fig. 2): a situation of relatively early supply, with the highest concentration at $Z_\ell(1)$, an evenly distributed supply and a relatively late supply with the highest concentration near the soil surface. Although these three distributions cannot be directly translated into actual field situations, a comparison of the three may be used to investigate the relative importance of the degree of synchronization.

TABLE 1. List of symbols and parameter values used.

Symbol	Description	Dimension	Value
f_i	interception fraction of nutrient i by the root system in one growing season	[-]	-
θ_{sat}	saturated volumetric water content	[-]	0.33
K_a	apparent adsorption constant	[ml/cm^3]	0 (NO_3) 3 (NH_4) 10 (K)
$l_w(t)$	flux density of leaching water	[(m^3/m^2)/year]	
$L_w(1)$	leaching intensity in one year $= \int_0^1 l_w(t)dt$	[m^3/m^2]	
t,T	time	[year]	
z	depth below soil surface	[m]	
$Z_\ell(T)$	leaching depth at time T	[m]	
$Z_\ell(1)$	leaching depth after one year	[m]	
$Z_{r,i}$	effective rooting depth for nutrient (i)	[m]	
$Z_{r,N}$, $Z_{r,K}$	idem, for N and K respectively	[m]	
$Z_r(c)$	idem, of the crops in a shifting cultivation system	[m]	
$Z_r(f1)..Z_r(f3)$	idem in year 1 .. 3 of the fallow.	[m]	

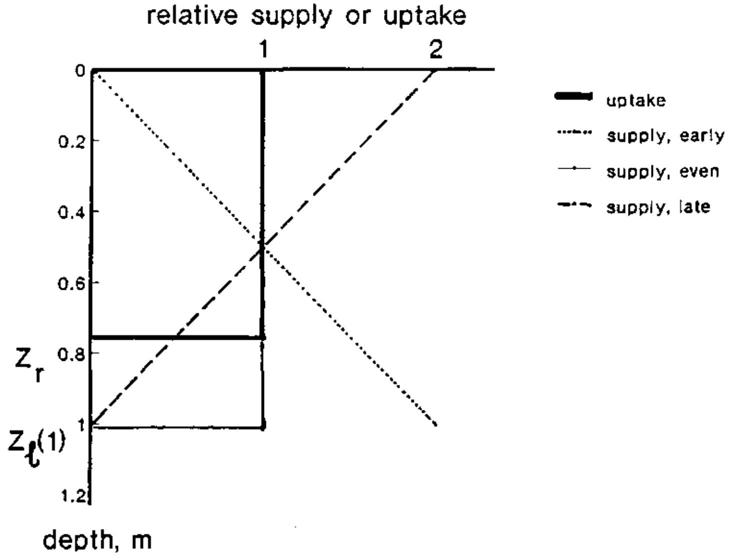

Figure 2. Distribution of nutrients with depth at the end ot the growing season, for a relatively early, an evenly distributed and a late supply in the top soil; complete uptake is assumed up to effective rooting depth $Z_{r,i}$ and no uptake beyond that depth.

For each nutrient i a different "effective rooting depth" $Z_{r,i}$ can be defined above which the possible uptake of available nutrient resources meets a set criterion. Except for P, we can take complete utilization of available nutrients as the criterion. The definition of $Z_{r,i}$, similar to the one often used for water uptake, assumes compensation for incomplete uptake for $z < Z_{r,i}$ by partial uptake from below $Z_{r,i}$. In a schematic description we may state that for $z < Z_{r,i}$ complete uptake of available resources and for $z < Z_{r,i}$ no uptake is possible. From the available theory (De Willigen and Van Noordwijk, 1987) we may estimate that $Z_{r,N}$ equals the depth at which the root length density has decreased to 0.1 cm/cm³ and $Z_{r,K}$ the depth at which the root length density has decreased to 1 cm/cm³; more precise values require knowledge of soil water content, relative root distribution and apparent adsorption constant.

Using this definition of $Z_{r,i}$ we can now define the possible interception fraction, f_i, of leached nutrients by integrating the function describing the nutrient concentration with depth from 0 to $Z_{r,i}$. For the three types of nutrient release the result is:

for $Z_{r,i} >= Z_\ell(1)$: $f_i = 1$ (2a)

for $Z_{r,i} < Z_\ell(1)$: $f_i = (Z_{r,i}/Z_\ell(1))^2$ for the early release, (2b)

$f_i = Z_{r,i}/Z_\ell(1)$ for the even release, (2c)

$f_i = 2(Z_{r,i}/Z_\ell(1))-(Z_{r,i}/Z_\ell(1))^2$ for late release. (2d)

The lower part of figure 3 shows the relation between rainfall surplus, $L_w(1)$, and annual leaching depth $Z_\ell(1)$ for various values of the apparent adsorption constant K_a; in the upper part annual leaching depth $Z_\ell(1)$ is plotted against interception fraction f_i for three values of

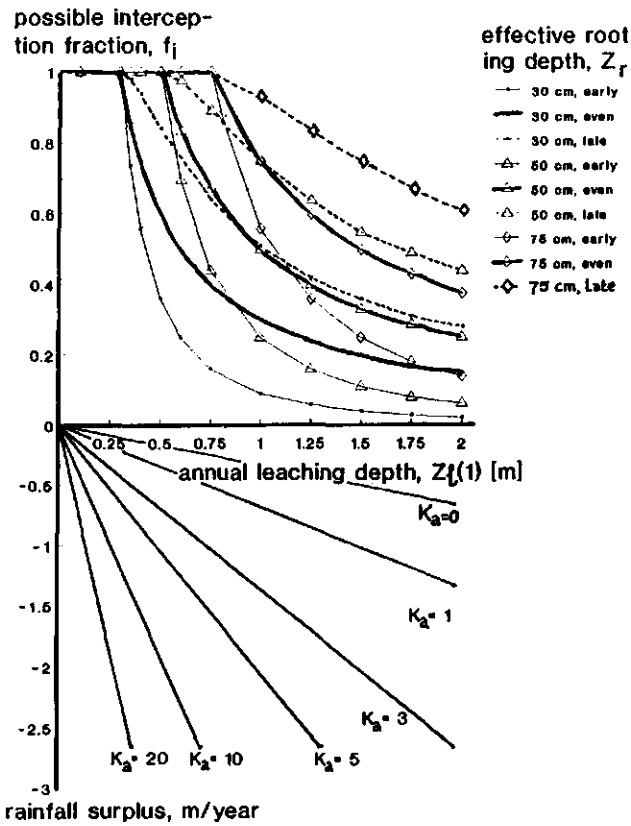

Figure 3. Relation between annual rainfall surplus L_w, annual leaching depth $Z_\ell(1)$ and possible interception fraction f_i, according to equations (1) and (2), for $\theta_{sat} = 0.33$.

effective rooting depth Z_r and three types of nutrient supply. An interception fraction of about 50% under conditions where $Z_\ell(1)$ just exceeds 1 m can be obtained by three combinations of rooting depth and nutrient supply: 0.30 m with "late" supply, 0.50 m with "even" supply and 0.75 m with "early" supply.

If we specify a target interception fraction f_i, the required rooting depth can be expressed as a fraction of $Z_\ell(1)$. By solving the quadratic function in $(Z_{r,i}/Z_\ell(1))$ in equations (2b) and (2d), table 2 was constructed. In combination with equation (1) we now obtain:

$$Z_{r,i} = \frac{Z_{r,i}\ Z_\ell(1)}{Z_\ell(1)} = \frac{(Z_{r,i}/Z_\ell(1))\ {}_0\!\int^T l_w(t)\ dt}{(1 + K_a).\theta_{sat}} \qquad (3)$$

where $Z_{r,i}/Z_\ell(1)$ can be obtained as a function of f_i in table 2.

An example of results for 80% interception is given in table 3. It shows that the required rooting depth for 80% interception strongly depends on the apparent adsorption constant K_a and on the local climate

TABLE 2. Ratio of effective rooting depth and annual depth of leaching front, $Z_{r,i}/Z_{\ell}(1)$, as a function of interception fraction f_i for three patterns of nutrient supply (equation 2a-d).

supply	Interception fraction f_i 1.00	0.90	0.80	0.70	0.60	0.50
late	1.0	0.68	0.55	0.45	0.38	0.29
even	1.0	0.90	0.80	0.70	0.60	0.50
early	1.0	0.95	0.89	0.84	0.77	0.71

TABLE 3 Required effective rooting depth $Z_{r,i}$ (m) for 80% interception of nutrient i for three values of apparent adsorption constant K_a, roughly corresponding to nitrate, ammonium and potassium, respectively.

	------ $K_a = 0$ ---			----- $K_a = 3$ ---			--- $K_a = 10$ ml/cm³		
$L_w(1)$ m	$Z_{\ell}(1)$	$Z_{r,0}$ early	$Z_{r,0}$ late	$Z_{\ell}(1)$	$Z_{r,3}$ early	$Z_{r,3}$ late	$Z_{\ell}(1)$	$Z_{r,10}$ early	$Z_{r,10}$ late
0.25	0.75	0.67	0.41	0.19	0.17	0.10	0.07	0.06	0.04
0.50	1.5	1.34	0.82	0.37	0.33	0.21	0.14	0.12	0.08
0.75	2.25	2.00	1.24	0.56	0.50	0.31	0.20	0.18	0.11
1.0	3.0	2.67	1.65	0.75	0.67	0.42	0.28	0.25	0.15
1.5	4.5	4.00	2.47	1.12	1.00	0.62	0.42	0.37	0.23
2.0	6.0	5.34	3.30	1.5	1.33	0.83	0.55	0.49	0.30

via the excess of rainfall over transpiration. The "late" pattern of nutrient supply allows a rooting depth of 62% of that required for the "early" supply; for the "even" supply it is 90% of this value.

POSSIBLE RECOVERY BY A DEEP-ROOTED FALLOW

As in many cases food crops grown on the acid soils usually found under high-rainfall conditions will not have the required rooting depth as calculated above, losses of nutrients to the subsoil will occur. In shifting cultivation systems the cropping phase, with presumably shallow-rooted crops, is alternated with a natural fallow vegetation which is usually supposed to be deep-rooted. Nutrients leached downward during the cropping phase may then be recovered from the subsoil by the subsequent fallow vegetation. The validity of this concept can be investigated with the simple leaching theory outlined above. As numerical examples we will use a rooting depth of 0.3 m for the crop $Z_r(c)$ and rooting depths of 0.75, 1.5 and 2.5 m in year 1, 2 and 3 of the fallow $Z_r(f_1)$, $Z_r(f_2)$ and $Z_r(f3)$, respectively. These parameter values probably represent a rather exaggerated difference between crop and fallow rooting depths. For the calculations an "even" distribution pattern of nutrients is assumed.

Nutrients lost from the root zone of the crop in the last year of cropping can be found within depth interval $[Z_r(c)$ to $Z_\ell(1)]$. At the end of fallow year 1 these nutrients occur at depth $[Z_r(c) + Z_\ell(1)$ to $2.Z_\ell(1)]$ and at the end of year T in the depth interval $[Z_r(c) + T.Z_\ell(1)$ $(T+1).Z_\ell(1)]$. The possible recovery by the fallow vegetation can now be quantified:

a. for $Z_\ell(T) =< Z_r(c)$ no losses during the crop phase are expected, unless total supply exceeds crop demand, so no recovery by the fallow will occur ($f_i = 0$),

b. complete recovery in fallow-year T is possible for:

$$Z_r(c) < Z_\ell(1) =< \frac{1}{T + 1} Z_r(T), \quad f_i = 1$$

c. for intermediate leaching intensities, partial recovery is possible:

$$\text{for: } \frac{1}{T + 1} Z_r(T) =< Z_\ell(1) =< \frac{Z_r(T) - Z_r(c)}{T},$$

$$f_i = \frac{Z_r(t) - Z_r(c) - T.Z_\ell(1)}{Z_\ell(1) - Z_r(c)},$$

c. no recovery is possible ($f_i = 0$) for high leaching rates, when

$$Z_\ell(1) >= \frac{Z_r(t) - Z_r(c)}{t}. \qquad (4)$$

Similarly, recovery from the last-but-x year of cropping can be worked out. Complete recovery in fallow year t is possible for $Z_\ell(1) < Z_r(T) / (T + x + 1)$. Numerical results for the recovery fraction f_i are shown in figure 4. Figure 4A shows the possible interception of nutrients lost in the last year of cropping in fallow years 1, 2 and 3; figure 4B shows recovery in fallow years 1 till 3 of nutrients lost in the last five years of cropping. Both figures show that recovery by a deep-rooted fallow of nutrients lost in the cropping phase is confined to a relatively narrow range of annual leaching depths $Z_\ell(1)$ and hence annual rainfall surplus L_w. Under conditions of faster leaching (lower K_a or higher L_w), the depth of the leaching front exceeds the rooting depth of the fallow vegetation. For the rather exaggerated numerical example chosen, with a shallow-rooted crop and a deep-rooted fallow, the range of conditions where recovery is possible is confined to an annual leaching depth of 0.3 to 0.7 m. The climatic zone in which this leaching depth occurs depends on the apparent adsorption constant K_a as shown in table 4.

For example for sites in the humid tropics with L_w of 1 - 1.5 m, a deep-rooted fallow might recover nutrients with a K_a of about 5, but no nutrients of a higher mobility. Possibilities for a deep-rooted fallow

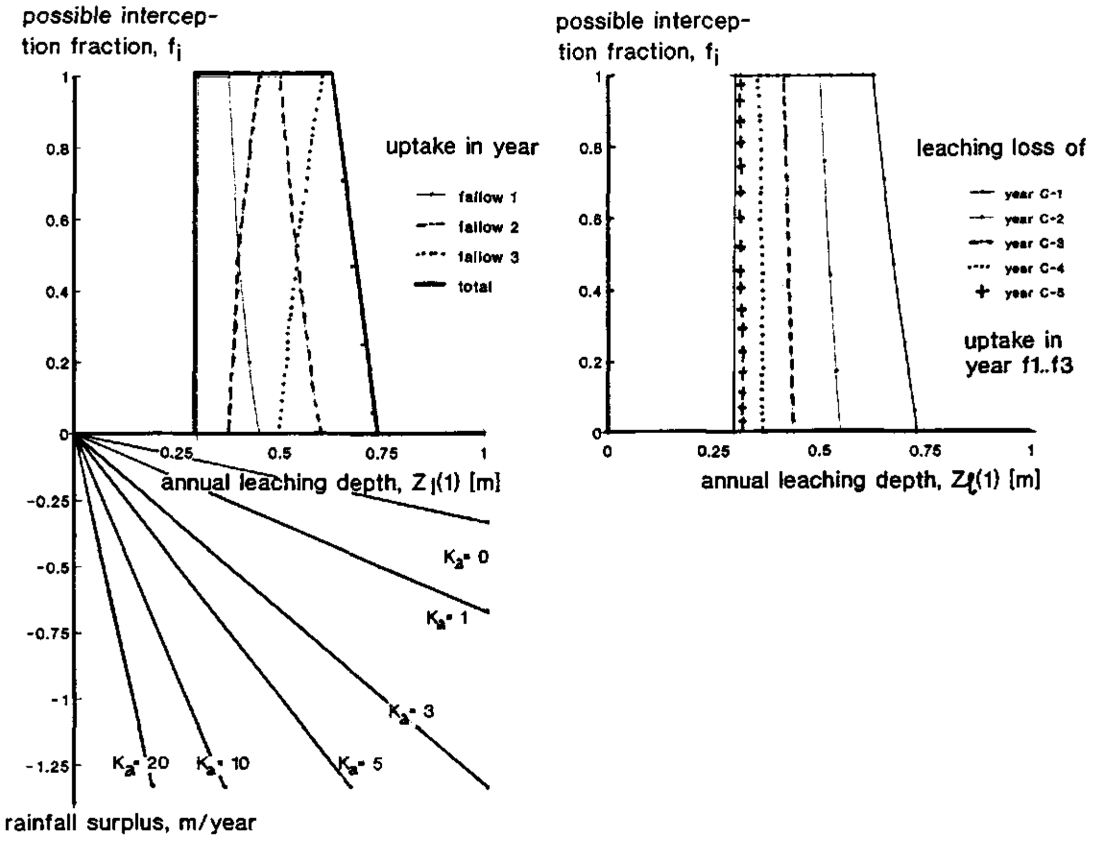

Figure 4. A. Fraction of nutrients leached in the last year of cropping which can be recovered by a subsequent fallow in a shifting cultivation system, in relation to annual leaching depth and rainfall surplus; equations (1) and (4); B. Recovery of leached nutrients in the last 5 years of the cropping cycle.

TABLE 4. Range of values of the annual excess rainfall, $L_w(1)$, for which the concept of nutrient loss from a shallow-rooted crop and recovery by a deep-rooted fallow can be valid, as a function of apparent adsorption constant K_a.

K_a ml/cm³	$L_w(1)$ m
0	0.1 - 0.25
1	0.2 - 0.5
3	0.4 - 1.0
5	0.6 - 1.5
10	1.1 - 2.75
20	2.1 - 5.25

to recover nitrate-nitrogen apparently are confined to the savannah zone, with L_w of 0.5 m or less. For the rain forest zone deep-rooted components of the cropping system are required within each growing season to minimize losses of nutrients with low K_a, as recovery in a later stage is impossible. Mixed cropping of shallow and deep-rooted crops may be part of the solution; under really high-rainfall conditions growth of deep-rooted crops towards the ultimate rooting depth would have to be rapid. Trees with a permanently deep root system and potentially high nutrient demand early in the growing season may perform this function best. Alley-cropping with deep-rooted hedgerow trees thus seems a realistic option under high rainfall conditions, especially for nutrients with a low apparent adsorption.

SELECTING SUITABLE CROPS, CROP COMBINATIONS AND ALLEY-TREES

For the high rainfall substation of I.I.T.A. in S.E. Nigeria, with an annual rainfall of about 2.4 m, the annual excess of rainfall over rainfall over transpiration in the growing season is estimated to be about 1.2 m (De Willigen, 1985). The experimental site of the nitrogen management project in S. Sumatera has a similar annual rainfall, but differently distributed over the year (figure 5).

Under such high rainfall conditions we may expect a dramatic reduction in nitrogen interception if the soil pH would be changed from a value where ammonium is the dominant nitrogen form to a value where nitrate is the dominant form unless rooting depth increases by a factor 4. Detailed calculations by De Willigen (1985) illustrate this point.

Estimates of effective rooting depths, $Z_{r,N}$ and $Z_{r,K}$ as defined above, of some food crops on a tropical ultisol in S.E. Nigeria are given in table 5. Upland rice was found to have at least double the root

TABLE 5. Estimates of "effective rooting depth" in m for N and K uptake for some food crops on a tropical ultisol in Onne, S.E. Nigeria (Hairiah and Van Noordwijk, 1986); $Z_r(K)$ is based on a root length density of 1 cm/cm³, $Z_r(N)$ on 0.1 cm/cm³.

	$Z_r(K)$	$Z_r(N)$	Remarks
Maize, 2 weeks	0	0.1	
5 weeks	0	0.2	
8 weeks	0.1	0.25	
14 weeks	0.1	0.25	
Upland rice 3 w	0	0.1	
5 weeks	0	0.2	
9 weeks	0.2	0.35	
14 weeks	0.2	0.7	
Cowpea 5 weeks	0.1	0.1	
8 and 14 weeks	0.2	0.4	
Cassava 2 weeks	0*	0	
5 weeks	0*	0.2	* 30-50% of root length
8 weeks	0*	0.3	infected with V.A.mycorrhiza
14 weeks	0*	0.35	
10 months	0*	0.6	

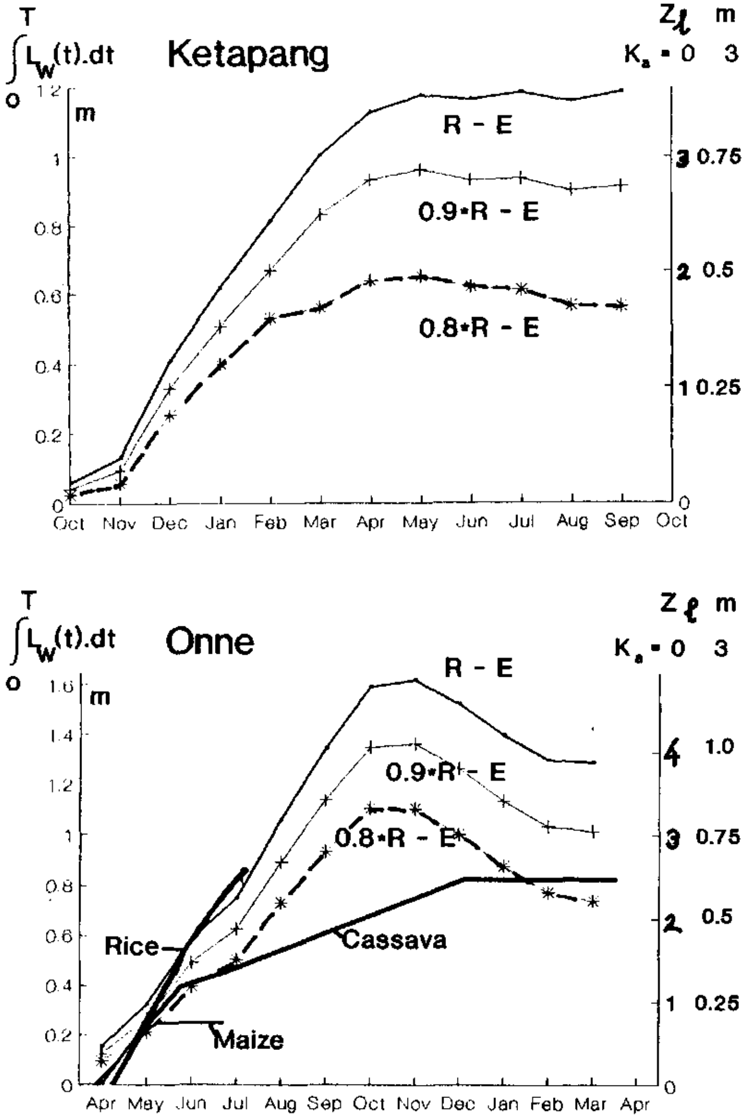

Figure 5.A. Cumulative rainfall surplus during the growing season for the experimental site of the nitrogen management project in S. Sumatera and predicted depth of the leaching front, $Z_{\ell,i}$, for three values of K_a; the three lines indicate three values of the run-off fraction; average rainfall data for the period 1974-1986 about 20 km from the experimental fields; potential evapotranspiration estimated at 4 mm/day. B. idem, for Onne, S.E. Nigeria; effective rooting depth for nitrogen uptake is plotted on the K_a=3 axis (data from table 5).

ing depth of maize. The considerably higher nitrogen recovery by rice compared with maize found by Arora and Juo (1982) can at least partly be accounted for by this difference in root development. A monoculture of maize will lose nitrogen beyond $Z_{r,N}$ unless nitrogen is applied in a larger number of split applications. Mixed cropping of maize and cassava provides a possibility for recovering part of the leached N from the subsoil, provided K_a is around 3. Rooting depths of various leguminous cover crops are described by Hairiah and Van Noordwijk (1989).

For the presumed role of alley-trees as nutrient pumps a deep root development would be required; horizontal development in the topsoil should be limited so as to reduce competition from crop roots. Tree species which have this pattern of root distribution and also fulfill other requirements such as tolerance of frequent pruning are scarce, but they exist. Figure 6 shows data on root distribution of shade trees used in tea plantations in Indonesia on deep volcanic soils. *Leucaena leucocephala* showed the deepest root penetration. Coster (1932) studied a large number of trees considered as potential understory trees in *Tectona*-plantations. Trees with a deep root system and few superficial roots generally showed a slow initial growth and a shoot: root ratio of 0.4 to 2.5 (on a dry weight basis); trees with a deep taproot as well as extensive horizontal development in the topsoil showed faster growth and had shoot: root ratios of 2 to 6; a group of trees and shrubs with only shallow rooting had shoot: root ratios of 2 to 30. Apparently trees with the desirable root pattern invest a large fraction of their carbohydrates in root growth and consequently have a slow initial growth (figure 7). On the basis of later root development *Leucaena leucocephala* and *Acacia villosa* appear to be suitable for alley-cropping: after a relatively fast establishment phase with some horizontal roots in the topsoil as well as a deep root, later development is largely confined to the subsoil.

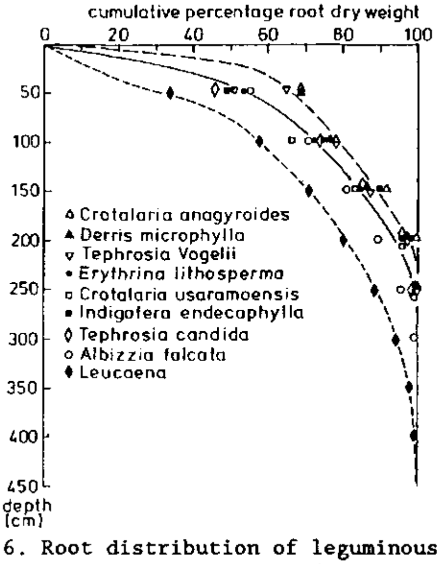

Figure 6. Root distribution of leguminous trees used in tea-plantations in Indonesia (data of Keuchenius (1927), presented in Hairiah and Van Noordwijk, 1986).

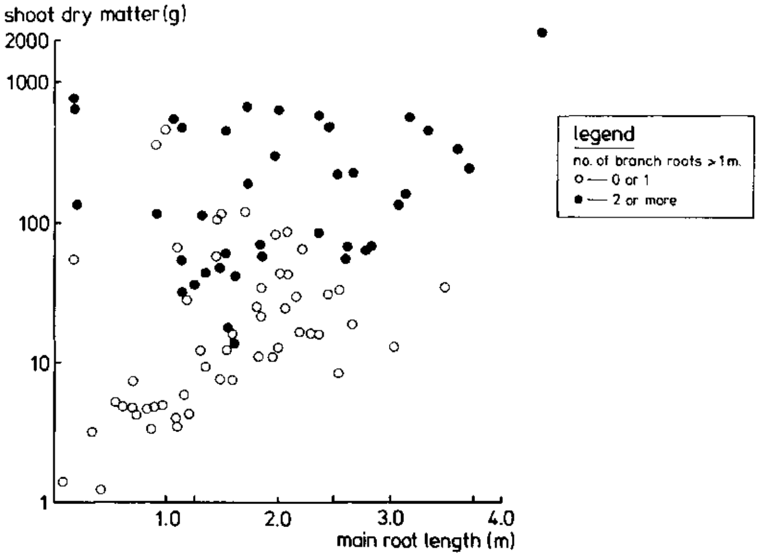

Figure 7. Relation between depth of the main root and shoot dry weight (logarithmic scale) for a large number of trees and shrubs, after 6 months, classified according to horizontal branch root development (data of Coster, 1932).

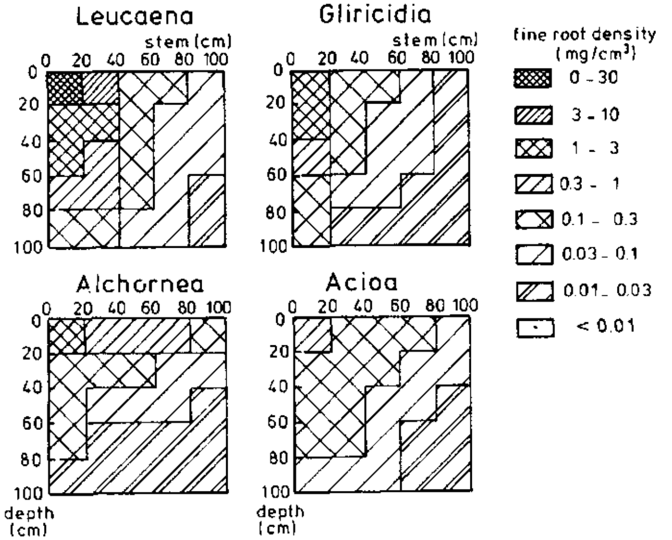

Figure 8. Root distribution with depth and radial distance to the stem of *Leucaena leucocephala*, *Gliricidia sepium*, *Alchornea cordifolia* and *Acioa barteri* in alley cropping experiments at I.I.T.A., Ibadan, Nigeria (data of Cole (1983) presented in Hairiah and Van Noordwijk, 1986).

Root studies in the alley-cropping experiment at I.I.T.A. in Ibadan, Nigeria, showed that *Leucaena leucocephala* comes closest to the desirable root pattern, with *Gliricidia sepium* and *Acioa barteri* as a second choice (figure 8). *Alchornea cordifolia* showed a largely horizontal development and is probably not suitable as hedgerow tree. Limited observations on an acid soil in Onne, S.E. Nigeria (Hairiah and Van Noordwijk, 1986) showed *Alchornea* roots to be even more restricted to the topsoil; *Leucaena* and *Flemingia congesta* formed many roots in the top- as well as in the subsoil. *Anthonata macrophylla* hedgerows got established slowly, but had a reasonably deep root system. Of four local tree species investigated in S. Sumatera, *Peltophorum inerme* had the most promising root distribution (figure 9, Van Noordwijk et al. 1989). The search for suitable tree species, especially for acid soils has to continue. Root observations in an early stage may help to select tree species and discard less suitable ones. In view of the long duration of such experiments, early selection is obviously profitable.

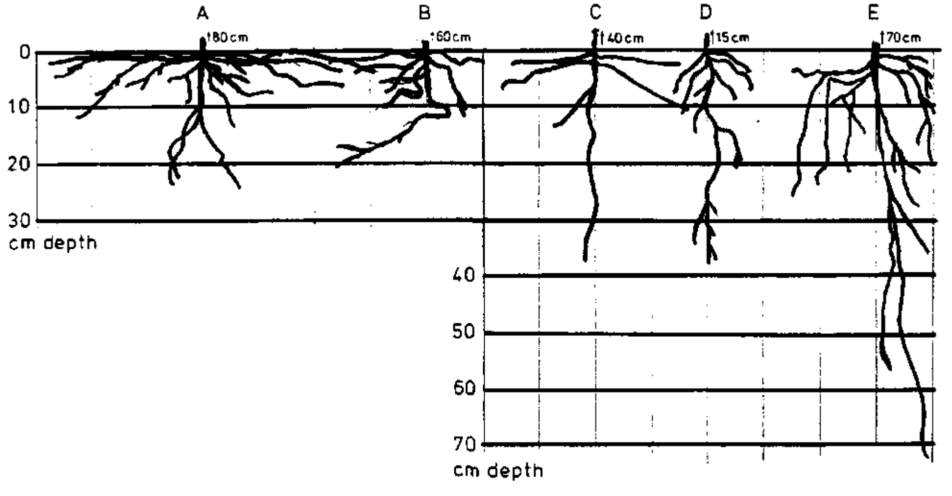

Figure 9. Root distribution of some spontaneous tree seedlings in S. Sumatera considered as potential alley-cropping tree; shoot height is indicated; A *Peronema canescens* (local name: Pohon sunjkai); B and C *Commersonia bartramia* (local name Pohon waru); D and E *Peltophorum inerme*; botanical identifications by Dr Riswan, Herbarium Bogoriense.

CONCLUDING REMARKS

The simple leaching model presented here obviously needs refinement and testing. Soil biological, chemical and physical properties generally vary with depth and the linear approximations used here may not be valid. Yet the description of leaching used here is essentially the same as used by De Willigen and Van Noordwijk (1989) in a more elaborate model, which gives reasonable agreement with field experiments. Both the "effective rooting depth" as the annual leaching depth vary considerably for different nutrients on the same soil in the same climate. A more precise use of the term "leaching" in explaining observed changes in nutrient content of the topsoil is desirable (Andriesse, 1987).

Further subdivision of the humid tropics according to rainfall surplus is desirable: in an area with 3 to 5 m annual rainfall (Hancock, 1989) leaching will be at least twice as fast as in an area with 2 m rainfall per year, the excess of rainfall over evapotranspiration will being 2 - 4 and 1 m, respectively.

Details of rain infiltration (run-off and run-on) can be very relevant for nutrient leaching patterns in the humid tropics, while their effect on crop water availability will be much less pronounced than in drier areas.

Root investigations on each experimental site in an initial stage, although labour-intensive and destroying part of the plots, may be worth the time and energy invested, especially where long-term experiments are planned.

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ROOTING DEPTH, SYNCHRONIZATION, SYNLOCALIZATION AND N-USE EFFICIENCY UNDER HUMID TROPICAL CONDITIONS

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SUMMARY

A model is presented with which calculations on the nitrogen balance of a soil can be performed. The processes considered include leaching, transformation of mineral and organic N, adsorption, and plant uptake. Model calculations on the nitrogen balance for conditions of continuous leaching during the growing season in the humid tropics show a reasonable agreement between N uptake as predicted on the basis of observed root distribution and actually measured uptake. Practical possibilities for increasing nutrient use efficiency through better synchronization and synlocalization of nutrient supply in relation to nutrient demand by the crop are discussed.

INTRODUCTION

The traditional upland crop production systems in large parts of the humid tropics rely on a short cropping period followed by a long bush fallow period for soil fertility restoration. This production system is characterized by a low cropping intensity and low crop yields, with little or no input of chemicals. These systems have provided farmers for generations with stable production methods. However, during the last few decades the traditional system is undergoing rapid changes, mainly due to increasing population pressure. This has led to an increase in cropping intensity and shortening or elimination of the much-needed fallow period, resulting in a rapid decline in natural fertility and low yields.

For prolonged or continuous cropping, the loss in soil fertility in the cropping phase must be compensated for by the use of organic nutrient sources and/or fertilizers. Traditional farmers in many parts of the humid tropics cannot afford costly inputs. So-called modern techniques for fertilization are often characterized by low efficiencies, except where they are based on knowledge of local soil, climate and crops. For fertilizer recommendations for tropical countries Janssen et al. (1988) use an apparent N recovery of 20-35%, depending on soil type. With such efficiencies, fertilizer use by small farmers is often not economically justifiable. Therefore, efforts have to be made to reduce dependence on chemical fertilizers by maximizing recirculation of all available waste materials and by maximizing biological N fixation, and/or to increase efficiency of fertilizer use.

In this paper we will use a model for nitrogen uptake by maize in the humid tropics to investigate the effects of rooting depth and method of fertilizer application (synchronization and synlocalization) on the N-use efficiency obtained. The model (based on De Willigen, 1985) will first be tested with experimental data for a location in southeastern Nigeria (Onne). The model is subsequently used to examine the effects of different root distributions, different methods of application of fertilizer and different infiltration patterns of rain water into the profile.

Experiments with N-15 in the humid zone of southeastern Nigeria indicate that recovery of nitrogen given in three split applications during the growing season of maize and localized near the crop is only about 40% (Van der Heide et al., 1985). Low uptake efficiencies under these conditions may be expected, as there is continuous leaching during the growing season. In this respect the situation resembles that in artificial substrates in modern horticulture. In contrast to the horticultural situation, however, the amount of water moving through the profile is not under direct human control. Leaching can only be reduced by increasing surface runoff, with the risk of increased erosion; it may be possible, however, to influence the pattern of infiltration, for instance by ridging or by covering parts of the soil surface with mulch material to create differential infiltration patterns, i.e. zones with increased and zones with reduced infiltration.

By carefully selecting combinations of techniques, higher N-use efficiencies might thus be obtained. Measurements of root distribution have shown maize to be shallow-rooted in this soil, with soil acidity and/or soil compaction as limiting factors for deeper rooting (Hairiah and Van Noordwijk, 1986). A description of the climate and of some physical and chemical properties of the soil in Onne is given by Lawson (pers. comm.) and Pleysier and Juo (1981), respectively. Van der Heide et al. (1985) provide data on maize growth and N-use efficiencies.

MODEL DESCRIPTION

Geometry and time resolution

In the model a two-dimensional cross section of the unit soil area is considered for a maize plant in a row. This rectangular soil area is described by 55 compartments (five "columns" of 11 layers each). Within each compartment the concentration of nutrients and the root density is assumed to be uniform. The first four layers have a thickness of 5 cm, the next four of 10 cm, and the remaining three of 20 cm, the total length of the column thus comprising 120 cm. Because of the high infiltration rate in the growing season (see below) leading to high rates of vertical transport of nutrients, the lateral transfer of nutrients (which will, for the most part, be due to diffusion) plays only a minor role; it is neglected completely in the model. The five columns together cover half the row distance of 1 meter, each column having a width of 10 cm.

The time-interval used in the calculations was 1 day.

Transport and N transformations

Data on precipitation and evapotranspiration are shown in figure 1. The description in the model of water and solute transport, adsorption of ammonium and nitrate, and the biological N-transformations have been

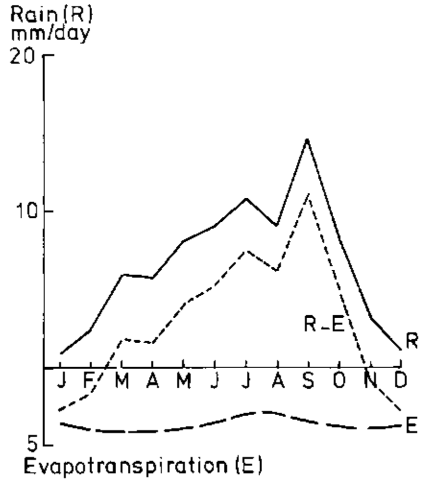

FIGURE 1. Average precipitation (R), evapotranspiration (E) and net precipitation (R-E) at Onne, Nigeria (Lawson, pers. comm.).

discussed earlier (De Willigen, 1985), where details and justification of the chosen description can be found.

Maize growth and N-demand

Potential growth of the crop for the climatic conditions of Onne is calculated as outlined by Van Keulen and Wolf (1986). Gross photosynthesis for a closed crop canopy as a function of irradiance was computed by the model of De Wit (1965). Net photosynthesis is derived from gross photosynthesis, taking into account the extent of soil cover and the respiration (at the average temperature of 26 °C). Distribution of dry matter over the various parts of the shoot (leaves, stems and cobs) was calculated as a function of stage of development, using the data on maize presented by Van Keulen and Wolf (1986). The stage of development was calculated as the sum of average daily temperature, less a base temperature of 10 °C, divided by the temperature sum at silking. The value of the latter has been taken from Allison (1963).

In our model the actual growth rate is calculated by multiplying potential growth rate by a factor depending on the ratio of actual nitrogen content to optimal nitrogen content (figure 2). The optimal nitrogen content is set at 3% in the exponential growth phase and decreases in a linear fashion to 1.3% in the linear growth phase, which starts when the amount of aboveground dry matter reaches a level of 1000 kg/ha. These figures were estimated from experimental data, collected in Onne (Van der Heide, pers. comm.)

The nitrogen demand of the crop follows from its growth rate and the optimum nitrogen content. If the nitrogen content is sub-optimal the demand also includes the amount to be taken up to restore the content to the optimum value.

The amount of nitrogen in the crop at any one moment, N_{pl} in kg/ha, is:

$$N_{pl} = Y_D \, N_c \, / \, 100 \; , \tag{1}$$

where:

Y_D = aboveground crop dry matter [kg/ha],
N_c = nitrogen content of the shoot [%].

Differentiating (1) with respect to time yields the nitrogen demand:

$$\frac{dN_{pl}}{dt} = \frac{1}{100}\left[N_c \frac{dY_D}{dt} + Y_D \frac{dN_c}{dt}\right] . \qquad (2)$$

The first term on the right-hand side of (2) represents the uptake rate required to maintain the nitrogen content at N_c, the second term the additional uptake required to restore the optimal nitrogen content, if necessary.

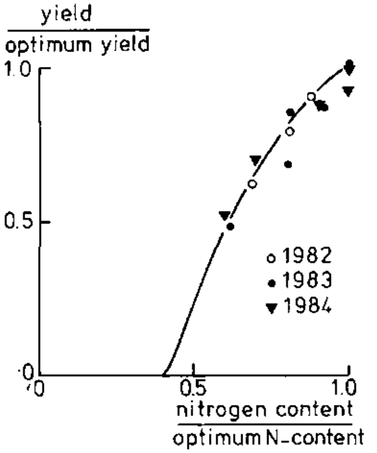

FIGURE 2. Assumed relation between rate of dry matter production and average content of the shoot; points refer to relative yields of maize in three years (data of Van der Heide, pers. comm.).

It is assumed that whenever the nitrogen content is suboptimal, the additional uptake rate is such that optimum nitrogen content can be reached within a week, if the external supply permits, in a first-order fashion:

$$\frac{dN_c}{dt} = \left(\frac{N_{c,o} - N_c}{R_c}\right) , \qquad (3)$$

where:
$N_{c,o}$ = optimum nitrogen content [%],
R_c = time constant [days].

The crop takes up nitrogen at the required rate if possible, or at the maximum rate allowed by the soil supply and root system. Possibilities for uptake depend on the distribution of roots and of mineral nitrogen in the soil.

Root distribution

Root distribution is not calculated in the model. It is introduced in the model as a forcing function based on data collected by Hairiah and Van Noordwijk (1986) for actual root distribution of maize in 1985. Figure 3a presents schematized data on root density distribution throughout the growing season as derived from vertical root maps and from washed pinboard samples. No maize roots were observed below 30 cm and the majority of roots were found in the top 10 cm, especially later in the growing season.

Root distribution in the topsoil was further investigated by mapping roots in the unit soil area (the reciprocal of plant density) on a horizontal surface at about 5 cm depth at four times in the growing season. Root densities on the maps were scored in a 5x5 cm^2 grid, and were classified into five classes: 0-0.1, 0.2-0.5, 0.6-1.2, 1.3-2.5, and >2.5 cm/cm^3. A cumulative frequency distribution of root densities for each observation date was calculated. With the frequency distribution a description of the horizontal root distribution over the five soil columns distinguished in the model, as it develops in time, was constructed. It was assumed that the lowest root densities will be found midway between the plant rows, and the highest in the immediate vicinity of the plant. From the cumulative frequency distribution curve the average value of root density for which the cumulative frequency is 20% or less can be read. This value is then allotted to soil column 5. The average value found for the cumulative frequency between 20 and 40% is allotted to soil column 4, etc. The distribution in the first layer (depth 5 cm) obtained in this way is given in table 1a. The horizontal distribution in deeper layers was derived from the average root densities given in figure 3. By assuming that in each layer the ratio between the numbers of roots in the soil columns was identical to that in the top layer, root length density in a soil column at a given depth can be calculated from the average root density at that depth. The roots were assumed to be distributed uniformly in each compartment. So around each root a soil cylinder can be constructed, the radius of which is a function of the root density in the compartment. The root system constructed in this way will be indicated by the term standard root system.

To study the influence of root distribution, two root systems in addition to the standard system were constructed: a deeper root system (designated as "deep" in the following) and a horizontally more extended root system ("wide"), both with a total root length equal to the standard root system. The vertical distribution of the deep root system is given in figure 3b, its horizontal distribution is identical to that shown in table 1a. The assumed horizontal distribution of the wide root system is shown in table 1b, its vertical distribution is identical to that given in figure 3a. In the model a value for root density for each compartment on each day is found by linear interpolation between the values given in figures 3 a and b and table 1.

N-uptake

Uptake of nitrogen by the root system is calculated iteratively. First (step 1) the nitrogen demand calculated with (3) is divided by the total root length to obtain the required uptake per unit root length.

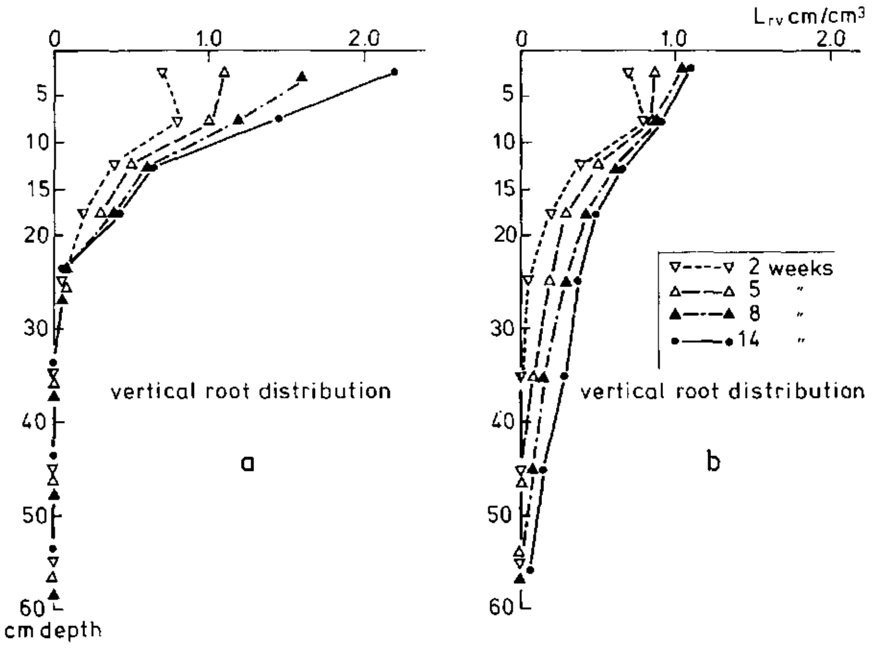

FIGURE 3. a. Root length density of maize as a function of time (weeks after sowing) and depth. Data of Hairiah and Van Noordwijk (1986). b. Assumed root length density distribution of the hypothetical deep root system.

Multiplying this by the root length in a compartment yields the required uptake from each compartment. As explained elsewhere (De Willigen and Van Noordwijk, 1987), the distribution of nutrient concentration around a root can very well be approximated by a steady-rate profile. For such a profile the average concentration C_0 in the soil cylinder around a root, when the concentration at the surface of the root is zero, can be calculated as a function of uptake rate and root density. If the average concentration in a compartment exceeds C_0, uptake from this compartment equals the required uptake. If the average concentration is less than C_0, the roots in the compartment behave as zero-sinks and their uptake can be calculated as a function of the average concentration (De Willigen and Van Noordwijk, 1987). For convenience these compartments will be indicated as compartments of category 1. The total uptake by the root system is the sum of the uptake rates of the individual compartments. If the uptake in each compartment can proceed at the required rate, total uptake equals nitrogen demand and no iteration is required. If uptake is lower than the nitrogen demand, it is checked whether uptake from those compartments where the concentration was sufficiently high to meet the original demand (for that particular compartment) can be raised to increase total uptake, possibly enough to meet the nitrogen demand.

This is achieved as follows. In step 2, first the difference between demand and total uptake, as calculated in step 1, is divided by the total root length of those compartments (category 2) that were able to satisfy the required uptake rate of step 1. This yields an additional uptake rate. The required uptake rate for compartments of category 2, in step 2, now equals the required uptake rate of step 1, augmented with

TABLE 1. Horizontal distribution of root length density in cm/cm^3 at 5 cm depth at four times.

a. Distribution based on observations by Hairiah and Van Noordwijk (1986), used for the standard and deep root system.

	Distance from plant row in cm (soil column)				
Time in weeks from sowing	5 (1)	15 (2)	25 (3)	35 (4)	45 (5)
2	3.0	0.4	0.1	0.0	0.0
5	3.5	1.5	0.4	0.1	0.0
8	4.0	2.6	1.2	0.2	0.0
14	4.5	3.7	2.2	0.5	0.1

b. Assumed distribution for the wide root system.

	Distance from plant row in cm (soil column)				
Time in weeks from sowing	5 (1)	15 (2)	25 (3)	35 (4)	45 (5)
2	3.0	0.4	0.1	0.0	0.0
5	3.5	1.0	0.6	0.3	0.1
8	3.5	2.0	1.2	0.8	0.5
14	3.5	2.5	2.2	1.8	1.0

the additional uptake rate. With this uptake rate for each compartment of category 2, C_0 is calculated, and it is examined if the compartment can satisfy the required uptake. If not, roots in such compartments behave as zero-sinks. If all compartments of category 2 can satisfy the required uptake of step 2, total uptake equals demand and the iteration ends. If none of the compartments of category 2 can satisfy the required uptake of step 2, i.e. if in all compartments of category 1 and 2 zero-sink uptake occurs, the iteration also ends. If only a part of the compartments of category 2 can satisfy the required uptake of step 2, iteration proceeds to step 3, etc.

This calculation procedure implies that roots growing under favorable conditions will compensate as much as possible for roots growing under less favorable conditions. It is thus assumed that information about the necessary behavior, as far as uptake is concerned, is instantaneously available throughout the complete root system.

MODEL RESULTS

Dry matter yield and nitrogen recovery under standard conditions

Model calculations for a situation resembling actual experiments in Onne were compared with actual results of N-uptake by the crop as a function of N-fertilization. Maize was grown in a nitrogen fertilizer trial with five treatments: 0, 45, 90, 135 and 180 kg/ha. Row width was 100 cm, plant spacing in the row 25 cm. Nitrogen was given in the form of ammonium nitrate in three split applications and placed about 20 cm from the plant. In our model all fertilizer was added to column 2. As no information was available on the mineral nitrogen content of the soil at the start of the growing season, this parameter was used for roughly calibrating the N uptake without fertilizer addition; an initial amount of 20 kg/ha seems reasonable.

Figure 4 shows the measured and calculated time course of dry matter production of maize, for a fertilization rate of 90 kg/ha (only in this treatment was the time course of dry matter determined). A reasonable fit appears to exist between calculations and measurements.

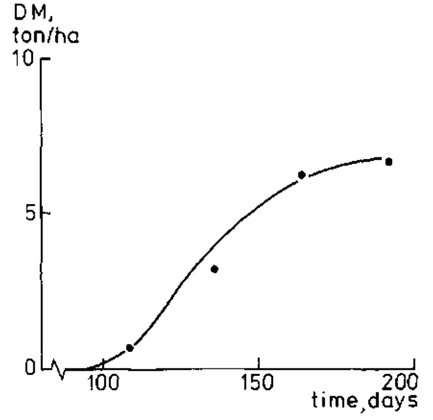

FIGURE 4. Time course of dry matter production of a maize crop at Onne, as calculated (line) and as measured, at an N-fertilization rate of 90 kg/ha. Data of Van der Heide (pers. comm.).

As shown in figure 5, the model also reasonably well describes final nitrogen uptake as a function of application rate in the experiment, although the efficiency of nitrogen use is overestimated. Uptake without fertilizer use is slightly underestimated (calculated 37 kg/ha, measured 41 kg/ha), uptake at intermediate fertilizer application levels is overestimated.

Different root distributions

The model was subsequently used for examination of the effects of root distribution, under various conditions of localization and time-distribution of the nitrogen fertilizer, and for a large range of fertilization rates. Table 2 summarizes the results. It gives the amount of fertilizer required to achieve a nitrogen uptake of 85 kg/ha, which corresponds to a yield of 6.5 t/ha, or about 90% of the potential yield, and the recovery of the fertilizer nitrogen.

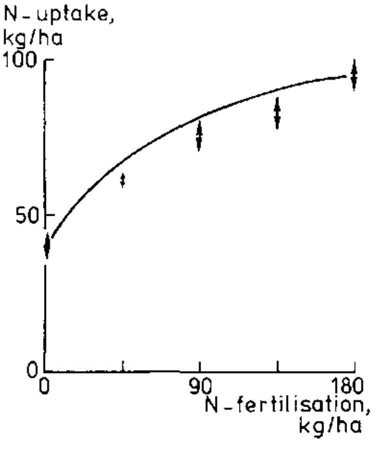

FIGURE 5. Nitrogen uptake as a function of N-fertilization in experiments at Onne; calculated uptake (line) is compared with experimental results, the vertical lines indicate the range of the experimental results. Data of Van der Heide (pers. comm.).

TABLE 2. Application rate of fertilizer nitrogen in kg/ha required to obtain a yield of 6.5 t dry matter per ha (90% of potential yield), and in brackets percentage recovery of fertilizer nitrogen. Br = broadcast, Lo = localization of fertilizer at 20 cm from plant, Sp = fertilizer applied in three splits, Nsp = application at start of growing season.

	Treatment					
	Uniform infiltration				Non-uniform infiltration	
Root system	Br Nsp	Br Sp	Lo Nsp	Lo Sp	Br Sp	Lo Sp
Standard	300(16%)	130(37%)	300(16%)	95(51%)	100(48%)	70(69%)
Deep	90(41%)	75(49%)	90(41%)	50(74%)	75(49%)	45(82%)
Wide	250(18%)	90(49%)	300(15%)	80(55%)	90(49%)	65(49%)

According to the calculations, crops with a deep root system need much less nitrogen fertilizer to realize a yield of 6.5 t/ha than crops with either of the other two root systems. The wide root system usually gives somewhat better results than the standard root system, except where fertilizer is placed and given as a basal dressing.

Uptake without N-fertilization for both the wide and the deep root system was higher than that for the standard root system, viz., 41, 48 and 37 kg/ha, respectively. The wide root system occupies the whole topsoil faster than the standard root system and thus utilizes mineralized nitrogen in column 5 more efficiently; the deep root system recovers nitrogen leached to deeper soil layers in the initial growth period.

Synchronization

Under climatic conditions with a continuous surplus of rain during the growing season, synchronizing the fertilizer supply with crop demand is very important; comparison of columns 1 and 2 of table 2 shows that if all N would be given at sowing, much more nitrogen would have to be applied to obtain a yield of 6.5 t/ha than when it would be given in three equal splits. By further increasing the number of splits, recovery could be improved; labor costs of such spoon-feeding would have to be evaluated as well as the benefits.

Synlocalization

The data in columns 3 and 4 of table 2 show that localization of fertilizer is only beneficial if it is combined with split application. As might be expected, the N recovery of the wide root system improves when N is broadcast. Localization closer to the plant, in the first instead of in the second column, would give higher recoveries, but osmotic problems of high salt concentrations close to the seed may limit applicability of such localization.

Nonuniform infiltration

If it would be possible to reduce infiltration in the immediate vicinity of the plant, for instance by ridging and/or by covering the soil surface with a mulch of plastic or banana leaves, one would expect that higher recoveries could be obtained. To calculate the effect of a modified pattern of infiltration, the average infiltration rate was multiplied by a factor of 0.33, 0.67, 1.0, 1.33 and 1.67 for the five soil columns, respectively. As the last two columns of table 2 show, a considerable improvement of recovery might be obtained in that way, especially when fertilizer is localized. In this case, localization of the fertilizer within 10 cm of the plant would give even better results.

DISCUSSION

As shown in figure 5, the relation between amount of N applied and amount taken up by the crop is curvilinear. If different amounts of nitrogen are applied in a constant number of splits, such a curvilinear response may be expected for conditions of high precipitation surplus, because of the small buffering capacity which protects only a small absolute amount of N against leaching.

Calculated apparent N-recoveries as shown in table 2 give an indication of the prospects for improving N-efficiency in actual practice. To obtain the same production, the amount of N required varies between 45 and 300 kg/ha, with efficiencies of 82% and 16%. The experimental techniques chosen, split application and localization (column 4 in table 2), obviously are much better than broadcast application as a basal dressing (column 1). Further improvement may be possible, however.

With current fertilization techniques, manipulation of rooting depth would have a positive effect on N-recovery. Cultivar selection for tolerance to acid soil conditions may be the safest way to achieve a deeper root development, because increasing soil pH by liming would lead to increased N-mobility and leaching (De Willigen, 1985). Selection for a more rapid colonization of the whole top layer by a more laterally developed root system would only be effective in the case of broadcast fertilizer application. If the N-source consists of decomposing (leguminous) cover crops, localization would not be possible to the same extent as with fertilizer as the N-source.

Manipulating the pattern of infiltration, in combination with localization of the N-source near the plant, would be effective. Split application of fertilizer N might not be required if leaching through the zone near the plant could be reduced. Practical ways of achieving such a heterogeneous infiltration will now be investigated in new field experiments.

A question is how homogeneous the actual infiltration pattern in the field is. Heterogeneity of infiltration is much more important for solutes than for water itself; the whole topsoil will be water-saturated after heavy rainfall, regardless of the infiltration pattern. In practice, infiltration will be influenced by local relief and topsoil structure as well as by characteristics of the plant canopy. Stem-flow, especially for plants such as maize where the leaves may lead a water film onto the stem during rain, may concentrate water around the plant; drip-tips of leaves may have an umbrella effect, increasing infiltration between the plants. Localization of fertilizer at 20 cm from the stem might prove to be the best practice in that situation. Remarkably little research appears to have been done on such aspects of crop canopies.

Mixed cropping of maize and cassava under the conditions at Onne leads to an increased efficiency of N use, at least partly because of the deeper root development of cassava (Hairiah and Van Noordwijk, 1986). Cassava thus utilizes nitrogen leached from the root zone of maize. Alley-cropping (Kang et al., 1985) with certain tree species may have a similar positive effect on N-use efficiency, although selection of trees with suitable root systems requires local research on each soil type. Our analysis shows that detailed information on root length distribution of crops is important for understanding nitrogen use efficiencies in the highly dynamic situation in the humid tropics. In climates where leaching losses are negligible during the growing season, details of root length distribution are less important. There, even a sparse root system can take up all nitrogen (nitrate) at the required rate, at least when the soil is not too dry (De Willigen and Van Noordwijk 1987).

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ROOT DISTRIBUTION OF LEGUMINOUS COVER CROPS IN THE HUMID TROPICS AND EFFECTS ON A SUBSEQUENT MAIZE CROP

Key words: Leguminous Cover Crops Shoot: root Ratio Root Distribution Mucuna pruriens utilis Vigna unguiculata Pueraria phaseoloides Centrosema macrocarpum Desmodium ovalifolium Calopogonium mucunoides Crotalaria anagyroides Crotalaria juncea

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Abstract

Leguminous cover crops can be used in the humid tropics to increase the production of subsequent food crops, through effects on nitrogen availability in the soil, suppression of weeds and/or changes in soil physical conditions. Nodulation, total root and shoot mass and depth of root development are important characteristics of cover crops.

Root development of several cover crops is described here for two sites with acid soils, in S.E. Nigeria and S. Sumatera, Indonesia. Short-lived annual species have a higher shoot: root ratio than perennial species. *Mucuna pruriens utilis* had the most shallow root system, but good nudulation and, through its fast growth, it was best in suppressing weeds (in a 4-month period).

Mucuna and *Crotalaria juncea* gave the best effect on a subsequent maize crop in an experiment on a dark grey alluvial soil in Malang, E. Java, Indonesia. Apart from being a source of N, the cover crops also had a positive effect on subsequent maize growth by increasing water storage in the soil and by improving root development of maize.

Introduction

In the humid tropics leaching of N and other nutrients to the subsoil may occur throughout the growing season. Efficiency of N-use under such conditions is often very low, due to lack of synchronization of crop demand for N with the mineralisation rate. The ability to develop deep root systems is important in this situation for recovery later in the growing season, of nutrients leached early on (Van Noordwijk, 1989). There may be variation in the demand curve of the crop and in the mineralisation rate, due to differences in soil microclimate or other factors (figure 1). Complete synchronization of supply and demand is almost impossible. The larger the difference between supply and immediate demand, the lower the adsorption of the nutrient to the soil and the higher the rainfall during the growing season, the deeper the nutrient will leach into the soil. Rooting depth required to recover nutrients leached early in the growing season will vary accordingly. Deep-rooted cover crops in the crop rotation may be helpful to recover leached nutrients.

Leguminous cover crops can provide N-rich organic matter to the soil and thus decrease the need for N-fertilizer (Greenland, 1985). Apart from the direct N-supply to the next crop, cover crop biomass may improve soil physical conditions (Bouldin, 1988). Aboveground biomass production of cover crops is important as a source of organic matter and for its effects on weed growth. The root system of the cover crop is important for recovering nutrients from deeper layers and possibly for improving soil conditions for and root development of subsequent food crops. To be usefull as an intercrop between food crops, the cover crop should have few roots in the topsoil.

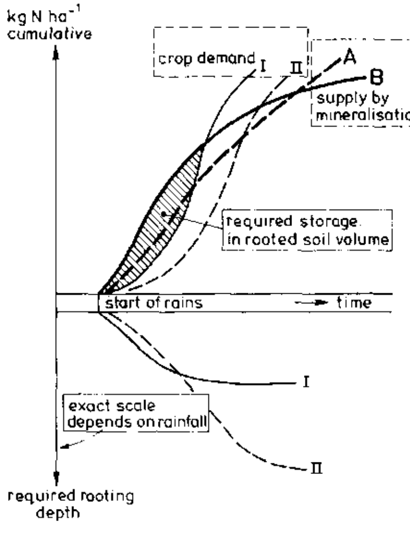

Figure 1. Schematic interactions between degree of synchronization of supply of nutrients by mineralisation and crop demand for N (upper part of the figure) and the rooting depth required for full recovery of leached N (lower part of the figure). Two situations of demand, a rapidly (I) and a slowly (II) establishing plant, and two situations of supply, a fast (B) and a slow (A) mineralisation rate, are shown.

The purpose of the research, presented here, was to select cover crops, to be used in crop rotations, with the following characteristics:

- rapid plant establishment and high biomass production, yielding a good soil cover and good weed control,
- deep root development,
- good nodulation and N-fixation.

Results will be discussed here for three locations: Onne (S.E. Nigeria), Ketapang (S. Sumatera, Indonesia) and Malang (E. Java, Indonesia). In Malang the effects of cover crops on a subsequent maize crop were tested as well.

TABLE 1. Soil properties of the fields used for cover crop experiments; O = Onne (S.E. Nigeria), K = Ketapang (S. Sumatera, Indonesia), M = Malang (E.Java, Indonesia)

Soil depth (cm)	pH (H_2O)	pH (KCl)	% N	% C	C/N	P-Bray II (ppm)	Exch. Cations (1 N NH_4OAc, me/100 g) K	Na	Ca	Mg	Total (me/100 g)
O 0 - 5	4.5		0.111	1.78	16.0	78.7	0.17	0.21	1.03	0.46	1.64
5 - 15	4.5		0.071	1.31	18.5	54.0	-	0.19	0.64	0.21	1.80
15 - 25	4.5		0.061	0.98	16.1	47.7	-	0.16	0.74	0.05	2.01
25 - 40	4.5		0.082	0.73	8.9	46.8	-	0.24	0.56	-	2.05
K 0 - 3	6.10	5.20	0.14	1.73	12.3	5.0	0.75	0.66	2.80	2.25	
3 - 29	4.60	3.80	0.06	0.43	7.2	3.0	0.12	0.21	1.85	0.45	
29 - 66	4.80	3.80	0.03	0.18	6.0	1.0	0.10	0.37	2.55	0.30	
M 0 - 30	7.40	5.90	0.15	1.71	11.4	5.0	0.45	0.44	11.10	5.85	
30 - 60	7.20	5.80	0.11	1.02	9.30	2.0	0.65	0.58	10.88	5.10	

Soil depth (cm)	CEC (me/100 g)	Sand (%)	Silt (%)	Clay (%)	Texture	Bulk density (g/cm^3)	Particle density (g/cm^3)	Porosity (%)
O 0 - 5	3.53	83	13	4	loamy sand	1.40 ± 0.14		
5 - 15	2.90	83	13	4	loamy sand	1.50 ± 0.08		
15 - 25	3.10	77	12	11	sandy loam	1.48 ± 0.05		
25 - 40	2.99	73	10	17	sandy loam	1.40 ± 0.08		
K 0 - 3	7.4	74.5	12.0	13.5	sandy loam			
3 - 29	6.5	64.1	12.8	23.1	sandy clay loam			
29 - 66	7.3	63.1	12.2	24.8	sandy clay loam			
M 0 - 30	45.00	17.00	39.00	44.00	clay	1.14	2.06	44.53
30 - 60	46.78	46.00	27.00	27.00	sandy clay loam	1.30	2.28	42.92

Methods

Soil properties at the three sites are shown in table 1. The Malang site (annual rainfall about 1800 mm) has a dark grey alluvial soil of high pH, high CEC and low P-status. Ketapang and Onne (annual rainfall about 2200 and 2400 mm, respectively) are ultisols: acid, low-activity loamy soils with low CEC and clay content increasing with depth. The Onne soil is remarkably rich in P.

Onne: Plots with leguminous cover crops for root observations were sown at IITA's high-rainfall substation at Onne (Port Harcourt), S.E. Nigeria in April 1985. The experimental site was mechanically cleared of forest and tree stumps more than 10 years before, and had been under continuous mechanized farming. Before the cover crops experiment was started, the area was covered by a natural grass fallow, which was cut regularly. Six species of leguminous (cover) crops were used (nomenclature following Allen and Allen, 1981): *Centrosema macrocarpum* Benth. (CIAT 5062), *Desmodium ovalifolium* Wall. ex Merr. (CIAT 3784), *Pueraria phaseoloides* (Roxb.) Benth., *Psophocarpus palustris* Desv., *Mucuna pruriens* (L.) DC. var. *utilis* (Wall. ex Wright) Backer and *Vigna unguiculata* (L.) Walp.. In the experiment the effect of liming (CaCO3, 1 t/ha) was tested (Hairiah and Van Noordwijk, 1986). Samples of the root system were taken with a pinboard at 2, 5, 8 and 14 weeks after sowing. At the same dates aboveground biomass was sampled from three rows of 1 m length in each plot. Both samples were dried at 65 C and weighed.

Ketapang: Six species of leguminous cover crops were used: *Centrosema pubescens* Benth., *Pueraria phaseoloides* (Roxb.) Benth. (= *P. javanica* Benth.), *Calopogonium mucunoides* Desv., *Mucuna pruriens* (L.) DC. var. *utilis* (Wall. ex Wright) Backer, *Crotalaria anagyroides* HBK, and *Crotalaria juncea* L. Samples of the root system were taken with a pinboard 8 months after planting (MAP), except for *Mucuna* which was taken at 5 MAP. Root patterns from washed pinboard samples were copied on a fine-grid paper.

Malang: The experiment (Hairiah, 1987) was carried out during the rainy season. The experimental site had been used as a sawah (paddy field) for lowland rice under traditional cultivation for a long period. Before the cover crops were planted the area was covered by *Imperata cylindrica* and some other weeds. Four species of leguminous cover crops were used: *Centrosema pubescens* Benth., *Mucuna pruriens* (L.) DC. var. *utilis* (Wall. ex Wright) Backer, *Crotalaria juncea* L., *Calopogonium mucunoides* Desv.; a maize crop fertilized with 125 kg N/ha, 45 kg P_2O_5/ha and 30 kg K_2O was used as control. The experiment was laid out as a randomized, complete design with 3 replications and a plot size of 6 x 2 m^2. Aboveground biomass was incorporated into the soil after 3 months and incubated for 2 weeks; biomass of maize in the control plot was removed and the soil was cultivated in the same way as the cover crop plots. Maize was sown in the second season; all plots received a basal application of P (as triple superphosphate) and K (as KCl) at a rate of 100 kg/ha each. Average rainfall was 2.4, 10.9 and 10.2 mm/day, respectively, for the three months in which the cover crops were grown, 8.6 mm/day for the incubation period and 3.5, 3.9 and 0.16 mm/day respectively for the three months of maize growth. Three randomly chosen plants from each plot were harvested at 2, 4, 8 and 13 weeks after planting; a mixed sample was made for N and P analysis. Washing roots from this soil proved to be difficult and maize root distribution was studied by mapping root distribution in a vertical and in a horizontal plane, 8 weeks after planting. In the same soil pits soil bulk density, available water content (between pF 2.5 and pF 4.2) and penetration resistance were measured.

Results and discussion

Onne

Figure 2 shows the shoot: root ratio, based on dry weights, for the six species, in the 14-week observation period. In the initial stages all species had a shoot: root ratio of 4, but later in *Vigna* and *Mucuna* root growth almost stopped while shoot dry weight continuously increased, leading to a shoot: root ratio of about 12. The other species maintained a shoot: root ratio of 4, or even decreased it to 2. At 14 weeks *Centrosema*, *Pueraria*, *Psophocarpus* had the greatest root dry weight and *Mucuna* and *Vigna* the greatest shoot production.

Mucuna and *Vigna* exhibited fast growth and early senescence, a low shoot: root ratio and a relatively high N-concentration in the shoots. These crops may benefit from the flush in N-mineralisation at the start of the rains through rapid uptake; they may be suitable as a short-term cover crop, releasing N from decaying biomass in the second part of the growing season. Their root development and consequently their chances of

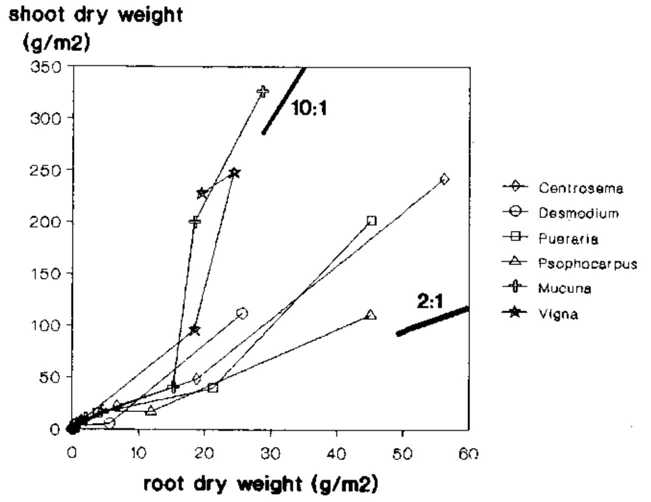

Figure 2. Shoot: root ratio of the six cover crops in Onne (Hairiah and Van Noordwijk, 1986).

TABLE 2 Biomass production, nutrient concentrations (on a dry-matter basis) and estimated total nitrogen content of cover crops, 14 weeks after planting in Onne (Hairiah and Van Noordwijk, 1986).

	N %	P %	K %	Ca %	Biomass t/ha	Sh.:root ratio	N-content kg/ha
Mucuna	3.0	0.23	1.23	0.21	3.42	14	110
Vigna veget.	1.8	0.22	1.00	0.21	2.30	10	45
,, pods	3.2	0.22	0.43	0.02	1.26	-	40
Centrosema	2.2	0.23	0.82	0.33	2.18	3.8	60
Pueraria	2.5	0.24	0.95	0.21	2.02	4.4	62
Psophocarpus	2.8	0.26	0.92	0.21	1.03	2.2	42
Desmodium	2.0	0.16	0.79	0.19	1.02	3.5	26

recovering leached nutrients are not impressive. *Pueraria* established itself relatively slowly but showed the best nodulation of the six species tested. *Centrosema* had poor nodulation, but developed the deepest root system (70 cm). *Psophocarpus* and *Desmodium* proved to be unsuitable under these conditions as they started slowly and had to be weeded frequently.

The liming treatment had little effect on root distribution and shoot growth (Hairiah and Van Noordwijk, 1986). Table 2 summarizes the N-contribution to the soil of above- plus belowground cover crop residues. No effort was made to separate N-fixation from soil N-uptake. For *Mucuna* the highest N-contribution to the soil was found, 110 kg/ha, and for *Desmodium* only 26; for the other species 40 to 60 kg/ha was found, assuming *Vigna* pods to be removed from the field.

Ketapang

Figure 3 shows the root development of cover crops at maximum growth as observed from pinboard samples. The root system of the six cover crops had the same overall shape with a vertical taproot and abundant branch roots in the topsoil; there were, however, marked differences in depth of root development (table 3). Remarks on the general performance of six cover crops are further summarized in table 3.

Species with creeping stems and fast initial development, as illustrated by *Mucuna* and to a lesser extent by *Calopogonium*, gave good initial weed control. The erect *Crotalaria* species do not directly cover the soil but it may shade out the weed *Imperata* in the longer run. *Mucuna* and *Calopogonium* had a shallow root system; their deepest roots reached a depth of about 50 cm; *Crotalaria* roots went deeper, with the deepest roots at about 80 cm. The other species developed too slowly to control all weeds initially; once established, however, they may be interesting because of a deep root development (*Centrosema*) or good nodulation (*Pueraria*). The rooting depth of *Centrosema* and *Pueraria* was about 80 cm.

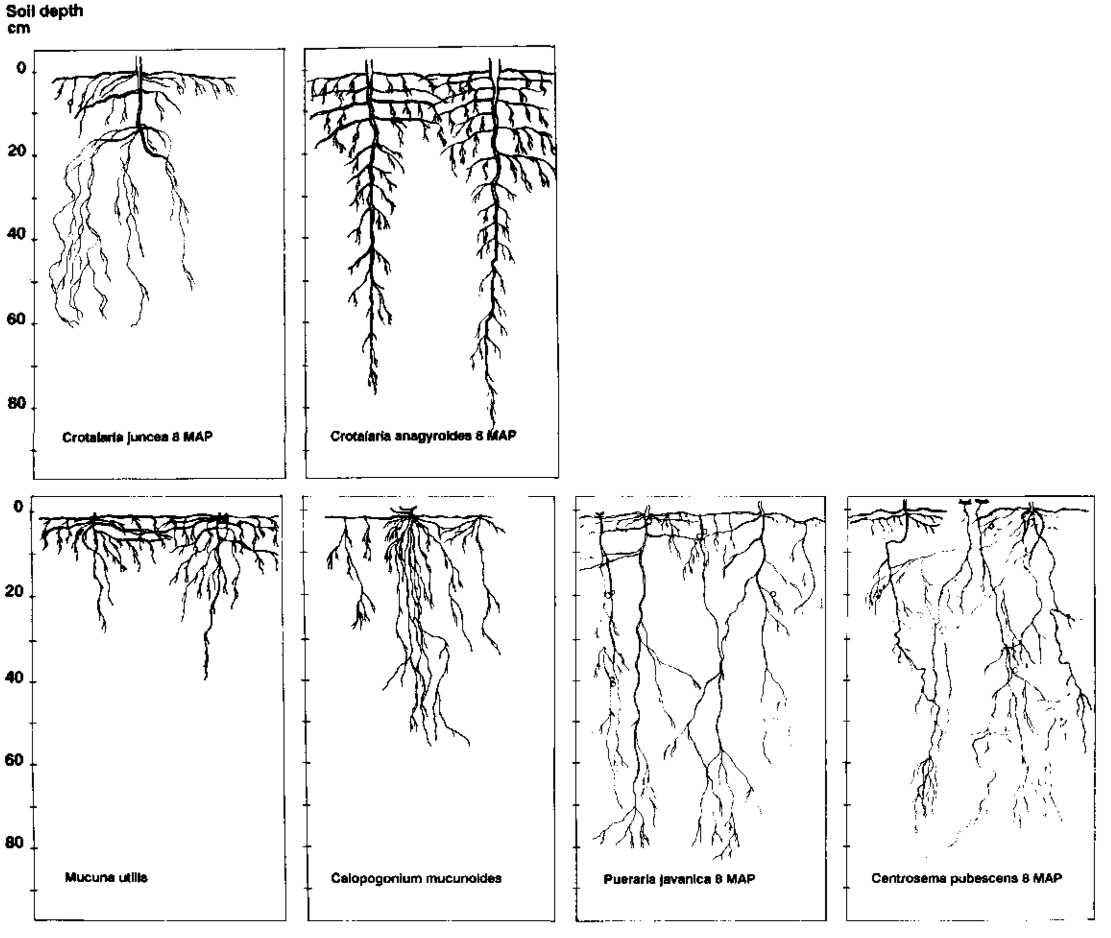

Figure 3. Root development of cover crops in Ketapang as observed from pinboard samples 8 months after sowing (Mucuna at 5 months) (Hairiah and Van Noordwijk, 1987).

TABLE 3. Observations on cover crop development in Ketapang S. Sumatera, sown in january after the start of the rains; form: c = creeping, e = erect; I.g. = initial growth: ++ = fast, + = good, 0 = slow; I4 and I8 = *Imperata* control at 4 and 8 months, respectively: ++ = good, + = limited and 0 = poor; r = *Imperata* regenerating.

Species	Form	Duration	I.g.	I4	I8	Root system & nodulation
Mucuna p. uti.	c	5 months	++	++	+(r)	shallow, many nodules
Calopogonium m.	c	perennial	+	++	0	rather shallow, few nod.
Crotalaria jun.	e	8 months	+	+	++	deep branch root, few nod.
Crotalaria ana.	e	perennial	+	+	++	deep tap root, few nodules
Centrosema pub.	c	perennial	0	0	+	shallow rhizomes, deep branc
Pueraria phase.	c	perennial	0	+	+	roots, nodules in subsoil too

Malang

In the experiment in Malang four cover crop species were used in the first part of the growing season, with a fertilized maize crop as the control. Table 4 shows the total N-contribution of the cover crops to the soil. It was calculated as N-concentration times measured above-ground dry weight of each crop; roots were included by using estimated shoot: root ratios. The highest N-concentration (on a dry-weight basis) was found in the *Mucuna* biomass, but the highest biomass production and N-contribution to the soil was obtained from *Crotalaria*. N-input in the control plot was calculated to be 125 kg/ha as fertilizer minus N-uptake, which was 44.5 kg/ha.

TABLE 4. N-contribution of legume cover crops to the soil.

	Dry weight (t/ha)	N-content (%)	C : N	shoot: root	N-contr. (kg/ha)	N : P
Centrosema pubescens	1.37	2.08	17	4	36	5.5
Mucuna utilis	3.62	2.85	20	12	71	4.7
Crotalaria juncea	9.08	1.87	23	4	198	6.0
Calopogonium mucunonoides	2.54	2.04	18	4	65	5.2

During the second season maize was grown as a test crop and a number of soil parameters were measured (Figure 4). Bulk density and soil penetration resistance were lower for the cover crop/maize plots than for the maize/maize plots in the zone 0 - 20 cm depth. The "available water" content, stored between pF 2.5 and 4.2, was also higher. These measurements were only performed in a single plot for each treatment, along with the root observations, so no statistical reliability can be given for the differences.

Table 5 shows that statistically significant effects between pre-cropping with various cover crops and maize gradually emerged. After four weeks (4 WAP), *Mucuna* as a pre-crop had a significant, positive effect on dry weight of maize; at 8 WAP *Crotalaria* as a pre-crop resulted in significantly higher maize biomass as well. At harvest time (13 WAP) all four cover crop plots gave a significantly higher grain yield than maize as a pre-crop; the *Mucuna* plots gave the best results, followed by the *Crotalaria* plots.

Figure 5 shows that the N and P concentrations in aboveground biomass of maize gradually decreased during the growing season. Only at 4 WAP, were differences in N-concentration between treatments apparent. The relatively high harvest index for N on the control plots (table 6) suggests that the control maize plants were N-limited, at least in the last part of the growing season. N-concentration in the grain did not differ between treatments (table 5), but control plants remobilized a larger part of their N-content to the grains. P-concentrations in maize tended to be high in *Mucuna* plots throughout and low in *Calopogonium* plots (Figure 5). The harvest index for P (table 6) suggests that maize following

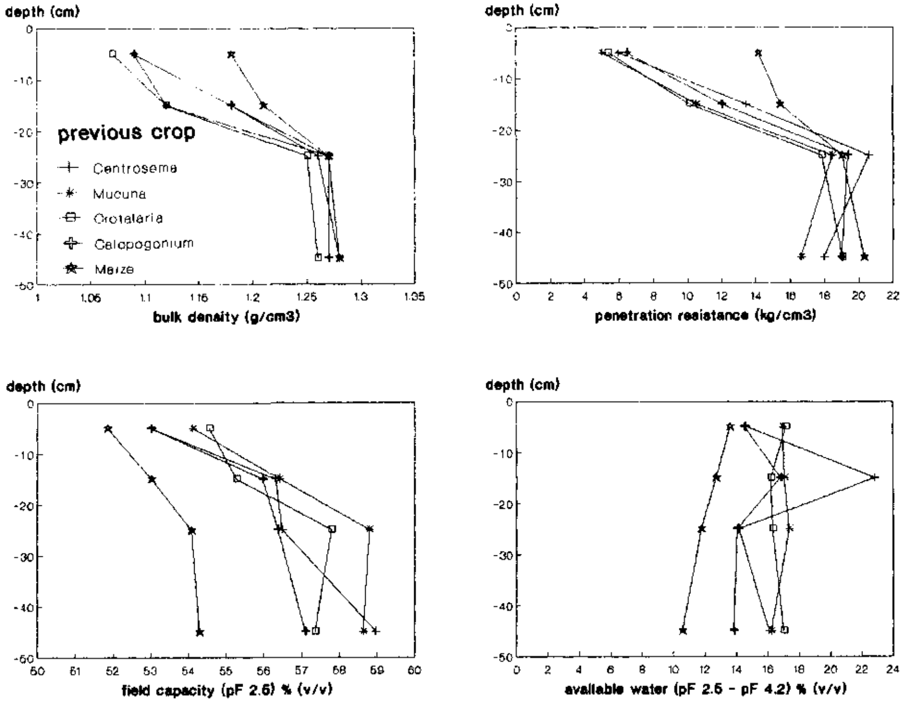

Figure 4. Bulk density, penetration resistance, field capacity and available water content of the soil of maize plots which had 4 different cover crops and maize as preceding crops.

TABLE 5. Dry weight of maize (second season) as influenced by preceding crop. Values followed by the same letter do not differ significantly (p=0.05).

Preceding crop	Dry weight of total biomass (t/ha) at 2	4	8	13 WAP	Grain dry weight	%N
Mucuna utilis	0.011a	0.027b	5.6c	14.7c	4.0d	1.6a
Crotalaria j.	0.006a	0.020a	4.6b	12.9bc	3.1c	1.7a
Calopogonium	0.007a	0.019a	2.8a	10.1b	2.4b	1.7a
Centrosema p.	0.008a	0.020a	2.5a	8.8ab	2.1b	1.6a
maize-control	0.007a	0.015a	2.5a	4.8a	1.4a	1.6a

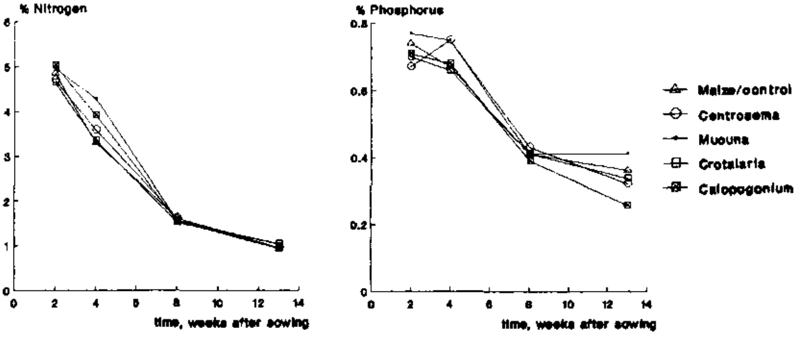

Figure 5. Nitrogen and phosphorus concentrations in aboveground biomass (N and P as of dry weight) of maize during the growing season.

Calopogonium and *Centrosema* was more P-stressed than maize on the other plots, including the control plots (which had received a P dressing in the first maize season as well).

Maize root distribution was observed 8 weeks after planting. The rooting pattern of maize following cover crops differed from that of maize after maize. The vertical root maps in figure 6 show that the *Crotalaria* plot gave the highest, and the control plots the lowest root density. In the control plots roots of neighbouring plant rows hardly intermingled. The horizontal root maps at a depth of 10 cm in figure 6 show that some space on the map of the control plot is still empty; empty spaces indicated more possibilities for nutrients leaching to deeper layers.

The fact that maize yields were more than doubled by a cover crop in the preceding season suggests that, in the absence of N-fertilizer, growing a non-food cover crop for half the year might even be profitable: it increased maize production per ha per year. There are several possible explanation for the positive yield effects of a preceding cover crop: increased N-supply, increased water storage, improved root development of the test crop, fewer weeds, pests and diseases.

In table 6 the N-balance of maize as affected by the preceding crop is given. The extra N-uptake by maize on a plot with a cover crop as the preceding crop is compared with the N-input from the first seasons crops. Excess N-uptake and calculated N-input were of the same magnitude, but the order of *Mucuna* and *Crotalaria* differed. *Crotalaria* gave the highest cover crop biomass and highest N-input, and resulted in the highest (second season) maize root density. Yet, *Mucuna* had an even stronger effect on maize production. Due to the relatively high C : N ratio of *Crotalaria*, about 23, a relatively slow decomposition may be expected. For *Mucuna* we assume either that the N-input was underestimated by neglecting N-release into the soil during the *Mucuna* growth, or that improved rooting made soil N from deeper layers available. Unfortunately no information was obtained on the amount of N fixed from the atmosphere and that taken up from the soil.

Yield effects on the maize through effects on weeds, pests or diseases could not be excluded, but no diseases were observerd, and weed

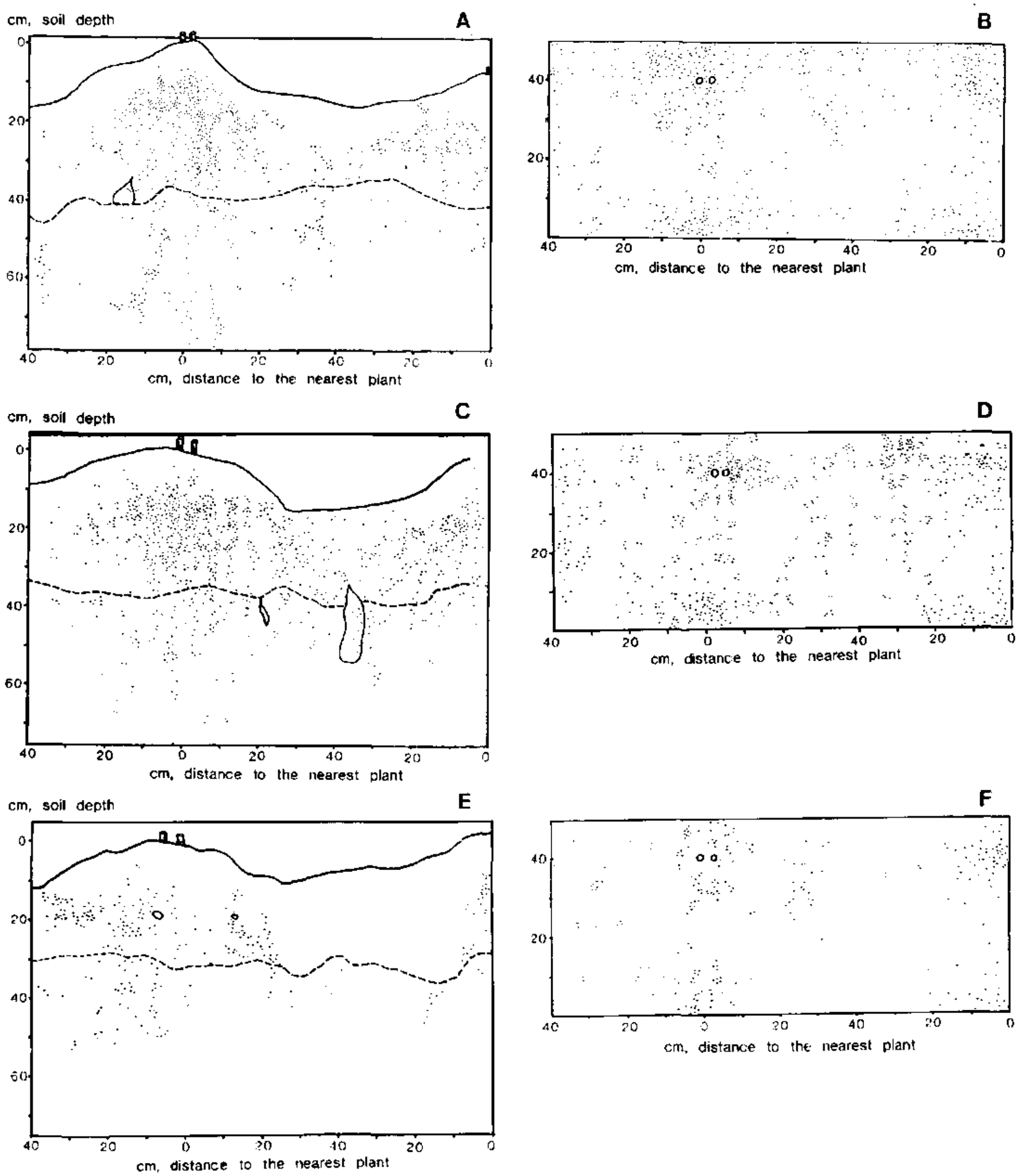

Figure 6. Distribution of maize roots on vertical (A,C,E) and horizontal (B,D,F) root maps, at 8 WAP, on plots with different preceding crops: *Mucuna* (A,B), *Crotalaria*(C,D) and maize (E,F).

TABLE 6. N-input from preceding crop, excess N-uptake relative to control plots and harvest indices (fraction of total N or P content or dry weight found in the grains at harvest), for maize in the second season.

Preceding crop	N-input kg/ha	Excess N-uptake	------Harvest index------- N	P	dry weight
Mucuna p. uti.	71	147	0.29	0.38	0.21
Crotalaria j.	198	121	0.28	0.37	0.19
Calopogonium	65	67	0.30	0.45	0.19
Centrosema p.	36	52	0.29	0.40	0.19
maize-control	80	0	0.33	0.38	0.23

levels were kept low in all plots. Positive yield effects on the maize may have resulted in part from improved water storage in the soil, especially in the final part of the maize growing season, with low rainfall. Such positive effects, which cannot be replaced by fertilizer supply, are relevant in high-input agriculture as well (Bouldin, 1988). The better rooting of maize following a cover crop may have been a combined result of a higher N-supply and improved soil physical conditions. In the second part of the growing season improved root development probably contributed to better use of water, stored in deeper layers, and hence to higher production.

Conclusions

Positive effects of cover crops in a crop rotation are not only confined to their N-contribution to the soil: weed control, improvement of soil physical conditions and improved root development of the food crops can be relevant as well. The choice of a cover crop for a particular cropping system should depend on the most important aspect. For the cover crops tested here the following conclusions can be drawn:
Mucuna grew fast and aged quickly on both the acid soils and on alluvial soil. It had a shallow root system with many nodules on the acid soils. On the alluvial soil it had the best yield effect on a subsequent maize crop.
Crotalaria grew fast on the acid soil in Lampung and on the alluvial soil at Malang. It had a deep and well-branched root system on the acid soil, with few nodules.
Pueraria established itself relatively slowly and showed the best nodulation of all species tested, on both acid soils.
Centrosema had a slow start on the acid soils as well as on alluvial soils; it had a deep and well-branched root system.

Mucuna and *Crotalaria* were shown to be the most suitable species as short-term cover crop in a rotation with maize. If *Mucuna* species with a deeper root system on acid soils could be discovered with a possible improvement of Al tolerance and/or better ability to penetrate dense soil layers, positive effects on following crops may even become greater.

Acknowledgements

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CHANGES OF NUTRIENT CONCENTRATION IN THE SOIL SOLUTION AND OF NUTRIENT STATUS UNDER DIFFERENT CROPPING SYSTEMS IN SOUTHERN NIGERIA.

Key words: NO_3, K, Soil solution, Fertilizer efficiency.

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SUMMARY

NO_3-N and K concentrations in the soil solution of three soils (Entisol, Alfisol, Ultisol) under different cropping systems in southern Nigerial were monitored by means of ceramic soil solution probes. A knowledge of the actual nutrient concentration in the soil solution and its changes during the growing season is desirable because it indicates the state of availability and its change under a crop.

The highest concentrations were found in the top layer with a sharp decrease towards the deeper layers. The NO_3-N and K concentrations invariably decreased very rapidly and reached a very low minimum already at mid season. This means that split doses of fertilizer dressings are called for in order to ensure an adequate nutrient supply during the whole growing season. Fertilizer applications during the growing season were rapidly taken up by the crop so that even under high rainfall conditions no leaching losses occurred.

INTRODUCTION

Bush fallow and shifting cultivation, the traditional farming system in most parts of the humid tropics has proved to be a stable agricultural system with respect to maintaining soil fertility, if, however, at a low level. Because of population pressure this system is gradually being abandoned and replaced by some form of permanent cultivation. As a consequence the delicate equilibrium between soil, vegetation and climate with regard to nutrient withdrawal and regeneration of the nutrient status is disrupted and soil fertility tends to decline (Sanchez, 1981). There is ample evidence to support such view (Friedman, 1977).

It is, however, possible to establish a stable productivity level with permanent cultivation by adopting appropriate cropping systems, such as alley cropping and by applying inputs adjusted to the yield target as well as to the ecological and the socio-economic situation. Apart from the longterm strategy there are also shortterm factors that have to be considered. Large areas of the humid and subhumid tropics consist of highly weathered soils which are characterized by low nutrient and waterholding capacities (Greenland, 1981). Low activity clay and rapid turnover of organic matter are primarily responsible for the low nutrient reserves and low nutrient storage capacity. The dominance of large pores (= transmission pores > 50 μ) is the major reason for the low available water holding capacity. This combination of soil factors together with high rainfall intensity and intervening dry spells often results in rapid changes of nutrient concentrations in the soil solution and suggests nutrient losses through leaching during the early growing season.

In order to study the changes of soil nutrient status and of nutrient concentrations in the soil solution a collaborative research project, which is now in its second phase, was set-up at IITA (Grimme et al., 1983).

MATERIALS AND METHODS

The experiments were established on three different soils (Entisol, Alfisol, Ultisol), two climatic zones of southern Nigeria (subhumid, Ibadan; humid, Port Harcourt and with different permanent cropping systems (rotation, mixed-cropping, alley cropping) in which fertilized and non-fertilized treatments were compared.

Soil solution probes and tensiometers were installed in the cropped fields with a vertical spacing of 10 cm down to a depth of 120 cm to monitor changes in soil moisture content and nutrient concentration in the soil solution as a function of time during the cropping period (for a detailed description of the methodology: Strebel et al., 1980; Grimme and Juo, 1985). The soil solution was sampled in irregular intervals (1-3 weeks) depending on available soil water content. Soil samples were taken for the determination of soil nutrient contents and soil water content (construction of soil moisture retention curves).

From each of the experimental sites a typical example will be presented. Of the nutrients only NO_3 and K will be considered.

RESULTS

Changes of NO_3 and K concentrations in the soil solution of an Alfisol under maize.

There were two treatments, unfertilized and fertilized. The fertilized plots were dressed with 120 kg N, 60 kg P, 100 kg K and 30 kg Mg per hectare. Half was applied as a basal dressing before sowing and half when about 25% of total dry matter had been produced.

The results from the fertilized and unfertilized treatments were qualitatively similar. There was, of course, a great quantitative difference. The results from the fertilized treatments will be presented (tables 1 and 2).

TABLE 1. Total dry matter yield of maize (fertilized treatment) (grain yield 2.5 $t.ha^{-1}$).

15/5	31/5	8/6	20/6	30/6	20/8
		($t\ ha^{-1}$)			
0.8	2.8	5.5	7.9	9.7	13.1

The highest concentrations of NO_3 and K were found in the top 30 cm of the soil and their concentrations dropped to very low levels by the middle of the growing season when only 60% of the total dry matter had been produced and the grain filling stage had just begun.

The second fertilizer application had been carried out 5 days before the second sampling so that then the NO_3 concentrations in the soil solution at that stage were in about the same range as at the first sampling. This was not the case with K, confirming again that K requirement is especially high during the first half of the stem elongation stage.

TABLE 2. NO_3-N and K concentrations in the soil solution during the first half of the growing season under maize. Concentrations below the rooting zone are not shown.

Depth (cm)	N-concentration (ppm)				K-concentration (ppm)			
	15/5	31/5	8/6	20/6	15/5	31/5	8/6	20/6
10	485	346	51	10	180	65	4	4
20	451	491	48	8	162	81	8	3
30	213	260	52	11	43	45	6	5
40	130	180	62	9	26	19	5	2
50	82	122	140	29	18	18	10	6

This rapid decrease of readily available N and K is of some significance. It means that already in the middle of the growing season nutrient availability had decreased to a very low level. On the other hand there was no evidence of substantial leaching losses in spite of the low water holding capacity of the soil (Grimme and Juo, 1985) and high rainfall intensity.

Changes of available NO_3 in a sandy Entisol under a maize crop in an alley cropping system

The solution probes and tensiometers were installed in the N_0 plots of the no-till treatments. Fertilizer dressings consisted of 20 kg P, 60 kg K, 10 kg Mg per hectare. The hedgerows were planted with Leucaena leucocephala. The objective was to compare the nutrient contents in the soil between the treatments where a) prunings were added to the soil and b) were removed from the field (see Kang et al., 1985 for more details).

The NO_3 and K concentration profiles and their change with time were similar to those in the Alfisol (table 2) but on an altogether lower level and will therefore not be shown. Instead the changes in available NO_3-N quantity will be presented. The NO_3-N content in the maize rooting zone was calculated from the NO_3-concentration in the soil solution and the soil water content. As shown in table 3, there was initially only a minimal difference in the NO_3-N levels between the treatment receiving Leucaena prunings and that with prunings removed. But by the end of May the treatment with prunings added to the soil contained approximately twice as much NO_3-N content between the end of april and mid May. However, further increases in NO_3-N levels after that date were only observed in the treatment with prunings added. In June the NO_3-content in the soil declined rapidly to very low levels in both treatments so that again by mid June in the middle of the growing season, the soil was practically devoid of NO_3-N.

TABLE 3. Nitrate content (kg N/ha) in soil solution sampled at different dates during the main season maize crop in 1983 from the no-nitrogen treatment.

Treatment	Sampling depth (cm)	28/4	15/5	30/5	12/6	18/6
Prunings removed	0 - 30	9	29	34	3	1
	30 - 60	7	21	20	2	≤ 1
	0 - 60	16	50	54	5	< 2
Prunings retained as mulch	0 - 30	15	36	58	5	1
	30 - 60	7	28	55	11	4
	0 - 06	22	54	113	16	5

K removals (20-50 kg $K.ha^{-1}$) were rather small as compared to the total available (exchangeable) K (310-520 kg $K.ha^{-1}$ in the rooting zone) so that the observed changes were not significant. The higher exchangeable K content in the treatments where the prunings were retained as a mulch was also reflected in the higher K concentrations in the soil solution (55 ppm as compared to 22 ppm). The fact that the K concentrations in the soil solution decreased much more drastically (from 55 to 5 ppm and from 22 to 4 ppm respectively) indicates that the changes of cation concentrations in the soil solution do not only depend on plant uptake (leaching losses can be discounted in this case) but also on other factors such as total electrolyte concentration in the soil solution and its changes. These changes will be very much influenced by microbial activity (CO_3^{2-}, HCO_3^- and NO_3^- production).

Change of NO_3-N concentration in an Ultisol under upland rice

Upland rice was grown as main crop in a rotation with cowpea under high rainfall conditions (2400 mm) near Port Harcourt. Non-fertilized and fertilized treatments were compared. The fertilizer treatment consisted of 90 kg N, 40 kg P, 75 kg K and 20 kg Mg per hectare. 50% were applied as a basal dressing before sowing and 50% during the stem elongation stage when 35% of the maximum dry matter yield had been attained.

As in the other experiments nutrient concentrations in the rooting zone decreased rapidly with time (table 4). The concentrations in the unfertilized treatment (not shown) behaved in the same way as in the fertilized treatment but were at the beginning of the growing season by a factor of 2 (NO_3) and t (K) lower. The second fertilizer application (May 15) did not have any effect on the composition of the soil solution at the next sampling after fertilizer application (table 4), because the nutrients had been absorbed by the plants very rapidly. there had been no leaching out of the rooting zone as is evidenced by the concentrations below the rooting zone which did not increase after fertilizer application (table 4).

The difference in N and K uptake between the unfertilized and fertilized treatments can nearly totally be accounted for by the amount of nutrients applied as fertilizer (table 5). The fertilizer N and K had not been fully used up to the first harvest. But this was made up by the uptake between the first and second harvest, the growth stage with the highest growth rate.

TABLE 4. NO_3-N and K concentration in the soil solution during the first half of the growing season. The second fertilizer application was on 30/5.

Depth	Concentration in the soil solution ppm							
	18/4		6/5		30/5		13/6	
	NO_3-N	K	NO_3-N	K	NO_3-N	K	NO_3-N	K
10	22.5	11.1	6.6	4.5	1.8	1.5	0.7	0.6
20	40.9	22.0	16.5	7.2	0.2	1.7	0.2	0.7
30	31.1	12.2	19.6	5.8	0.2	1.9	0.3	1.1
40	21.4	8.7	38.6	8.6	0.2	3.0	0.8	1.0
60	23.8	7.1	31.6	9.1	0.4	2.0	1.7	2.0
80	21.0	4.4	24.4	7.6	6.6	5.6	1.8	3.1
100	20.4	1.7	13.1	1.2	8.1	1.4	6.7	1.0

TABLE 5. N and K uptake by upland rice and the difference in uptake between unfertilized and fertilized (45 + 45 kg N/ha; 37 + 37 kg K/ha) treatments (second application at the first harvest).

Treatment	N-uptake (kg/ha)		
	0-1.	1.-2.	0-3. harvest
Unfertilized	47	28	66
Fertilized	57	81	148
Difference	10	53	82
	K-uptake (kg/ha)		
Unfertilized	16	30	58
Fertilized	42	88	128
Difference	26	58	70

CONCLUSIONS

In the highly weathered soils with low buffer power of many tropical environments, nutrient concentrations in the soil solution may change vary rapidly, which has drastic consequences for nutrient availability. At the same time there is the risk of leaching losses because of high rainfall intensity and low water storage capacity. As was pointed out in the introduction, permanent cropping on such soils will not be possible without fertilizer use.

In order to ensure an optimum utilization by the plants and minimize losses split applications are called for. Quantity and timing have to be carefully adjusted to the plants requirements.

As opposed to the practice in temparate regions and according to the results presented, basal dressings could be lower than applications during crop growth. Monitoring nutrient concentrations in the soil solutions helps to get a better insight into soil-nutrient-plant interaction.

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NITROGEN AND OTHER NUTRIENT IN RED YELLOW PODZOLICS OF KUMAI, CENTRAL KALIMANTAN UTILIZED UNDER ALLEY CROPPING SYSTEM

Key words: Alley Cropping, Nutrient Status, Red Yellow Podzolic.

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Abstract

Research for cultural practices to conserve, and if possible improve productivity of newly reclaimed red yellow podzolics was undertaken in Kumai Central Kalimantan from 1984 to 1987.

Alley cropping with lamtoro (*Leuceana leucocephala*) as hedge crop was used. The lamtoro hedge was maintained at 80 cm height and cuttings were returned to the soil. Crop residues were left in the field and together with the weeds incorporated into the soil during soil preparation for the next crop.

Alley cropping in combination with fertilizer application on red yellow podzolics was successful in maintaining or improving the soil pH organic C, Total N, Extractable P, Exchangeable bases substantially over the initial soil chemical properties.

Alley cropping prevented runoff and erosion from taking place.

Introduction.

Red Yellow Podzolics, distributed on all the major islands: Java, Sumatera, Kalimantan, Sulawesi, and Irian Jaya (Table 1), form the largest great soil groups available for transmigration in Indonesia.

TABLE 1. Distribution of Podzolics in Indonesia[1].

Island	Podzolics	
	Brown	Red Yellow
	(x 1000 ha)	
Java and Madura	-	325
Sumatera	2.363	12.332
Kalimantan	1.038	9.959
Sulawesi	625	683
Maluku and Irian Jaya	1.962	9.150
Nusa Tenggara	-	-
Indonesia	5.988	32.449

[1] Based on plannimetric measurement from a tentative soil map of Indonesia 1976, Central for Soil Research, Bogor

Kumai, in the Kabupaten Kotawaringin Barat, Central Kalimantan Province was designated as one of the agriculture settlement areas in Kalimantan. More than 80 percent of the land is upland, the remainder are lowlands with impeded drainage. The forested land was cleared in 1981. When the first settlers from Java arrived in 1982, the cleared land was under alang-alang (Imperata cylindrica), Mimosa sp. and Melastoma sp.

TABLE 2. Initial surface soil (0-20 cm) chemical and physical properties of the test farm in Kumai, Central Kalimantan in 1984.

Soil properties	Block			
	BS	MS	BU	MU
pH (H_2O)	5.5	5.0	5.3	5.1
pH (KCl)	4.5	4.0	4.3	4.1
CEC, me/100 g	10.7	4.6	4.1	9.6
Org. C, %	2.32	1.85	1.78	1.55
Total N, %	0.11	0.08	0.08	0.09
P-Bray ppm	1.8	1.6	1.7	0.5
NH_4OAc - extr., me/100 g				
K	0.06	0.007	0.08	0.07
Na	0.20	0.18	0.19	0.18
Ca	0.98	0.74	0.99	1.28
Mg	0.34	0.18	0.23	0.38
N KCl extr., me/100 g				
Al	1.05	2.27	1.68	1.42
H	0.25	0.50	0.20	0.18
KH_2PO_4 extr., ppm S-SO_4				
SO_4	tr	tr	tr	5.5
0.1 N HCl extr., ppm				
Cu	0.44	0.61	0.44	0.61
Zn	0.60	0.37	0.48	0.79
Texture, %				
Clay	23.3	29.2	22.6	28.2
Silt	16.1	13.7	13.1	12.5
Sand	60.6	57.1	64.3	59.3

tr = trace

Over 2000 families were resettled in the area into five settlement units (Satuan Pemukiman). Each family obtained a house with 0.25 ha as compound yard and 1.0 ha (of land) as farm land (Lahan Usaha I) to grow food crops, which would later on be supplemented by another 0.75 ha to grow perennial crops. However, in the following years, those still able to cultivate their land were faced with declining productivity as a result of severe N, P, and K deficiencies and limited fertilizer use.

Methods

The Faculty of Agriculture of IPB was assigned by the provincial government of Central Kalimantan to carry out various investigations in Kumai, Central Kalimantan from 1984 to 1987. For this purpose 13 ha of land was given to IPB, on which the primary forest had been cleared in 1981, but by 1984 was fully covered with Alang-alang. The landform had a shape of a turtle back, with slopes varying from 3 to 8 percent. The average annual rainfall is 2857 mm, the driest months occur between june and november. Severe draughts appear to occur every five years.

Some of the soil characteristics are presented in Table 2. The soil has; (1) low CEC, (2) sandy texture, (3) an substantial content of organic matter in the topsoil, (4) low base saturation, (5) acidic properties with high aluminium level of 1.5 me Al/100 g, (6) very low extractable P.

Contour lines with 0.5 m elevation difference were depicted in the field. On these contours one-meter patch of land were cleared from weeds. Dolomite and rock phosphate at rates of respectively 3 and 0.75 ton/ha were broadcast on the one-meter patch of cleared land and immediately incorporated into the soil. One week later, presoaked and inoculated Lamtoro was sown at planting distance of 10 cm, two seeds in each hole. Half a quintal of urea and one quintal of KCl per ha were banded to a depth of 10 cm prior to sowing. The width of alleys ranged from 7 to 30 m depending on the slope of the land.

During the first 3 months the alang-alang was kept from encroaching the lamtoro rows. After 3 months Lamtoro hedges were about 60 to 80 cm high. From then on the height of the hedges was maintained at 80 cm. Lamtoro cuttings were laid over the alleys, one Lamtoro hedge for each alley. Once the Lamtoro hedges were established the alang-alang alleys were cleared manually and the soil in between rototilled. Alang-alang roots were uplifted, collected, put aside and burnt after they dried out.

TABLE 3. Number of alleys in each block.

Block	Alley Number
BS	00, 01, 02, 03, 04, 05
MS	06, 07, 08
BU	01, 02, 03, 04, 05
MU	08, 09, 10, 11, 12, 13

The alang-alang, Mimosa, and Melastoma leaves were incorporated in the soil. Dolomite and rock phosphate at rates of 3 and 0.75 ton per ha, respectively, were broadcasted and incorporated in the soil also. For this purpose the same rototiller was used.

On these prepared alleys (Table 3) several crops were grown. Crop production and treatments are presented in table 4, 5, 6 and 7.

TABLE 4. Crop rotation and use of major fertilizers in IPB Test Farm Kumai, Central Kalimantan from 1984 to 1987, Block BS.

Alley	Year	Crop	Urea	TSP	KCl	Yield	Remark
			- - - - - - -	(kg/ha)	- - - - - - -		
00	1984	Upland rice	200	100	100	680-1800	
	1984	Corn	200	100	100	1160-1700	
	1985	Upland rice	0-300	0- 400	0-150	92- 930	
	1985	Corn	200	100	100	1700-1392	
	1986	Soybean	50	200	100	Not recorded	Seed production
Total input			650-950	500- 900	400-550		
01	1984	Peanut	50	200	100	1720-2040	
	1984	Soybean	50	200	100	500- 960	
	1985	Upland rice	0-300	0- 400	0-150	34- 580	
	1985	Soybean	0-300	0- 400	0-150	533-1133	
	1986	Upland rice	200	100	100	862	
Total input			300-900	500-1300	300-600		
02	1985	Upland rice	0-300	0- 400	0-150	526-1133	
	1985	Peanut	0-300	0- 400	0-150	866-1206	
	1986	Upland rice	200	100	100	106	
	1986	Soybean	50	200	100	Not recorded	Seed production
Total input			200-850	300-1100	200-500		
03	1985	Peanut	50	200	100	Not recorded	Seed production
	1986	Upland rice	200	100	100	Not recorded	Seed production
		Soybean	50	200	100	Not recorded	Seed production
Total input			300	500	300		
04	1985	Peanut	50	200	100	Not recorded	Seed production
	1986	Upland rice	200	100	100	Not recorded	Seed production
	1986	Soybean	50	200	100	Not recorded	Seed production
Total input			300	500	300		
05	1985	Corn	200	100	100	Not recorded	Seed production
	1986	Upland rice	200	100	100	Not recorded	Seed production
	1986	Peanut	50	200	100	Not recorded	Seed production
Total input			450	400	300		

TABLE 5. Crop rotation and use of major fertilizers in IPB Test Farm Kumai, Central Kalimantan from 1984 to 1987, Block MS.

Alley	Year	Crop	Urea	TSP	KCl	Yield	Remarks
			- - - - - - - (kg/ha) - - - - - - -				
06	1985	Upland rice	200	100	100	-	Failed
	1985	Corn	200	100	100	Not recorded	Seed production
	1986	String bean	25- 75	50-100	50-100	4920- 6880	Fresh weight
	1986	Cucumber	50-100	50-100	75-150	19000-20740	Fresh weight
Total	input		475-575	300-400	325-450		
07	1985	Upland rice	200	100	100	-	Failed
	1985	Corn	200	100	100	Not recorded	Seed production
	1986	Red pepper	50-100	50-100	75-150	2560- 8840	Fresh weight
	1986	Cucumber	50-100	50-100	75-150	17200-22160	Fresh weight
Total	input		50-600	300-400	350-500		
08	1985	Upland rice	200	100	100	-	Failed
	1985	Corn	200	100	100	Not recorded	Seed production
	1986	String bean	25- 75	50-100	50-100	5010- 6000	Fresh weight
	1986	Eggplant*	50-100	50-100	75-150	14360-19280	Fresh weight, treated with LG leaves
Total	input		475-575	300-400	325-450		

* Each hill received 0 kg or 1 kg fresh LG leaves; planting distance 50 cm x 50 cm or equivalent to 20 ton fresh LG-leaves

After each harvest the crop residues were left on the field and incorporated into the soil before planting the next crop. How much biomass was left after each harvest was not measured. Soybean, peanut shells, rice husk and corn cobs were not returned to the field, but stacked up outside the plot and burnt. Grains removed for seed production purposes were not recorded. In certain cases (Table 7) Lamtoro leaves, collected elsewhere, were used as green manure. Upland rice, corn, soybean and peanut were harvested in the form of dry seeds or cobs. In the case of vegetables, they were harvested in the form of fresh weight.

Besides the major fertilizers, the plants received micronutrients in the form of $ZnSO_4.nH_2O$, $CuSO_4.nH_2O$, $Na_2B_2O_7$, and NH_4-molybdate as blanket treatments in the order of 5.0, 2.5, 2.5, and 0.05 kg per ha, respectively.

Appropriate pest control was conducted. However, some of the crops, such as upland rice, failed to yield satisfactorily (Table 5). The yields of multicropped plants grown in 1987 (Table 7) are not yet reported.

In June 1987 composite soil samples representing each alley (Table 3) were collected to a depth of 20 cm. These soil samples were further analyzed for their pH, org-C, N-total, P Bray-1, NH_4OAc extractable Ca, Mg, and K. The results are presented in Table 8. The soil characteristics of each alley were averaged for their respective blocks. The average block properties were compared with their initial characteristics. Table 9 shows the nutrient dynamics of the four blocks that underwent various cropping practices.

TABLE 6. Crop rotation and use of major fertilizers in IPB Test Farm Kumai, Central Kalimantan from 1984 to 1987, Block BU.

Alley	Year	Crop	Urea	TSP	KCl	Yield	Remarks
			- - - - - - - (kg/ha)		- - - - - - -		
01	1984	Peanut	50	200	100	1040-1550	
	1985	Upland rice	200	100	100	60- 500	
	1986	Soybean	50	200	100	Not recorded	Seed production
Total	input		300	500	300		
02	1984	Soybean	50	200	100	470-1380	
	1984	Corn	200	100	100	610-2170	
	1985	Upland rice	200	100	100	60- 500	
	1986	Peanut	50	200	100	Not recorded	Seed production
Total	input		500	600	400		
03	1984	Upland rice	200	100	100	420- 600	
	1985	Peanut	50	200	100	410-1320	
	1986	Upland rice	200	100	100	Not recorded	Seed production
Total	input		450	400	300		
04	1985	Peanut	50	200	100	410-1320	
	1986	Upland rice	200	100	100	Not recorded	Seed production
Total	input		250	300	200		
05	1985	Corn	200	100	100	1050-2360	
	1985	Soybean	50	200	100	Not recorded	Seed production
	Total	input	250	300	200		

TABLE 7[a]. Crop rotation and use of major fertilizers in IPB Test Farm Kumai, Central Kalimantan from 1984 to 1987, Block MU.

Alley	Year	Crop	Urea	TSP	KCl	Yield	Remarks
			- - - - - - - (kg/ha)		- - - - - -		
01	1985	Upland rice	100	200	200	2880-4090	Treated with
Total	input		100	200	200		fresh LG leaves
07	1985	Upland rice	100	200	200	2880-4090	Treated with
		Corn	100	200	200	3330-6610	fresh LG leaves
Total	input		200	400	400		
08	1985	Corn	100	200	200	3330-6610	Treated with
	1985	Upland rice	200	100	100	1250-1600	fresh LG leaves
	1986	Upland rice	200	100	100	533	
	1987	Soybean + Corn	80	180	100	-	Multiple cropping
Total	input		580	580	500		
09	1986	Peanut + Corn	80	180	100	1931+ 599	
	1987	Soybean + Corn	80	180	100	-	
Total	input		160	360	200		

TABLE 7[b]. Crop rotation and use of major fertilizers in IPB Test Farm Kumai, Central Kalimantan from 1984 to 1987, Block MU.

10	1986 Upland rice	200	100	100	416	
	1987 Soybean + Corn	80	180	100	-	
Total input		280	280	200		
11	1986 Peanut + Corn	80	180	100	1632+ 632	Multiple cropping
	1987 Soybean + Corn	80	180	100	-	
Total input		160	360	200		
12	1986 Upland rice	200	100	100	466	
	1987 Soybean + Corn	80	180	100	-	
Total input		280	280	100		
13	1986 Peanut + Corn	80	180	100	1415+ 666	Multiple cropping
	1987 Soybean + Corn	80	180	100	-	
Total input		160	360	200		

TABLE 8. Some soil chemical properties of various alleys under various fertilizer and crop management. Depth of 20 cm, 1987.

Block	Alley number	pH H_2O	Org. C	Total N	P-Bray	Ca	Mg	K
			- - - - (%)	- - -	(ppm P)	- - -	(me/100 g)	- - -
BS	00	5.5	1.82	0.10	35.2	5.44	1.44	0.17
	01	5.4	2.08	0.10	58.1	4.07	0.72	0.09
	02	5.5	1.93	0.10	104.8	5.05	1.08	0.11
	03	5.7	2.20	0.10	49.3	5.14	1.13	0.09
	04	5.4	2.08	0.10	84.8	4.38	1.13	0.09
	05	5.3	1.93	0.10	77.6	4.33	1.35	0.11
Average		5.5	2.01	0.10	68.3	4.74	1.15	0.11
MS	06	5.5	3.29	0.10	84.8	4.56	1.37	0.19
	07	5.5	2.08	0.09	35.2	3.93	1.26	0.16
	08	5.4	1.86	0.10	28.8	3.66	1.26	0.22
Average		5.5	2.41	0.10	49.6	4.05	1.30	0.19
BU	01	5.7	2.08	0.10	185.6	5.67	1.58	0.31
	02	5.7	2.01	0.10	71.7	4.33	1.19	0.27
	03	5.7	1.89	0.08	60.0	4.74	1.35	0.16
	04	5.7	2.60	0.08	68.8	4.38	1.44	0.36
	05	5.4	1.86	0.11	52.8	3.89	1.26	0.20
Average		5.7	2.09	0.09	87.8	4.60	1.36	0.26
MU	06	5.4	1.86	0.09	105.6	5.90	0.77	0.35
	07	5.8	1.89	0.10	63.7	6.17	1.17	0.29
	08	-	-	-	-	-	-	-
	09	5.3	1.93	0.09	32.0	5.45	1.17	0.11
	10	5.0	2.31	0.12	24.0	4.83	1.26	0.19
	11	5.0	2.08	0.12	44.8	4.60	0.90	0.15
	12	5.1	2.01	0.11	11.2	3.31	0.36	0.14
	13	4.7	2.27	0.12	14.4	2.50	0.77	0.16
Average		5.2	2.05	0.11	42.2	4.68	0.91	0.14

-: Data not obtained.

TABLE 9. The soil properties dynamics from 1984 to 1987 of the IPB Test Farm in Kumai, Central Kalimantan. Depth of 20 cm, averages of block.

Block	Year	Soil properties						
		pH H_2O	Org. C	Total N	P-Bray	Ca	Mg	K
			- - - - (%) - - -		(ppm P)	- - - (me/100 g) - - -		
BS	1984	5.5	2.32	0.11	1.8	0.98	0.34	0.06
	1987	5.5	2.01	0.10	68.3	4.74	1.15	0.11
MS	1984	5.0	1.85	0.08	1.6	0.74	0.18	0.07
	1987	5.5	2.41	0.10	49.6	4.05	1.30	0.19
BU	1984	5.3	1.78	0.08	1.7	0.99	0.23	0.08
	1987	5.7	2.09	0.09	87.8	4.60	1.36	0.26
MU	1984	5.1	1.55	0.09	0.5	1.28	0.38	0.07
	1987	5.2	2.05	0.11	42.2	4.68	0.91	0.14

Results and Discussion

The yields of upland rice were in general low, except for those that obtained various levels of Lamtoro leaves, which ranged from 2880 to 4090 kg of unhusked rice per ha. Lamtoro leaves up to an amount of 7 to 14 ton fresh weight per ha were incorporated into the soil and incubated for 2 weeks before rice seeds were drilled into the seed beds. These amounts of Lamtoro leaves can not be obtained from cuttings derived from one hedge that borders the alley.

Data on the fresh weight of Lamtoro cuttings per meter-hedge varied from 4 to 8 kg every 2 months. At a spacing of the alleys of 10 m, then one hectare has 1000 m of Lamtoro hedge, and every 2 month there will be 4000 to 8000 kg of fresh Lamtoro leaves as green manure, or 24 to 48 ton per ha per year.

Soybean yields were also low, peanut was slightly better, but corn was not quite satisfactory. The absence of pests and diseases appeared to be the decisive factor in getting good yields. The multicropping approach taken in 1986 (Table 7) looks to be promising. Upland rice yields were unsatisfactory, but peanut and corn grown together seems to be quite satisfactory. Judging from the vegetative performance of soybean + corn grown in 1987 (Table 7) in multicropping fashion yields in excess of 1400 kg soybean seeds and 3000 kg corn seeds per ha can be expected.

The duration of the various alleys under cultivation varied. Some were used since 1984, some later. This has some bearing on the total amount of urea, TSP, and KCl applied to each alley (Table 4, 5, 6 and 7), crop residues left in the field, and Lamtoro leaf cuttings returned to the soil, which in turn affected the nutritional status of the soil (Table 8 and 9).

The addition of dolomite, rock phosphate, and to a certain extend TSP gave a rise in pH, or kept it at the same level (Table 9).

In general the soil organic content increased from values less than 2 percent to over 2 percent in Blocks MS, BU, and MU. In Block BS the reverse took place (Table 9). The alleys in this block were the widest, from 18 to 30 m. It can be expected that the amount of Lamtoro leaf cuttings returned to the soil per unit area will be less compared with narrower alleys.

Keeping the crop residues and Lamtoro in the field and later on incorporating all the organic materials in the soil succeeded in increasing the soil organic C content. Even though the soil had a sandy texture, a soil condition that may favor fast mineralization of organic matter, this practice persistently and consistently maintained and most likely built up the organic matter content of the soil.

The total soil nitrogen of Block MS, BU, and MU was improved by 0.0 to 0.2 percent over the initial content measured in 1984 (Table 9). This was a substantial increase, especially if the timespan in which this change took place was considered. This increase cannot solely be the result of the incorporation of crop residues and Lamtoro leaf cuttings, but should also be attributed to the total urea input (Table 4, 5, 6, and 7) varying from 160 to 600 kg per ha.

Since the establishment of lamtoro hedges grown on contour lines no erosion was observed in Kumai Test Farm, which can be considered as one of the decivice factors contributing to the improvement of the soil properties.

Other nutrient properties worth mentioning are the P-Bray 1, and the exchangeable bases Ca, Mg, and K (Table 9). The addition of rock phosphate and TSP drastically changed the P-Bray 1 from practically nothing to values exceeding 40 ppm P. The application of dolomite has considerably increased the exchangeable Ca and Mg, whereas adding KCl every time a crop was grown had doubled the exchangeable K from 0.06 or 0.08 me to 0.11 or 0.26 me K per 100 g. These K values are still considered to be on the low side.

Conclusion

Alley cropping practiced on undulating Red Yellow Podzolic of Kumai, Central Kalimantan was successful in maintaining, even improving the soil properties closely related to agricultural production.

Soil pH was maintained at or increased over its initial level by addition of dolomite, rock phosphate, and TSP. Leaving crop residues in the field and returning Lamtoro leaves to the soil substantially increased the C-organic content of the soil. This increase of organic matter content was also reflected in the total N of the soil. The P-Bray1 and the exchangeable bases Ca, Mg, and K were higher than that of the initial levels. The increases were due to TSP and KCl used at each planting time and Dolomite plus rock phosphate application as an amelioration measure at the onset of the investigations.

Alley cropping prevented runoff and erosion from taking place.

UPTAKE OF NITROGEN FROM UREA FERTILISER FOR RICE AND OIL PALM - THE MALAYSIAN EXPERIENCE

Keywords : Alluvium Ammonium sulphate Ammonia volatilisation Fertiliser Leaching losses Malaysia Nitrogen recovery Oil palm Rice Sedentary soils Sulphur-coated urea Urea

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SUMMARY

The paper reports the findings of researchers on the efficacy of applied urea-N in rice and oil palm under Malaysian conditions. The flooded rice is normally planted in the alluvial soils (marine and riverine) while oil palm is planted in the alluvial and sedentary soils.

In rice cultivation, the recoveries of applied N from urea varies between 22 to 65%. Leaching losses as high as 43.3% were reported while volatilisation losses of ammonia were between 6-10%. Despite this low recovery of applied N, urea is still the prefered source of nitrogen for rice.

In the case of oil palm, urea is used in the alluvial soils although ammonium sulphate is slightly superior. In the sedenraty soils, urea is only used in areas where volatilisation losses of ammonia can be minimised. Volatilisation losses of ammonia as high as 38% in sedentary soils were reported. In a comparison study between urea and ammonium sulphate, volatilisation losses from urea-N of 22.5% N on sandy loam soils and 16.5% N on clay soils were observed compared to 0.1% and 0.4% in the case of ammonium sulphate for the sandy loam and clay soils, respectively.

INTRODUCTION

Malaysian agriculture is dominated by the perennial crops of rubber, oil palm, cocoa, coconuts and fruits. The distributions of these crops are given in Table 1. From this table, it can be said that only rubber and tobacco are not food crops.

TABLE 1 : Distributions of Crops in Malaysia, 1980-1985

Item	1980	1981	1982	1983	1984	1985
			('000 hectares)			
Rubber	2,004.7	2,006.1	2,005.8	1,971.3	1,978.6	1,959.0
Oil Palm	1,023.3	1,117.9	1,182.8	1,253.0	1,349.2	1,464.9
Cocoa	123.8	158.8	193.5	215.1	242.0	258.0
Rice	735.2	767.6	758.4	764.2	769.8	775.2
Coconut	349.4	318.0	319.0	324.0	298.0	274.0
Pepper	12.7	13.4	12.8	11.4	10.6	10.0
Pineapple	12.2	11.6	10.6	11.1	10.6	10.3
Vegetables[1]	12.8	12.5	7.5	7.6	7.8	8.1
Orchards[2]	93.0	87.8	89.0	90.0	92.0	94.0
Tobacco	12.5	14.3	9.6	9.4	9.3	9.2
Total	4,379.6	4,508.0	4,589.0	4,657.1	4,767.9	4,862.7

Source : Adapted from Fifth Malaysia Plan 1986 - 1990

Note : 1 Refers to Peninsular Malaysia only and includes leafy, fruits and root vegetables.

2 Includes fruit trees, bananas and watermelon but excludes pineapple.

The areas of cultivation for these crops can be broadly divided into two main areas; that is the coastal alluvium (marine and riverine; heavy clay to loam) and the sedentary soils (sandy loam to heavy clay). Rice, coconuts and vegetables are generally planted on the alluvium soils while rubber, oil palm and fruit trees on the sedentary soils. For all these crops, various N-fertilisers such as ammonium sulphate, ammonium nitrate, ammonium chloride, and urea have been used for their nutrition. Amongst these N-fertilisers urea is the cheapest per unit of N.

The estimated amount of urea consumed by the major crops in Malaysia in 1986 is 240,000 tonnes (Table 2). Oil palm is the major user with 100,000 tonnes, followed by rice which consumed 90,000 tonnes. The consumption of urea by all crops between 1980 and 1985 can also be gauged by the country's import figures, as shown in Table 3. In 1980, Malaysia imported 210,247 tonnes of urea while the figure for 1985 stood at 268,630 tonnes. It is estimated that in 1987 Malaysia will require about 250,000 tonnes of urea. Over 95% of the urea is used for agriculture.

TABLE 2 : 1986 Urea Usage in Malaysia

Crops	Amount (tonnes)
Rice	90,000
Oil Palm	100,000
Rubber	20,000
Cocoa	10,000
Others	20,000
Total	240,000

Source : Chew, K.L. (1987)

TABLE 3 : Malaysia's Import of Urea, 1980-1985

Year	Quantity (tonnes)
1980	210,247
1981	138,565
1982	171,893
1983	182,278
1984	302,562
1985	268,630

Source : Ministry of Trade and Industry

The importance of urea as the source of nitrogen in Malaysian agriculture was heightened by the establishment of the Asean Bintulu Fertiliser (ABF) Plant in Bintulu, Sarawak, Malaysia in 1980. The fertiliser plant has the capacity to produce 1,500 and 1,000 tonnes of granular urea and ammonia per day, or 495,000 and 330,000 tonnes per year, respectively. The urea was on stream in 1986.

The efficacy of urea as applied on the alluvium soils seemed to be superior to that on the sedentary soils. The differences in efficacy are mainly due to differences in the physical and chemical properties of these two groups of soils. The objective of this paper is to present experimental results from various researchers in Malaysia on the efficiency of urea-N fertilisers for some selected food crops, namely rice and oil palm.

RICE (*Oryzae sativa*) CULTIVATION IN MALAYSIA

As in most asian countries, rice is the staple food in Malaysia. The total rice growing areas in Peninsular Malaysia is 429,500 ha (Van Vreden and Abdul Latif, 1986) and over 70% of the planted area is double-cropped. Rice is grown under flooded conditions, either transplanted or direct seeded. In the MADA (Muda Agricultural Development Authority) Irrigation Schemes, covering an area of 95,800 ha, 65% of the rice grown in the area is direct-seeded; while in the Besut Irrigation Scheme (4,660 ha) 90% of the area is direct seeded (Arulandoo et al. 1987).

The fertiliser requirements for rice is subsidised by the government at the rate ranging from 60-80 kg/ha of N, 8.7-17.5 kg/ha of P and 16.6 kg/ha of K depending on the regions in Peninsular Malaysia (Table 4). The nitrogen is supplied in the form of mixtures (17.5-8.7-8.3) for basal dressing at 15 days after transplanting and urea for top dressing at 60 days after transplanting. In the 1984-85 seasons 80,600 tonnes of urea were used under the Subsidy Scheme (Zulkifli et al. 1987).

TABLE 4 : Fertiliser Rate for Rice in Peninsular Malaysia Under the Subsidy Scheme

Region	N	P (kg/ha)	K
1	80	13.1	16.6
2	60	17.5	16.6
3	80	8.7	16.6

Source : Adapted from Zulkifli et al. (1987)

Efficiency of Urea-N in Rice

The applied fertiliser-N can be lost due to ammonia volatilisation, fixation, denitrification, leaching and run-off. Researchers in various parts of the world have reported that the recovery of applied nitrogen vary from 10 to 60% (Brady et al. 1974; De Datta, 1978; Craswell, 1987; Vlek and Byrnes, 1986). Under Malaysian conditions, nitrogen recoveries between 22 to 65% have been reported (Samy, 1980; Samy and Arulandoo, 1987; Aziz Bidin et al., 1987).

In a study by Samy (1980), in which three varieties of rice (Bahagia, Ria, Sri Malaysia II) were grown on three different soils (Chengai, Tualang, Hutan), the nitrogen uptake of urea-N in rice plant (straw and grain) was found to be between 22 to 48%. This study was conducted in the MADA Irrigation Schemes and nitrogen was applied at the rate of 40, 80, 120, and 160 kg N/ha. The characteristics of the three soils series are presented in Table 5.

Similar findings were obtained by Aziz et al. (1987) in a nitrogen balance study using 15N labelled urea. They reported that the recoveries of fertiliser N in the plant-soil-water system, when applied at 40-50 kg N/ha, was 65%. However, when the urea was applied at 100-120 kg N/ha, the recoveries were between 28 to 60% depending on the soil types. In this investigation, the micrometeorological method of Denmead (1983)

TABLE 5 : Characteristics of Chengai, Tualang and Hutan Series Soils

Soil Series	Chengai	Tualang	Hutan
(a) USDA Taxonomy	Tipic Pelluderts	Tropo Fluvents	Aeric Tropaquepts
(b) Mechanical Analysis			
Clay (%)	75	60	41
Silt (%)	20	30	18
Fine sand (%)	4	9	37
Coarse sand (%)	1	1	4
(c) pH			
(Air-dry soil - 1 : 2.5)	4.8	4.5	4.8
(d) Chemical Analysis			
Organic matter (%)	3.4	2.8	4.3
Carbon (%)	2.0	1.5	2.5
Total nitrogen (%)	0.19	0.16	0.20
Ammonical nitrogen (ppm)	70	90	90
C/N ratio	10	9	12
Potassium (ppm) (0.5N acetic acid)	63	53	127
Phosphorus (ppm) (0.1N NaOH soln.)	96	168	23
C.E.C. (meq/10 g soil)	32	19	17

Source : Samy (1980)

and the floodwater analysis technique of Freney et al. (1985) were used. The study was undertaken at the MARDI Research Stations in Bumbong Lima, Penang and Tanjung Karang, Selangor. Urea was applied at the rate of 56 and 128 kg N/ha in Bumbong Lima while in Tanjung Karang N was applied at 40 and 80 kg/ha.

Aziz et al. (1987), in their nitrogen balanced study, also observed the volatilisation losses of N and found that the loss of ammonia was low - ranging between 6-10% of applied urea. They attributed their findings to the fact that environmental factors in Malaysia are not conductive for large volatilisation loss, as shown by conditions in Bumbong Lima and Tanjung Karang. These conditions are the short duration of high pH, the fast transformation of urea, and fast dissappearance of ammonium-N in the flood water. Furthermore, the windspeed in these two areas is low. However, Aziz et al. (1987) postulated that denitrification loss could be high as shown by the high total-N loss in their 15N study. Further research should be done in this aspect.

Leaching losses of nitrogen, as ammonium and nitrate, from applied urea through seepage and percolation in the rice fields were found to vary at different growth stages and crop seasons. In a study undertaken by Arulandoo et al. (1980), at the MARDI Research Station Bumbong Lima, 80 kg N/ha of urea were applied in three split applications - 40 kg N as basal, 20 kg N at panicle initiation, and 20 kg N at heading stage. The study was conducted in the dry season of 1978 and the wet season of 1978/79. They reported that the loss is higher during the wet season (43.3%) compared to that in the dry season (32.8%) (Table 6). The difference was attributed to the heavy rainfall in the wet season. More leaching losses were also found to occur for urea applied at panicle initiation compared to those applied as basal or at heading stage (Table 6).

Leaching losses of nitrogen can be reduced by incorporating the crop residue into the soil and by the use of coated-urea. Arulandoo et al. (1980), in the same study mentioned earlier, reported that 25.1%, 31.6% and 37.2% of applied nitrogen (ammonium and nitrate-N) were found in the leachate when the crop residues were incorporated, burnt or removed, respectively (Table 7). They also observed that when urea and rubber-coated urea were used, 4.9% and 2.7% of applied nitrogen were found in the leachate, respectively (Table 8).

TABLE 6 : Leaching Losses of Nitrogen In Rice Field At MARDI Research Station Bumbong Lima

Time and rate of N application	Leaching losses (kg N/ha)			
	Dry season 1978	As % of applied N	Wet season 1978/79	As % of applied N
Basal, 40 kg N/ha				
NH_4^+-N	9.17	25.78	8.93	31.88
NO_3^--N	1.14		3.82	
Panicle initiation, 20 kg N/ha				
NH_4^+-N	8.24	58.20	9.60	67.55
NO_3^--N	3.40		3.91	
Heading, 20 kg N/ha				
NH_4^+-N	2.63	21.35	7.34	42.00
NO_3^--N	1.64		1.06	
Total loss	26.22		34.66	
As % of total applied	32.78		43.33	

Source : Arulandoo et al. (1980)

TABLE 7 : Influence of Crop Residue Management on the Leaching Losses of Nitrogen

Residue Management	Ammonium-N (kg N/ha)	Nitrate-N (kg N/ha)	Percentage of applied nitrogen
Residue incorporated	18.67	1.39	(25.08%)
Residue burnt	21.31	3.96	(31.59%)
Residue removed	28.2	1.56	(37.20%)

Source : Arulandoo et al. (1980)

TABLE 8 : Leaching Losses of Nitrogen as Affected by Forms of Nitrogen

N-form	Ammonium-N	Nitrate-N	Percentage of applied nitrogen
	(kg N/ha)		
Urea	3.33	0.57	(4.88%)
Rubber coated urea	1.10	1.07	(2.71%)

Source : Arulandoo et al. (1980)

OIL PALM (*Elaeis guineensis* Jacq) CULTIVATION IN MALAYSIA

Oil palm was first introduced into Malaysia (then Malaya) in 1870 mainly as ornamentals. Interests as an agriculture crop for its oil started only in 1911. The first commercial estate was established in 1917. However, by 1985 1,464,900 hectares (Table 1) have been planted in Malaysia. It is projected that by 1990 and 1995, 1.52 and 1.56 million hectares, respectively will be planted (PORIM Report 1983). It is estimated that 20% of the current crop is planted on the coastal alluvium, while the rest is on the sedentary soils (Zin Zawawi, 1987).

The fertilisation schedule for oil palm, being a perennial crop, is more complicated than that of rice. The fertiliser requirements for the first 8 years of growth are as shown in Table 9. The ammount of N applied varies with age of the palm as well as the soil types. For the alluvial soils, urea is used as the source of N. In the case of the sedentary soils, normally ammonium sulphate is used except in areas where volatilisation of ammonia from urea-N can be controlled.

For the first two years of growth, the fertilisers are applied in the weeded circles. They are applied 3-4 times a year to minimise leaching losses. When the palms are 3-6 years old, the fertilisers are normally applied in a broad circular band within the periphery of the canopy. At this stage, the fertilisers are applied twice a year.

TABLE 9 : Recommended Fertiliser Rates (kg/palm/year) for 1-8 Year-old Oil Palm

Age	Alluvial Soils			Sedentary Soils		
(Years)	N	P	K	N	P	K
1	0.06-0.13	0.08	0.16-0.37	0.08-0.17	0.15	0.26-0.52
2	0.13-0.21	0.15	0.37-0.89	0.17-0.34	0.30	0.62-1.31
3	0.17-0.25	0.19	0.47-1.10	0.21-0.42	0.38	0.79-1.57
4	0.17-0.25	0.23	0.52-1.26	0.21-0.42	0.45	0.89-1.83
5	0.17-0.25	0.26	0.63-1.47	0.21-0.42	0.53	1.05-2.10
6	0.21-0.32	0.30	0.42-1.05	0.25-0.53	0.60	0.89-2.36
7	0.25-0.42	0.30	0.21-0.52	0.34-0.63	0.60	0.73-2.62
8	0.32-0.53	0.30	0.0	0.42-0.84	0.60	0.52-2.88

Source : Adapted from Foster et al. (1986)

In later years, when the roots are fully developed, the fertilisers are applied once a year (Foster et al. 1986).

Efficiency of Urea-N in Oil Palm

The efficacy of applied Urea-N fertilisers for oil palm vary significantly between the alluvial and sedentary soils. This was highlighted by Pushparajah (1982) whereby urea when broadcasted on to an alluvial soil (Briah Series) yielded 33.0 tonnes FFB (fresh fruit bunch) per hectare per year compared to 23.4 tonnes FFB/ha/yr on a sedentary soil (Rengam Series); even though nitrogen was applied at a rate three times higher (1.6 kg N/palm) than that of the alluvial soil (0.5 kg N/palm).

In a preliminary report by Foster et al. (1987) in which granular urea (sizes 2.9 mm and 7 mm diameter) and ammonium sulphate were applied on 18 different soil series (alluvial and sedentary) at three different rates of 0.4, 0.8 and 1.2 kg N per palm per year, it was observed that average oil palm yields (FFB) was 20-30% lower than that of ammonium sulphate. These differences in yields were attributed to N volatilisation losses from urea. However, if the yields of oil palm from the alluvial soils were compared with that of the sedentary soils, the differences were reduced to only 4-8%.

In the same study, as reported by Foster et al. (1987), comparing two methods of fertiliser application, i.e. applying the fertiliser in the weeded circle and broadcast overall, it was found that both urea fertilisers gave a lower yield compared to ammonium sulphate when applied in the weeded circle. However, when the fertilisers were broadcast overall the bigger urea fertilisers (7 mm diameter) gave a significantly higher average yield and was comparable with that of ammonium sulphate.

In an earlier study carried out by Chemara (1964), it was observed that the oil palm yield (FFB) was 45% higher when ammonium sulphate fertilisers were used compared to that of urea. However, in a similar study reported by Sinasamy et al. (1982) in which nitrogen was applied at the rate of 0.9 kg N/palm/year, urea was found to give superior yields (FFB) compared to that of ammonium sulphate. These differences in yield pattern are mainly due to differences in soil types and climatic conditions of the study areas.

Losses of nitrogen through the volatilisation of ammonia are affected by differences in soil texture and moisture conditions. Sinasamy et al. (1982) reported that losses as high as 22.5% N from urea were obtained in sandy loam soils compared to 16.5% N for the clay soils. In the same study, volatilisation of ammonia from ammonium sulphate were found to be 0.1% and 0.4% for the sandy loam and clay soils, respectively. Sinasamy et al. (1982) also observed that the volatilisation losses of nitrogen from urea were 25% in moist soils compared to only 11.2% in saturated soils; where as in the case of ammonium sulphate the losses were 0.3% and 0.1%, respectively. The study was conducted on Munchong, Rengam, and Kuantan series soils.

In another volatilisation study conducted by Chan and Chew (1983), prill urea was applied in the weeded circle at the rate of 250 and 500 kg N/ha on three soil series (Table 10). This is equivalent to 1.6 and 3.2 kg N per palm, respectively. In this study, it was observed that at the end of the three days the volatilisation losses of N were between 27-35% of applied N at the lower rate of application and between 35-38% at the higher rate of application (Table 11). At the end of seven days, the losses were even higher ranging from 29-38% and 42-48% of applied N for the 250 and 500 kg N/ha, respectively (Table 11).

TABLE 10 : Some Chemical and Physical Properties of Selangor (Typic Tropaquept), Rengam (Typic Paleudult), and Serdang (Typic Paleudult) Series Soils

Soil Series	pH (H_2O)	Org.C %	N (%)	P (ppm) Total	P (ppm) Avail	Exchangeable cations (m.e.%) K	Ca	Mg	C.E.C. (m.e.%)
Selangor	3.9	2.10	.22	198	4.1	.41	1.1	1.7	26.6
Rengam	4.4	1.66	.16	163	27.1	.06	1.2	.16	11.9
Serdang	4.0	1.15	.13	234	9.0	.08	3.4	.38	7.9

Soil Series	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Water holding capacity (%)
Selangor	0	3	41	56	88
Rengam	33	14	5	48	67
Serdang	29	30	8	33	45

Source : Chan and Chew (1983)

TABLE 11 : Urea Volatilisation Losses On Various Soils Under Oil Palm

N Rates	Selangor Series	Rengam Series	Serdang Series
<u>3 days</u>			
250 kg N/ha	29	27	35
500 kg N/ha	38	35	38
<u>7 days</u>			
250 kg N/ha	29*	38	42
500 kg N/ha	42*	45	48

* Losses from soil cores determined in the Laboratory
Source : Chan and Chew, 1983

CONCLUSIONS

In Malaysia, where rice is cultivated under flooded condition, the recoveries of nitrogen from urea varies between 22 to 65% of the applied N. Leaching losses as high as 43.3% were recorded while volatilisation losses of ammonia of between 6-10% were observed. Despite this seemingly low efficiency of uptake of nitrogen from urea, it is still the preferred source of N for rice.

In the case of oil palm, urea is used for the alluvial soils although ammonium sulphate is slightly superior. This is mainly due to the fact that urea is still the cheapest source per unit of N. However, for the sedentary soils, urea is only used where ammonia volatilisation can be minimised. Losses of urea in sedentary soils can be reduced by adjusting the timing and method of fertiliser application.. Nevertheless, oil palm being a commercial crop, the choice of N-sources and methods of applications ultimately depends on the cost of production of the fresh fruit bunch.

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LEGUME COVER CROPS FOR RED-YELLOW PODZOLIC SOILS.

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Introduction.

Soils, known as red-yellow podzolic soils in the Indonesian soil classification, have a very poor fertility status with a low CEC, low pH and a low N and P content. Most nutrients in these soils are derived from soil organic matter. Therefore, soil fertility decreases rapidly after forest clearing for agricultural purposes, unless measures are taken to maintain or improve the ornanic topsoil. Agricultural production is even more hampered by the rapid invasion of alang-alang (Imperata cylindrica).

Past experiments have shown that the use of legume crops in crop rotations can have beneficial effects. The nitrogen fixed by the legume crops after decomposition can be utilized by succeeding crops, and the biomass produced helps the build-up of soil organic matter.

It is surprising that in spite of the obvious importance of legume cover crops, information on their use on red-yellow podzolic soils of Indonesia is very limited.

Research done at IITA, Nigeria, has shown that the production of nitrogen by Psopocarpus palustris and Centrosema pubescens varied from 89-161 kg N/ha (Mulongoy and Akubundu, 1985). Reddy et al (1986) studied nitrogen production of several tropical legumes on sandy coastal plains in southeastern USA. They found that Cajanus cajan (L.) Millsp., and Crotalaria spectabilis Roth., Mucuna deeringiana (Bort.) Merr. were able to produce up to 250 kg, 170 kg and 190 kg/ha nitrogen respectively.

The objectives of the experiment diccussed here are to evaluate a number of legume cover crops for their biomass production, their effect on soil-N, and their effect on the growth and yield of the suceeding crops of maize and soybean. In this paper the results from the first two years will be discussed of the experiment, which will be conducted for several more years.

Materials and methods.

The experiment was carried out on a red-yellow podzolic soil at Negara-Tulang Bawang, Lampung, Sumatera, which had been previously cleared of secundary forest. Some soil properties are presented in table 1. Land-clearing was done by cutting and burning the above-ground vegetation leaving the larger treestumps in place.

Crops were planted in plots of 12 x 8 m. without soil tillage according to the plantcombinations as shown in table 2.

Cover crops were sown at a spacing of 0.2 x 0.2 m, and maize, cv. Arjuno, was sown at a spacing of 1.0 x 0.4 m (two seeds per hill). Soybean, cv. Willis, was sown at a spacing of 0.25 x 0.25 m after the maize had been harvested.

All plots were given P_2O_5 and K_2O at the rate of 60 and 20 kg/ha respectively. Nitrogen fertilizer application of plots receiving 60 kg/ha was divided in two splits: half at planting and the other half 30 days later. Handweeding was done at regular intervals.

Table 1. Selected soil properties of a representative soil profile at the experimental site in Negara-Tulang Bawang, Lampung.

Soil depth	pH		Texture			C-org	Tot-N	P	Exchangeable bases				CEC
			%					Bray-2	meq/100 gr				
cm.	H_2O	KCl	Sand	Silt	Clay			ppm	Na	K	Ca	Mg	
0-5	4.9	4.0	74.5	12.0	13.5	1.73	0.14	5	0.66	0.75	4.80	2.25	7.40
5-29	4.6	3.8	64.1	12.8	23.1	0.43	0.06	3	0.21	0.12	1.95	0.45	6.50
29-45	4.7	3.8	63.8	12.1	24.1	0.38	0.04	2	0.32	0.08	2.40	0.30	8.10
45-66	4.7	3.8	61.3	11.6	27.1	0.18	0.03	1	0.37	0.10	2.55	0.30	7.30
66-89	4.8	3.8	62.0	11.3	26.7	nd	0.02	1	0.16	0.06	2.40	0.30	10.6
88-110	4.9	3.8	61.2	11.1	27.7	nd	nd	nd	0.16	0.05	3.00	0.30	11.4
110	4.8	3.8	56.2	12.8	31.0	nd	nd	nd	0.18	0.08	2.70	0.30	23.6

Texture: Hydro meter. C-org.: Walkley and Black.
Exchangeable bases extracted with NH_4-acetate, pH 7.0,
Na and K determined with flame photometer, Ca by titration.

Soil nitrogen and organic carbon were analysed after harvesting the cover crops. Soil samples were collected from a depth of 0-20 cm. and 30-40 cm, consisting of 10 subsamples/plot.

Table 2. Cropping sequence *).

Exp. code	First year	Second year
01	Mp-Mo-S	Mo-Mp-Mo
11	Mp-Mn-S	Mn-S-Mp-Mn
02	Pp-Mo-S	Mo-F-Mo
12	Pp-Mn-S	Mn-S-F-Mn
03	Cp-Mo-S	Mn-Cp-Mo
13	Cp-Mn-S	Mn-S-Cp-Mn
04	Cm-Mo-S	Mo-Cm-Mo
14	Cm-Mn-S	Mn-S-Cm-Mn
05	Cj-Mo-S	Mo-Cj-Mn
15	Cj-Mn-S	Mn-S-Cj-Mn
06	Fl-Mo-S	Mo-Fl-Mo
16	Fl-Mn-S	Mn-S-Fl-Mn

*): Mp = *Mucuna pruriens*; Pp = *Pueraria phaseoloides*; Cp = *Centrosema pubescens*; Cm = *Calopogonium mucunoides*; Cj = *Crotalaria juncea*; Fl = Fallow; Mo = Maize, 0 kg N/ha; Mn = Maize, 60 kg N/ha; S = Soybean; F = Flamingia.

Results and discussion.

Cover crops.

Visual observations in the first experimental years (Smilde, 1986, Van Noordwijk and Kurniatun Hairiah, 1986) indicated that the capacity of various legume cover crops to suppress alang-alang ranked from *Crotalaria juncea*, *Centrosema pubescens*, *Calopogonium*, *Pueraria phaseoloides*, *Mucuna*, the last showing luxurious growth and best weed suppression.

Although all cover crops after one year had developed a more or less complete groundcover, additional criteria such as growing speed and root development led to the following tentative conclusions (van Noordwijk and Kurniatun Hairiah, 1986):

- As a short-term cover crop (e.g. 3 months), Mucuna is suitable, as it gives a good weed control, covers the soil, and dies off spontaneously at the end of the dry season. Few seeds are produced.
- For a longer-term cover (e.g. 6 months) Calopogonium seems a good choice, as it is able to pull down most of the weeds with its creeping stems, remaining low to the ground itself.
- Crotalaria gives a high crop, shading out most of the weeds but leaving the ground uncovered.
- Pueraria and Centrosema did not sufficiently control weeds during the period of observation.

Legume biomass production presented in table 3, show that Pueraria and Centrosema produced more biomass than the other crops. However, in the first years of the experiment, no significant differences in N and C content of the soils were observed between the different treatments.

Table 3. Biomass production by cover crops and N- and C- content of the soil after harvesting.

Plantingl	Dry matter kg/ha	Soil N (%)		Org. C (%)	
		0-20	20-40	0-20	20-40
1. Mucuna pruriens	5889.91bcd*)	0.14	0.13ab	2.30	2.01
2. Mucuna pruriens	5603.08bcd	0.14	0.11bcd	2.31	1.69
3. Pueraria phaseoloides	7381.96ab	0.14	0.12abc	2.31	1.73
4. Pueraria phaseoloides	8124.91a	0.13	0.12abc	2.26	1.78
5. Centrosema pubescens	7776.04ab	0.14	0.14a	2.18	1.85
6. Centrosema pubescens	7929.84ab	0.15	0.13ab	2.36	1.90
7. Calopogonium mucunoides	6878.83bc	0.13	0.11bcd	2.06	1.52
8. Calopogonium mucunoides	6987.36abc	0.14	0.11bcd	2.26	1.59
9. Crotalaria juncea	5569.21d	0.14	0.10bcd	2.01	1.36
10. Crotalaria juncea	5932.89bcd	0.14	0.11bcd	1.99	1.80
11. Fallow	6048.50bcd	0.14	0.09d	2.03	1.28
12. Fallow	5894.56bcd	0.12	0.10cd	1.98	1.63

*) Yields followed by the same letter do not differ significantly.

Maize

Biomass and grainproduction of maize planted after cover crops are given in table 4. For the first year, the preceding cover crops did not influence dry matter production of maize. However, significant differences in maize grain yield were observed. In some treatments, the application of N-fertilizer resulted in a significantly higher maize yield. Because of dry weather conditions in the second year, the cover crops were not planted. Therefore, maize production was influenced by N-fertilizer application only, and no residual effect of cover crops occurred.

Table 4. Effect of cover crops on biomass production and grain yield of maize following cover crops (kg/ha).

Treatm.	First year		Second year		Third year	
	Dry m.	Grain y.	Dry m.	Grain y.	Dry m.	grain y.
01	2908	3206bc	2410	2721	3328ef	2741gh
11	3048	3436abc	2936	3853	4317bc	3757bc
02	2837	3733ab	2509	3148	3387ef	2299h
12	3147	4597a	2975	4005	4454ab	3512cd
03	3071	3167bc	2428	2844	4301bc	3265de
13	2683	2649bc	3274	3962	4416b	4299a
04	2522	2723bc	2445	2894	4163bc	3104ef
14	2691	3635abc	2687	3564	4898a	4117ab
05	3289	2463c	2847	3168	3091f	2443gh
15	2597	2511bc	2956	3729	3600de	2799fg
06	2662	2539bc	2558	3020	2566g	2101h
16	2765	3146bc	-	4090	3953cd	3292de
Maize 0 kg N/ha			2553a	2996a		
Maize 60 kg N/ha			3002b	3867b		

Results followed by the same letter are not significant at LSD 0.05

Both dry matter and grain yield of maize in the third year were significantly influenced by the residual effects of the preceeding cover crops.The highest maize yields in both the unfertilized and the fertilized treatments were observed after Centrosema (03 and 13), followed by Calopogonium (04 and 14). A high nitrogen response was observed after Mucuna (11) and on the fallow (16).

Soybean.

The yields of soybean in the first year were not significantly affected by previous treatments. Soybean yields varied from 776 kg/ha to 1218 kg/ha, with means of 788 kg/ha seed, and 1123 kg/ha dry matter/ha. In the second year, an invasion of Nezara viridula prevented the soybean to produce seed. The mean dry matter production of soybean in this year was 2310 kg/ha.

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INTERCROPPING OF LEGUMES TO CONTRIBUTE NITROGEN IN LOW-INPUT UPLAND RICE-BASED CROPPING SYSTEMS

Key words: Intercropping Legumes Rice Cropping Systems Nitrogen Sustainability

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SUMMARY

Upland rice is generally produced on acid soils of low inherent fertility, with no inorganic nutrients applied. The utility of incorporating grain or forage legumes into intercrops with upland rice was examined with the objective to increase the N availability to rice. Rice N yields, when intercropped with determinate early-maturing legumes, were about the same as with sole rice, while grain yields were between 70 and 100 percent of sole rice yields. The net nitrogen benefit and the rice yield compensation observed were due to the increased soil and aerial space available after the legume was removed. Direct N transfer did not appear to play a significant role in net N availability to rice.

Indeterminate cultivars of cowpeas and lablab were tested as intercrops with rice to supply green leaf manure to the rice crop. They supplied 21 and 93 kg N/ha to intercropped rice when clipped as green leaf manure. Rice yields in the intercrop were maintained compared to sole rice. N uptake increased 21 to 66 percent. The legumes yielded an additional 1.02 t/ha and 0.5 t/ha grain, respectively. When plowed down at the end of the subsequent dry season, prior to planting the following year's rice crop, the lablab supplied 19.0 t/ha fresh green manure biomass over 100 kg N/ha. The results suggest that a production system based on intercropping rice and indeterminate legumes may substantially improve the sustained yield of upland rice in low external input conditions.

Upland or dryland rice is grown on 19 M ha worldwide, with 11.5 M ha of this total in South and Southeast Asia. The crop is a preferred subsistence food source for millions of small-scale farm families, but grain yields are low (ca. 1 t/ha). Average inorganic nutrient application is nearly zero in all but a few favored micro-regions of production.

Upland rice is predominantly grown on acid soils of low inherent fertility (Garrity, 1984). As much as one-third of the crop area is estimated to be grown on slopes exceeding eight percent, with soil erosion as a serious threat to sustained productivity. Forest or grass fallows have generally served as the farmer's fertility generating tool. But the land frontier has closed in most parts of the region. Population pressure has reduced or eliminated fallowing and cereal yields are declining (Magbanua et al, 1987). A severe cash constraint is a reality that small-scale upland farmers generally face.

In upland rice-growing areas with short growing seasons, particularly in South Asia, early duration cultivars of rice are grown in monoculture with no succeeding crop. In longer growing season areas upland rice is often produced as the initial crop preceding maize in a two-crop sequence. Nearly universal is the dominance of cereals or root crops in upland rice-based cropping systems. The role of legumes is relegated to a very minor position. Intercropping with upland rice is practiced to a limited extent, particularly in Indonesia, but the practice is confined predominantly to combinations of rice with other cereals, viz. maize and/or cassava. Nitrogen seriously limits biomass production and grain yield in all these cereal-based sequences.

To be advantageous over sole cropping, an intercropping system must show greater resource use efficiency. Although rice + maize and/or cassava intercrops are resource efficient, the productivity and efficiency is greatest only with favorable water and nutrient levels (Harwood and Banta 1974, Sooksathan 1976). Both crops aggressively compete for nutrients, particularly nitrogen.

In soils of low inherent fertility and without fertilizer inputs, the association of cereal and legume crops often leads to increased N availability to the cereal and stability in production (Willey 1979). Intercropping sorghum and millets with cowpea or pigeon peas is a common practice in many semi-arid areas of India and Africa (Dart and Krantz 1977). In Southeast Asia, soybeans are commonly grown in association with maize (Shanmugasundaran et al, 1980). Also, a substantial portion of the peanut crop in the Philippines is produced as an intercrop with maize.

Research was initiated at IRRI to examine the potential utility of incorporating grain or forage legumes into intercrops with upland rice. The research goals were to develop intercrop systems that will: (1) increase N availability to rice, (2) increase ecological sustainability of the production system by regenerating nutrients within the cropping system, and (3) improve subsistence farmers' food and nutritional security by reducing the risk of crop failure and increasing the harvest of protein. The objective of this paper is to briefly review some of the results and implications of this work.

INTERCROPPING WITH GRAIN LEGUMES

A number of agronomic experiments were conducted from 1983 to 1986 in several fields at each of two locations: the upland experimental form of IRRI at Los Baños, Laguna, and an on-farm research site in Claveria, Misamis Oriental, Mindanao. Soil at the IRRI farm are Typic Tropudalfs of clay to clay loam texture, mildly acidic (pH 5.3-5.6), with low inherent N fertility (0.10-0.14 %), but abundant P (18-50 ppm) and K (1.12-1.34 me/100 g). Soils at the rolling upland Claveria site are Oxic Dystropept of 70% clay, highly acidic (pH 4.0-4.5) and of low available P (7-14 ppm) and K (0.12 me/100 g).

The identification of compatible cultivars of cowpeas and mungbeans was an initial objective. Tests of materials which ranged widely in maturity and growth habit showed large variation in intercrop productivity (Figure 1). Indeterminate cultivars (such as VITA3 or VITA4) were aggressive in combination with rice, but early maturing

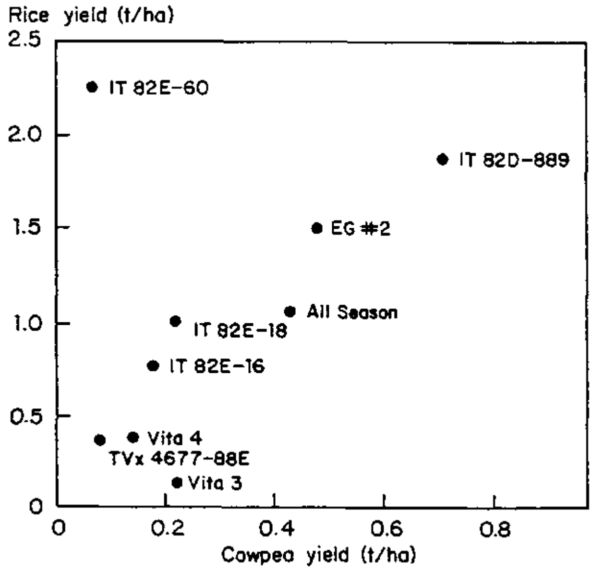

Fig. 1. Mean grain yields of rice and 9 cowpea cultivars when intercropped 50:50 (area basis). IRRI, 1985.

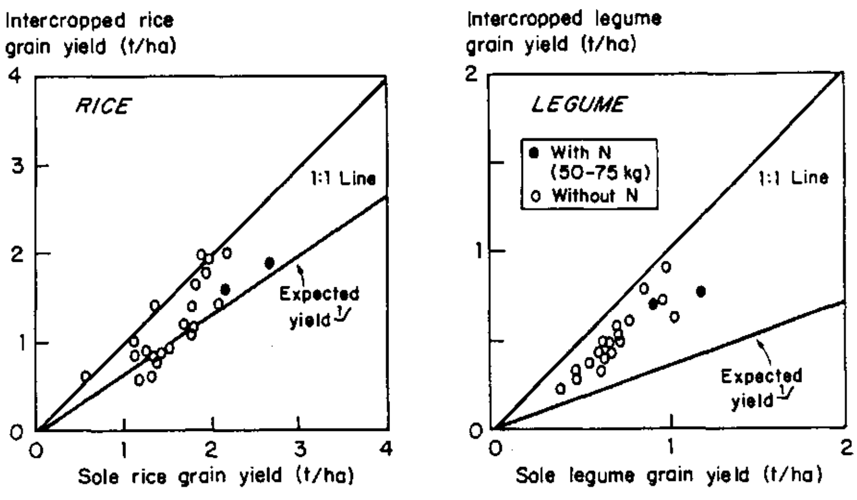

Fig. 2. Intercropped rice and legume yields as a function of their sole yields. Data from IRRI (1984, 1985, 1986) and Aggarwal et al (unpublished) 1/ Yield expected on the basis of field area occupied in the intercrop.

(60-65 day) determinate cultivars were identified which gave high yields with a low rice yield reduction, e.g. IT82D-889.

Early, determinate cultivars of both cowpeas and mungbeans were then combined with a modern upland rice variety (UPL Ri5 or UPL Ri7) of 125 days duration. The productivity and nitrogen dynamics of the intercrops were structured in experiments in which crop ratios, applied nitrogen, and irrigation water availability were varied. In the intercrop treatments, two or three rice rows alternated with one row of legume. Results of the individual experiments are described in detail in IRRI (1984, 1985 and 1986).

Grain Yield

The yield of sole rice in most experiments and treatments ranged from 1.0 and 2.5 t/ha, indicating limited yield potential of the sites without N application. When intercropped with mungbean or cowpea the grain yields of both rice and legume were reduced relative to the yield of sole crops (Figure 2). Two-thirds of the land area was occupied by the rice and one-third by the legume, but both crops always yielded more than that expected from their respective areas. In same cases, the grain yields of intercropped rice and sole rice were the same.

The yields of the intercrop components are plotted as a function of their respective monoculture checks in Figure 3. The Land Equivalent Ratios (LER) were calculated as the land area required using monoculture to equal the total yield of a hectare of the intercrop (Willey, 1979). The diagonal lines in Figure 3 represent LER levels. The LER varied between 1.2 and 1.8 indicating considerably increased resource use efficiency by the intercrop. The figure also shows that intercropped rice yields were generally between 70 and 100 percent of the sole crop whereas those of the intercropped legumes were between 60 and 80 percent of their sole crop yields.

TABLE 1. N yield (kg/ha) of sole and intercropped rice. Data is compiled from IRRI Annual Reports (1984, 1985, and 1986) and Aggarwal et al. (unpublished).

Experiment/ Treatment	Sole rice (kg N/ha)	Intercropped rice[a] (kg N/ha)	Intercropped rice[a] Percent[c]	Rice within intercrop[a] (kg N/ha)	Rice within intercrop[a] Percent[c]
1	21.6	23.7	110	35.4	164
2	26.6	19.5	73	29.1	109
3	27.7	28.6	103	42.7	154
4	28.1	28.0	100	41.8	149
5	29.8	33.8	113	50.4	169
6	31.0	34.8	112	51.9	167
7	34.1	31.5	92	47.0	138
8	34.6	25.8	75	38.5	111
9	35.4	33.4	94	50.0	141
10	39.5	35.9	91	53.6	136
Mean	30.8	29.5	96	44.0	142

[a]N yield per unit area of the intercrop.
[b]N yield per unit area of rice within the itnercrop, i.e., sole rice equivalent.
[c]percent of sole rice N uptake.

TABLE 2. Effect of plant interactions on grain yields of intercropped (I) rice and mungbean and N yield of rice (Aggarwal et al. unpublished).

	Treatment	Grain Yield (t/ha) Rice	Grain Yield (t/ha) Mungbean	N Yield of rice (kg/ha)	Percent N in rice grain
T1	Intercrop	1.40	0.81	33.4	1.23
T2	Intercrop with no-below ground interaction[a]	1.01	0.82	24.9	1.20
T3	Intercrop with slots prepared (Control for T2)[b]	1.30	0.74	33.1	1.19
T4	Intercrop with abscissed mungbean leaves removed	1.26	0.73	27.7	1.15
T5	Sole rice	1.76	-	35.4	1.02
T6	Sole rice - 3rd row removed[c]	1.34	-	28.6	1.13
T7	Sole mungbean	-	0.84	-	-
	ANOVA	**	**	**	**
	SE	0.12	0.05	3.1	0.04

[a]Galvanized iron sheets placed between rows in slots to 50 cm depth.
[b]Slots prepared for GI sheets as in T2 but sheets not inserted.
[c]Plants removed at harvest of mungbean.

N Uptake of Rice

The total N uptake of sole rice (straw + grain) varied between 21.6 and 39.5 kg/ha among experiments and treatments (Table 1). The N uptake of intercropped rice ranged from 19.5 to 35.9 kg/ha. Mean N yield for the intercropped rice was about the same as for sole rice. When the uptake of N was calculated per unit area of rice in the intercrop, the uptake exceeded that for sole rice in all experiments, indicating that the per plant N nutrition of rice in the intercrop was generally much more favorable than in monoculture rice. The reduction in N yield in intercropped rice was much lower than the reduction in grain yield. N availability to rice was greater when intercropped with a grain legume.

Partitioning Crop Interactions

The data suggest that a nitrogen benefit is experienced by a rice crop when intercropped with a grain legume. This increase in N availability might be due to (1) N transfer from the legume to the cereal, or (2) to the greater soil volume that may be explored by the intercropped rice; or to a combination of these two factors. N transfer itself may result from four mechanisms: a)direct excretion, b) nodule and root decay, c) leaching from leaves, or d) decomposition of fallen leaves (Burton et al, 1983; Elmore and Jacobs, 1987). N transfer in perennial forage mixtures is often considerable (Simpson, 1976). Broadbent et al (1982) found that up to 79% of the N in annual rye grass was transferred from ladino white clover. Brophy et al (1987) found that reed canary grass (*Phalaris arundinacea* L.) derived a maximum of 68% of its N from alfalfa (*Medicago sativa* L.) and 79% from birdsfoot trefoil (*Lotus corniculatus* L.) in an intercrop. This represented 13-17% of the N_2 fixed by the legumes, but N transfer occurred only over a distance of 20 cm.

N contributions from intercropped grain legumes to cereals have been inferred (Agboola and Fayami, 1972). ^{15}N tracer experiments have indicated N transfer from cowpeas to maize (Eaglesham et al, 1981). Patra et al (1986) observed that 28% of the total N uptake by intercropped maize (21.2 kg N/ha) was of atmospheric origin and was obtained from the cowpeas.

In a cereal+legume intercrop, N uptake by the cereal may be influenced by competition between the two crops for soil mineral N, which is in opposition to the supply from N transfer. Also, the second major mechanism responsible for the observed higher N uptake per plant in the intercropped cereal, greater root volume for exploration, must be considered in understanding the intercrop N balance. Greater root volume may be available to the cereal crop due to differences in rooting pattern (Angus et al, 1983), and due to the availability of the vacant soil volume after the harvest of the earlier maturing legume. In the case of a 125 day rice intercropped with a 65-day mungbean or 65-day cowpea, temporal complementarity of the crops for growth resources, including N, is substantial since maturities differ by 100%.

The contribution by the different growth resource factors to higher rice grain and N yields in the intercrop were explored in an experiment which attempted to partition these effects. The experiment consisted of two monocrops of rice, one monocrop of mungbean and four intercrop treatments (Table 2). Below ground contact between the intercropped rice and mungbean roots was prevented (T2) by placing vertical sheets of galvanized iron between the rows of the two crops to a depth of 50 cm. A control for this treatment was observed (T3) in which vertical openings 50 cm deep were prepared, as in T2. T3 was included to separate out possible effects on crop performance of the soil disturbance during insertion of the iron sheets. The N transfer of abscissed leaves of mungbean to intercropped rice was quantified by removing all abscissed leaves from the plots every second day, starting 40 days after sowing (T4). To quantify the advantage the intercropped rice would experience due to an increase in soil volume available per plant after the mungbean harvest, every third row of rice in a sole rice

TABLE 3. Grain and N Yield of Sole Rice and Rice Intercropped With Indeterminate Cowpea and Lablab (data from Aggarwal et al. unpublished).

Treatments	N Added by cippings	Yield per unit area of intercrop			Yield per unit area of rice		Legume grain yield
		Grain (t/ha)	N (kg/ha)	% N in grain	Grain (t/ha)	N (kg/ha)	(t/ha)
Sole rice	0	1.54	28.9	1.00	1.54	28.9	
Rice+cowpea intercrop	21.0	1.46	34.9	1.30	1.83	43.7	1.02
Sole rice with sole cowpea leaves	24.3	0.94[a]	-[b]	-[b]	1.88	-[b]	1.32
Rice+lablab intercrop	92.5	1.88	48.0	1.37	2.34	60.0	0.50
Sole rice with sole lablab leaves	109.2	1.46[a]	-[b]	-[b]	2.92	-[b]	
Sole cowpea	-	-	-	-	-	-	1.83
SE		0.19		0.04	-	-	-
ANOVA		**		**			

[a]Yields are expressed per unit of the total area occupied by both sole crops.
[b]Not sampled.

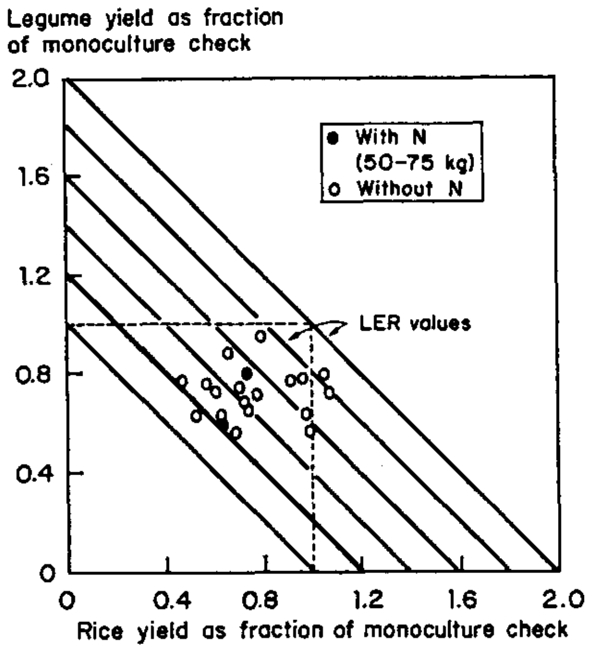

Fig. 3. Rice and legume yields as a fraction of the monoculture check yields, and Land Equivalent Ratios (LER). Data from IRRI (1984, 1985, 1986) and Aggarwal et al (unpublished).

treatment was harvested (T6) at the time mungbean was harvested in the intercrops. An undisturbed intercrop (T1), and sole rice (T5) and sole mungbean (T7) treatments were also included.

The grain yield of rice when intercropped with mungbean was 20 percent less than that of sole rice, but N yields were similar (Table 2). Where rice and mungbean were intercropped but separated by an underground partition (T2), rice yield and N content were significantly reduced. Mungbean grain and N yields were generally unaffected by intercropping with rice. The exception occurred when underground interaction was prevented (T2). The apparent absence of competition from the rice was probably due to the different growth durations of the two species as well as their different rooting depths (Angus et al. 1983). Abscissed mungbean leaves added 15.5 kg N/ha to the soil surface between 43 and 60 days after sowing, but their removal did not significantly reduce the yield of intercropped rice. The N yield of rice was 5.7 kg ha^{-1} (17%) lower when the abscissed mungbean leaves were removed but this was not statistically significant. Removal of every third row of rice at the time of mungbean harvest in the intercrop (T6) produced rice yields which were the same as those in the intercrop(T1) (Table 2). The N yield of rice was lower but not significantly so. The percent N in the rice grain was significantly reduced compared to the intercrop.

On the basis of the area covered by rice in the intercrop, the yield expected in the absence of any yield compensation in this experiment would be 1.76 t/ha sole crop yield 67% rice area coverage or 1.17 t/ha. The yield compensation observed was 1.40 - 1.17 or 0.23 t/ha (20%). The data suggest that this yield compensation was predominantly accounted for by the increased soil and aerial space available after the mungbean crop was removed. The N yield data indicate a relatively minor role for direct N transfer in the compensatory growth of the rice. These results have been confirmed by further experiments just completed during 1987 (data not shown). Comparison of T2 and T6 suggests that the substantial drop in rice yield with restricted rice root growth (T2) was

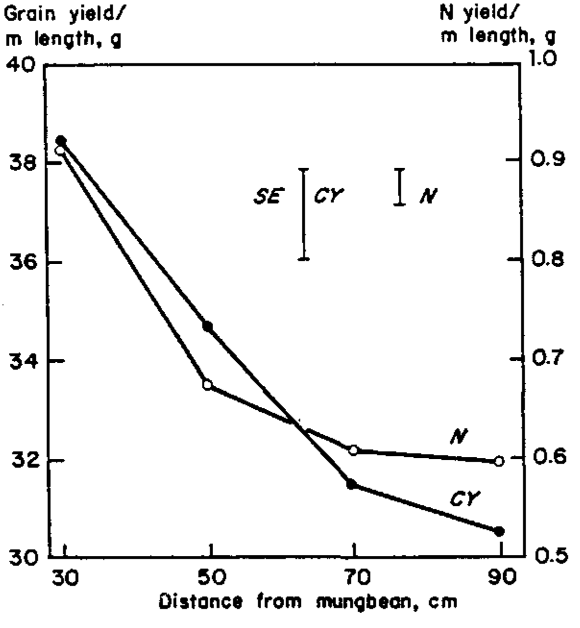

Fig. 4. Effect of distance from mungbean rows on grain yield and N uptake of intercropped rice rows.

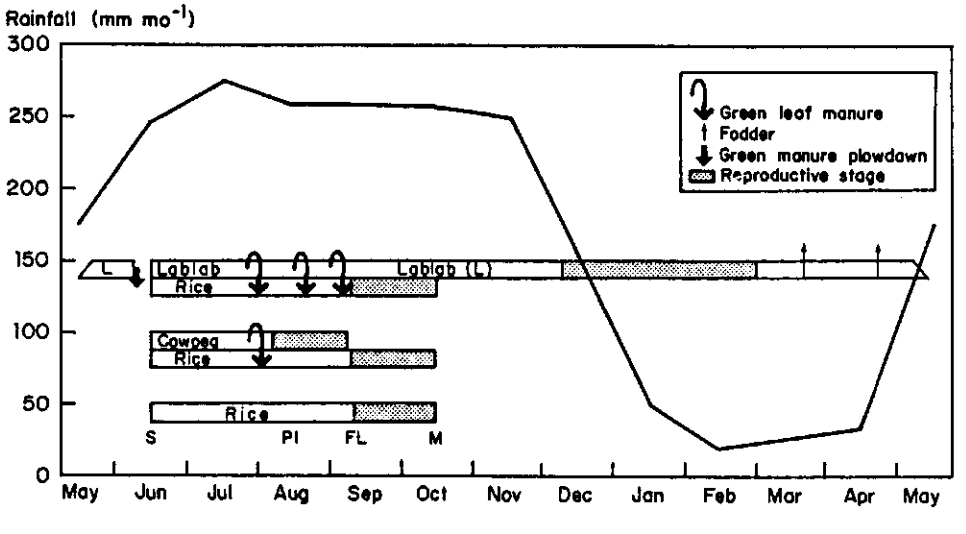

Fig. 5. Major treatments in an experiment on the intercropping of rice and indeterminate legumes for green leaf manure and plowdown green manure.

due primarily to the curtailment of soil volume accessible to the rice roots for N extraction before and after removal of the mungbean.

The compensatory benefit to adjacent rice rows in an intercrop was studied in greater detail in another experiment. The intimacy between rice and legume rows was varied by planting ten rice rows alternating with five mungbean rows. At maturity each rice row was harvested individually and its grain and N yield were determined. Figure 4 shows that rice yield and N uptake increased in successive rows as the distance between rice and mungbean decreased.

The rice row most intimately associated with mungbean had 26% higher grain yield and 52% higher N yield than the fourth row away, i.e., essentially sole rice. The effects were significant out to the second row at a distance of 50 cm from the mungbean. Again, these effects need not necessarily be due to N transfer, but could be accounted for by soil and aerial space availability to rice after the mungbean harvest.

INTERCROPPING WITH INDETERMINATE LEGUMES

The above discussion has shown that upland rice and determinate cowpea and mungbean are compatible crops and their intercropping at a 2:1 area coverage ratio, on the average, produces 80 percent of sole rice yield. In addition, considerable harvest of legume grain is obtained. Yet, any reduction in rice yield may not be acceptable to subsistence farmers having small land-holdings, large families, and whose primary staple food is rice. A more applicable objective by which to judge the advantage of intercropping for most upland rice farmers is that rice yields are maintained at their sole crop level, while production of additional yield from the legume component is treated as a bonus. This objective has been shown to be the basis for the widely practiced intercropping of sorghum and pigeon peas in India (Rao and Willey, 1980).

In order to meet this objective, we are now studying the feasibility of using indeterminate cowpea cultivars and lablab (*Lablab* purpureus, formerly Dolichos lablab L.) as sources of green manure for upland rice, with additional legume grain and fodder yield. Being indeterminate in habit, both crops have luxuriant vegetative growth and good N-fixation. Cowpea was selected because it is adapted to the acid, unfertile soils of most upland rice growing regions. Lablab is drought tolerant, produces quality fodder, has very good capacity to regrow after clipping, and its pods and seeds are edible.

The experimental approach was to grow upland rice between rows of either of the two legumes. These aggressive legumes would be clipped back several times during the rice growth and the tops applied as a green leaf mulch to transfer N to the cereal. Grain yield would be obtained from the cowpeas after clipping ceased at the rice reproductive stage. The lablab could continue to be maintained to supply green manure, fodder, and seed yield during the dry season.

The experiment conducted in 1986 consisted of five treatments grown under rainfed conditions (Fig. 5). Sole rice was sown in 20 cm rows. In the intercrops, 3 rice rows alternated with 1 legume row. In addition there were two treatments which consisted of sole plots of rice and equal sized sole plots of the legumes. Green leaf manure was clipped from the sole legume plots and applied to the sole rice plots at the same time that the intercrop legumes were clipped. These treatments simulated the application of green leaf manure from equal-sized areas outside the rice field.

Both legumes had excellent vegetative growth (Figure 6). The first clipping was done 40 days after sowing. Cowpea could not be clipped subsequently since it started flowering shortly afterwards. Since lablab does not flower under long days, it was clipped again on 58 and 73 days after sowing. The clipped foliage was applied as a mulch between the rice rows. In the intercrops the total N content of the clippings applied to rice was 21 kg/ha for cowpeas and 17, 28, and 48 kg/ha for a total of 92.5 kg N/ha from the first, second and third clippings of lablab. The sole cowpea plots supplied 24.3 kg N/ha in green leaf manure, the sole lablab yielded 109.2 kg N/ha. The grain yield and total N uptake (Table 3) of rice when intercropped with cowpeas (T2) was the same as for sole rice (T3). A bonus cowpea yield of 1.02 t/ha was obtained without adversely affecting rice productivity.

A

B

Figure 6. View of the field experiment on intercropping indeterminate legumes with upland rice for green leaf manure: (A) Rice+cowpea, (B) Rice+ lablab.

When sole rice was mulched with the green leaf manure from sole cowpea plots (T3), rice grain yields were substantially lower than when intercropped (T2). The N added by the cut and carry mulch did not compensate for the field area taken up by the cowpeas supplying the mulch in T3. The supply of N from cowpea clippings in the intercrop, together with the greater root exploration factor discussed above, enabled the rice crop to compensate entirely for the 33% reduction in field area occupied. The N uptake per unit area of rice increased from 28.9 to 43.7 kg/ha or 51%.

When intercropped with lablab (T4), rice yields were significantly increased by 340 kg/ha, and productivity per unit of actual rice area rose from 1.54 to 2.34 t/ha (Table 4). The increased rice yields in the intercrop were associated with a 66% increase in the rice N uptake per unit area of the intercrop, and a 104% increase in N uptake per unit area of rice within the intercrop. N uptake efficiency, as estimated by the increase in N yield per kg N applied in clippings, was relatively low at only 0.21. The ratio is 0.34 when calculated on the basis of N yield per unit area of rice. Thus, there appears to be a significant potential to increase the uptake efficiency. This could possibly be done through better manipulation of the legume cutting regime and soil incorporation of the green leaf manure. The cuttings were only applied to the soil surface as a mulch in this experiment.

The rice grain quality was observed to be substantially increased by intercropping (Table 3). The percent N content of the rice grain was 30% higher in the rice + cowpea intercrop and 37% higher in the rice + lablab intercrop.

The yield components of rice were studied to elucidate the factors controlling the greater productivity of the intercropped rice (Table 4). The higher grain yield in the rice + lablab intercrop was a function of a higher harvest index. The total dry matter of the rice did not differ between the sole and intercropped treatments, but the grain yield of the intercropped rice was higher. The number of panicles per m^2 was reduced in the intercrop but the number of grain per panicle and grain per m^2 was increased substantially. The harvest index of rice was also increased in the rice + cowpea intercrop, with a higher number of grain m^2.

Subsequent to the rice harvest the lablab was allowed to continue growing through the five-month dry season. The forage covered the plots to a height of more than one meter by the onset of the 1987 wet season. The biomass was incorporated into the soil just prior to seeding the following rice crop. The lablab had accumulated 19.0 t/ha of fresh biomass with over 100 kg N/ha. The plowed-down green manure produced a dramatic rice yield increase (data presently being analyzed).

We are continuing the 1986 research with the objective of confirming the results obtained, while investigating a number of other variations of upland rice intercropping with indeterminate legumes. The work has been expanded at IRRI and at the on-farm site at Claveria. The system is also being evaluated on a highly acid (ph 4.0) Orthoxic Palehumult at Cavinti, Laguna, Philippines.

If an herbaceous legume is seeded at the end of the wet season after the harvest of the cereal crop, high biomass of N production cannot be expected, since estabishment is often poor due to drought stress, and failure is frequently observed. If the crop is successfully established at this time, root system development is usually inadequate to maintain transpiration during the dry months. Therefore, methods of establishing the legume as a companion crop to the cereal appear to offer the best possibility to reap major gains of dry season green manure nitrogen.

Our results suggest that rainfed production systems can be developed in which the legume is established in the current rice corp without reduction in rice yields, enabling substantial green manure to accumulate during the dry season as plow-down for the following year's crop. Such a year-round production system is analogous to the perennial tree-legume alley cropping systems which have recently recovered much attention (IITA, 1984). Herbaceous legume intercropping systems may have certain advantages compared to tree legume alley cropping systems, due to their flexibility. Such systems deserve more research attention.

TABLE 4. Grain Yield and Yield Components of Sole Rice and Rice Intercropped With Indeterminate Cowpea and Lablab (data from Aggarwal et al. unpublished).

Treatment	Grain Yield (t/ha)	Dry Matter (t/ha)	Harvest Index (%)	No.of Panicles (/m2)	Grain Number (/m2)	Grains Per Panicle	1000-Grain Wt (g)
Sole rice	1.54	4.49	0.35	214	5674	26.5	27.3
Rice + cowpea	1.46	3.56	0.41	149	5439	36.5	26.8
Sole rice with sole cowpea leaves	0.94	2.91	0.32	144	3418	23.7	27.5
Rice + lablab	1.88	4.51	0.42	169	6839	40.5	27.5
Sole rice with lablab leaves	1.46	3.57	0.41	145	5088	35.1	28.6
SE	0.19	0.44	0.03	14	700		0.4
ANOVA	**	**	*	**	**		**

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SOYBEAN PERFORMANCE AS AFFECTED BY STABLE MANURE, PHOSPHATE AND LIME GROWN ON RED YELLOW PODZOLIC SOIL

Key Words: Lime phosphate Red Yellow Podzolic soil soybean stable manure

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Summary

A field experiment was conducted in Cigudeg, Indonesia to study the effect of stable manure, phosphate, lime and their interactions on the growth and yield of soybean (var. Americana) at the end of 1985-1986 wet season. The soil was Red Yellow Podzolic with low pH (4.2), high clay content (69.6%), high exch. Al (17.6 me/100g) and Al-saturation (61.6%), and very critical in nitrogen and phosphate. The experimental results indicated that lime rates of 2.2 tons and 4.4 t/ha were effective in increasing soybean yield, plant dry weight and plant height and promoting root development and root nodule formation. The highest lime rate increased the soil pH to 5.04 and decreased Al-saturation to 37.6%. Stable manure, TSP and the combination of the two were effective in promoting the growth and yield of soybean. They also induced root development and nodule formation. The combination of manure and TSP was better compared to manure or TSP when applied separately. It is suggested that breeding soybean varieties tolerant to low acidity and high Al-saturation are very important to reduce the use of lime to produce high soybean yield in acid soils.

Introduction

Among the grain legumes, soybean is the most important crop grown in Indonesia. It is used for food and fodder and plays an important role in the Indonesian diet as a source of cheap protein, much cheaper compared to protein from animal origin. Indonesia is selfsufficient in rice since 1984, but not yet in soybean. In 1977 soybean import was less than 100.000 t/yr, but since 1978 it has increased. During 1981-1984 the imports had reached 300-400.000 t/yr and in 1985 Indonesia still imported 200.000 tons of soybean.

The Government of Indonesia has made a strong effort to increase soybean production towards selfsufficiency through intensification and expansion of planted area. However, as a consequence of this expansion, new production areas are located on problem soils and marginal land, such as the Red Yellow Podzolics with acidic reaction. The major constraints to soybean production in these kind of soils are high acidity, deficiencies of phosphorus, calcium, potassium, magnesium, low organic matter and aluminium toxicity.

Red Yellow Podzolic soils cover an area of about 51 million ha, comparatively rare in Java, but common in Sumatera, Kalimantan, Sulawesi and Irian Jaya (Driessen and Soepraptohardjo, 1974). A strong effort was made by the government to convert these acid soils into productive land by soil-improving measures such as the use of lime and organic matter, balanced fertilizer application and the use of *Rhizobium* inoculum.

Available soil phosphate is often critical in Red Yellow Podzolic soils; therefore the use of phosphatic fertilizers is very important to promote high yield.

It is necessary to use lime in soils with high aluminium saturation in order to reduce or eliminate aluminium toxicity. The government launched a liming program in areas with acid soils during the last few years to promote soybean production.

The recommendation for lime application for soybean on the Red Yellow Podzolic soils at present is one and a half times the value of exchangeable aluminium, expressed in term of tons of lime per hectare if aluminium saturation is more than 20%. The priority are those soils which require not more lime than 3 tons per hectare. The experience indicated that lime application could promote soybean yield significantly on acid soils.

There is information available that lime application lower than one and a half times the value of exchangeable aluminium on soils with high aluminium saturation could increase soybean yield quite effectively (Ismunadji & Partohardjono, 1985).

In this paper information is presented on the effect of manure, phosphate and lime on the growth and yield of soybean grown on Red Yellow Podzolic soil with high aluminium saturation.

Materials and methods

A field experiment was conducted in Cigudeg, Jasinga (West Java) to study the effect of stable manure, phosphate, lime and their combinations on the growth and yield of Americana soybean variety at the end of the 1985-1986 wet season. The physical and chemical analysis of Cigudeg topsoil is presented in Table 1.

TABLE 1. Soil characteristics of Cigudeg topsoil

Parameters	Values
Texture	
Sand (%)	10.9
Silt (%)	17.6
Clay (%)	69.6
pH H_2O (1 : 2.5)	4.2
pH KCl (1 : 2.5)	3.8
Avail. P (Bray 2) (mg/100g)	0.54
Total N (%)	0.09
Total C (%)	0.95
CEC (me/100g)	33.4
Exch. Ca (me/100g)	9.8
Mg (me/100g)	1.1
K (me/100g)	0.33
Na (me/100g)	0.31
Al (me/100g)	17.6
H (me/100g)	0.91
Al saturation (%)	61.7

Table 1 indicates that the Cigudeg Red Yellow Podzolic soil has a high clay content, low pH, a very low phosphate and nitrogen content, and high exch. Al and Al-saturation. Exch. K and Mg are within the normal limit. Without inputs crops grow poorly in this area.

Three soybean seeds were dibbled per hole with 20 cm x 12.5 cm plant spacing. Poor grown plants or ungrown seeds were replaced one week after seeding. Soil preparation was similar to the local practice.

A factorial 4 x 3 design with three replicates was used to test the main effects and interactions between fertilizers (control, manure, phosphate and phosphate plus manure) and lime rates. The rates of manure were 0 and 5 tons/ha, TSP 0 and 200 kg/ha and lime 0, 2.2 and 4.4 t/ha. Manure and lime were broadcasted two days before seeding. All treatments were fertilized with 100 kg urea and 100 kg KCl/ha, broadcasted together with TSP. The manure, lime and inorganic fertilizers were mixed thoroughly with the soil. The lime used in this experiment was calcitic ground limestone. The plot size was 6 m x 4 m.

<u>Results and discussion</u>

The effect of manure, phosphate and lime on soybean grain yield is presented in Table 2.

TABLE 2. The effect of manure, phosphate and lime on soybean grain yield (t/ha).

Treatment	Lime rate (t/ha)			Mean
	0	2.2	4.4	
Control	0.55	0.93	1.25	0.91 a
Manure	0.77	1.10	1.40	1.09 ab
TSP	0.87	1.05	1.58	1.17 b
Manure + TSP	0.91	1.08	1.63	1.21 b
Mean	0.78 a	1.04 b	1.47 c	

Values followed by the same letter are not significantly different at 5% level

Table 2 indicates that lime application is effective in increasing soybean yield. The yield increased with increasing lime supply and almost doubled at the highest lime rate compared to control. The highest rate of lime application is equivalent to 0.25 x exch. Al; however this low lime rate is effective to promote soybean yield. Syaiful et al. (1984) reported that lime application at a rate of 3 t/ha increased soybean yield in a Red Yellow Podzolic soil in Sitiung 4 with high Al-saturation. Higher lime rates tended to yield lower. A recent experiment indicated that lime application at a rate of 1 x exch. Al was as effective as 2 x exch. Al on Red Yellow Podzolic soil with Al-saturation of 84.8% and yielded respectively 983 kg and 920 kg/ha. The control plants failed to grow well and yielded only 9 kg/ha (Anon. 1986).

In this experiment manure is as effective as phosphate to promote soybean yield. However the combination of manure and phosphate is better compared to manure or phosphate if applied separately. The importance of phosphate to increase the yield of soybean and other food crops grown on Red Yellow Podzolic soils was reported by many workers (Ismunadji and Partohardjono, 1985). Wade and Sanchez (1983) reported that green manure application decreased Al-saturation and increased soybean yield.

The effect of manure, phosphate and lime on plant dry weight at pod filling stage is presented in Table 3.

TABLE 3. The effect of manure, phosphate and lime on plant dry weight (g/plant) at pod filling stage

Treatment	Lime rate (t/ha)			
	0	2.2	4.4	Mean
Control	5.5	8.5	14.7	9.6 a
Manure	8.9	12.6	18.0	13.2 b
TSP	7.9	14.7	15.0	12.5 b
Manure + TSP	8.8	14.6	22.5	15.3 c
Mean	7.8 a	12.6 b	17.6 c	

Values followed by the same letter are not significantly different at 5% level

The effect of lime on plant dry weight is quite similar to the effect on yield. Soybean plant dry weight increases steadily by increasing lime rates. The dry weight is more than doubled at the highest lime rate compared to the control. As is the case with soybean yield, manure and phosphate are equally effective in increasing plant dry weight. The combination of manure and phosphate is even more effective.

The same trend is reflected with respect to plant height, as shown in Table 4.

TABLE 4. The effect of manure, phosphate and lime on plant height (cm) of soybean at pod filling stage

Treatment	Lime rate (t/ha)			Mean
	0	2.2	4.4	
Control	35.6	42.8	54.0	44.2 a
Manure	41.2	51.8	60.6	51.2 b
TSP	44.6	52.6	60.6	52.6 b
Manure + TSP	48.8	56.4	66.0	57.1 b
Mean	42.6 a	51.0 b	60.3 c	

Values followed by the same letter are not significantly different are 5% level.

Lime application is also effective in promoting root nodule formation. Root nodule dry weight increases significantly by lime application. Although the highest rate of lime has the highest root nodule weight, it is not significantly different compared to 2.2 t/ha of lime application (Table 5).

TABLE 5. The effect of manure, phosphate and lime on root nodule dry weight (mg/plant) at pod filling stage

Treatment	Lime rate (t/ha)			
	0	2.2	4.4	
Control	214	354	412	326 a
Manure	318	418	548	428 b
TSP	348	558	546	484 bc
Manure + TSP	378	556	606	514 c
Mean	314 a	472 b	528 b	

Values followed by the same letter are not significantly different at 5% level

Manure and phosphate are effective in promoting root nodule formation, but manure combined with phosphate is even better. Additional phosphate is essential in this Red Yellow Podzolic soil for root nodule development, since the soil is very critical in phosphate. Phosphate fertilizer application is also necessary for soybean growth, which has to provide carbohydrate to the root nodule bacteria. Therefore the phosphate application has a dual purpose, namely to promote root nodule development and soybean growth.

The root development is also affected by manure, phosphate and lime application (Table 6).

TABLE 6. The effect of manure, phosphate and lime on root dry weight (g/plant) at pod filling stage

Treatment	Lime rate (t/ha)			Mean
	0	2.2	4.4	
Control	0.9	1.1	1.5	1.1 a
Manure	1.1	1.4	1.7	1.4 b
TSP	1.3	1.6	1.7	1.5 bc
Manure + TSP	1.3	1.7	2.1	1.7 c
Mean	1.1 a	1.5 b	1.7 b	

Values followed by the same letter are not significantly different at 5% level

The control plants without lime has a poor root system, with only 0.9 g dry weight per plant. Lime application promotes root development and there is no significant difference on root dry weight between 2.2 tons and 4.4 t/ha lime application.

Manure and phosphate are also effective in promoting root development. Phosphate application is slightly better as compared to manure application, but the combination of manure and phosphate application has the best effect.

At the end of the experiment, composite soil samples were collected from the respective plots and analyzed for the soil pH and Al-saturation. The results are presented in Table 7 and 8.

TABLE 7. pH of Cigudeg soil after soybean harvest as affected by manure, phosphate and lime

Treatment	Lime rate (t/ha)			Mean
	0	2.2	4.4	
Control	4.65	4.71	5.14	4.83
Manure	4.63	4.81	4.99	4.81
TSP	4.70	4.65	5.15	4.83
Manure + TSP	4.65	4.72	4.86	4.73
Mean	4.65	4.72	5.04	

TABLE 8. Al-saturation (%) of Cigudeg soil after soybean harvest as affected by manure, phoshate and lime application

Treatment	Lime rate (t/ha)			Mean
	0	2.2	4.4	
Control	64.0	50.4	36.5	50.3
Manure	65.1	43.1	39.3	49.2
TSP	60.0	59.5	34.4	51.3
Manure + TSP	65.0	45.0	40.2	50.1
Mean	63.5	49.0	37.6	

Table 7 and 8 suggest that lime application could increase the soil pH and reduce Al-saturation. These effects seem to promote soybean growth, root nodule formation and yield. Lime application at a rate of 4.4 t/ha increases the soil pH to 5.04, which is quite favorable for soybean growth and development. The optimal pH range for soybean is 6.0-7.0 (Ignatief and Page 1958). Therefore it is expected that more lime application still could increase the soybean yield. The application of 4.4 t/ha lime reduces the Al-saturation to 37.6%. However in these conditions Americana soybean variety still could produce a reasonable high yield with an average of 1.47 t/ha, almost twice the yield of the control.

It could be concluded that the Americana variety is quite tolerant to high Al-saturation. This is in agreement with the result obtained by Mikoshiba and Somaatmadja using pot experiments (1984). It is the general assumption that the critical level of Al-saturation for soybean growth is 20%. Therefore it is very important to breed soybean varieties tolerant to soil acidity and Al saturation, which could reduce the use of lime. At present Bogor Research Institute for Food Crops is looking for soybean varieties tolerant to high Al-saturation. The released variety Shakti and Galunggung are considered to be quite tolerant to high Al-saturation (Mikoshiba and Somaatmadja 1984).

It is suggested to incorporate lime as deeply as possible for non irrigated crops sensitive to water stress (Soares et al. 1975). Deep lime incorporation reduces exch. Al to this depth and results in the development of deep root systems, which is effective in absorbing more water during occasional periods of dry weather.

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CALCULATING LONG-TERM CROP RESPONSE TO FERTILIZER PHOSPHORUS

Key words: Labile phosphorus Phosphorus uptake Residual effect of fertilizer phosphorus Simulation model Soil phosphorus cycle Stable phosphorus

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SUMMARY

A simple model designed to calculate the long-term recovery of fertilizer phosphorus was developed. In the model, a labile and a stable soil phosphorus pool are distinguished. With time intervals of 1 year, the model calculates the transfers between the pools, the uptake of phosphorus by the crop, and the resulting pool sizes. Most input data required to operate the model can be obtained from ordinary one-season fertilizer phosphorus trials. Calculated residual effects of fertilizer phosphorus were compared with results of long-term field trials and generally appeared to be in close agreement.

For easily soluble phosphorus fertilizers the residual effect can also be calculated with an equation:

$$Rt = (0.8 - R1)^{t-1} * R1,$$

where Rt and R1 are the recovery fractions in year t and year 1, respectively. During the first five years after fertilizer application the residual effects, as calculated with the equation, are almost equal to those obtained with the model.

INTRODUCTION

The first-year recovery of fertilizer phosphorus is generally low, particularly compared to that of nitrogen or potassium. In the long term the cumulative recovery of fertilizer phosphorus can be quite high, but in most situations it is unknown and cannot be calculated. If the yield increases resulting from phosphorus application and the profitability of the application are based only on the crop response in the first year, they are underestimated considerably. This was the reason that a model designed to calculate the long-term recovery of fertilizer phosphorus was developed.

The phosphorus cycle in the soil is quite complex, which is reflected by the many forms of phosphorus that can be distinguished. Apart from phosphorus in solution, at least three pools of inorganic phosphorus are considered, labile, stable and original soil minerals, and two pools of organic phosphorus, labile and stable. All these phosphorus pools interact directly or indirectly, and affect in this way the uptake by the crop and the effectiveness of fertilizer use. As the quantitative relationships of these processes are poorly understood, comprehensive models that distinguish all these processes, often yield unreliable results and in addition, are difficult to apply in practical situations. For these reasons a summary model was developed that is appropriate for calculating the recovery of fertilizer phosphorus in the year of application and its after-effects in the following years (Wolf et al.,1987).

For easily soluble phosphorus fertilizers it was shown by Janssen and Wolf (1988) that the residual effect can also be calculated with an equation, which is derived from the model.

MODEL STRUCTURE

In the model two dynamic pools of phosphorus are distinguished, a labile (LP) and a stable pool (SP) (Fig. 1). These pools include both inorganic and organic forms of phosphorus. Crops take up phosphorus from the labile pool and the uptake per cropping period (transfer 1 in Fig. 1) is calculated as a fraction of the labile pool (FRL). The stable pool serves as a slow-release buffer that replenishes the labile pool (transfer 2 in Fig. 1). There is also a transfer in the opposite direction (transfer 3), from the labile to the stable pool, representing all processes rendering labile phosphorus less available.

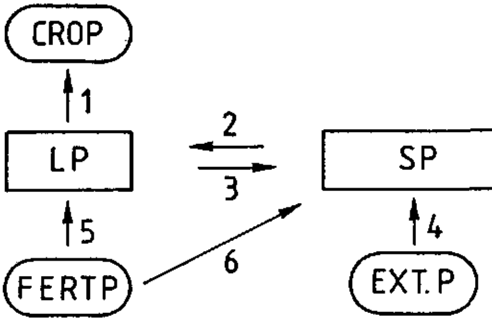

Fig. 1. The structure of the model. The numbers alongside the arrows refer to the transfers of phosphorus, discussed in the text. EXT.P = external P, phosphorus that does not belong to either the labile (LP) or the stable pool (SP). From Wolf et al., 1987.

The rates of transfer from the labile to the stable pool and vice versa are described in the model as fixed fractions of the pool sizes at the start of the time interval considered. The numerical values of these fractions are the reciprocals of the respective time constants of transfer. The sizes of both pools change in the course of time as a result of the transfers described above. These changes are added to the previous values of the phosphorus pools to arrive at the pool sizes at the beginning of the next year.

The stable and the labile pools, as used in the model, are not identified with phosphorus components in the soil. The labile pool in the model is defined as the phosphorus in soil that has an availability to crops equal to that of the labile fraction of broadcast fertilizer phosphorus. The stable pool comprises the store of soil phosphorus to which the time constants of transfer apply. Thus, the sum of stable and labile phosphorus is usually less than the total amount of soil phosphorus, because the soil may also contain phosphorus in minerals that weather very slowly.

The crop uptake of phosphorus is usually replaced in part by a net input of phosphorus (transfer 4 in Fig. 1), being the result of additions by weathering of phosphorus-containing soil minerals and supply through rainfall, volcanic dust and flood water, and losses mainly via soil erosion and leaching. Within the time scale pursued, the rate of net input can be assumed constant.

After application of fertilizer phosphorus, pockets with high concentrations of available phosphorus are formed surrounding the fertilizer granules, while the remainder is converted into less soluble compounds, which remain in the granule residue. These processes take place within a few days and therefore, fertilizer phosphorus in the model is partitioned directly to the labile and the stable pool (transfers 5 and 6 in Fig. 1).

Table 1 gives the distribution over the labile and the stable pool for some common phosphorus fertilizers.

TABLE 1. Indicative Values of Fractions of Labile and Stable Phosphorus for some common Phosphorus Fertilizers. From Wolf et al., 1987.

Fertilizer type	Labile fraction	Stable fraction
Ammonium phosphates	1.0	0.0
Superphosphates	0.8	0.2
Phosphate rocks	0.1 to 0.2 [1])	0.9 to 0.8 [2])

[1]) Fractions depend mainly on hardness and solubility of the phosphate rocks.

[2]) It is possible that in certain phosphate rocks a part of the phosphorus should be considered as inert, be it only because the rock is not properly grounded. Then the labile and stable fraction add up to less than one.

MODEL APPLICATION AND RESULTS

The data required to operate the model are the rate and type of fertilizer applied, the uptake of phosphorus by the unfertilized crop and that by the fertilized crop during the first year after fertilizer application, the net input of phosphorus and the time constants of transfer from the labile to the stable pool and vice versa. Rate and type of fertilizer are introduced by the user. Phosphorus uptake data are derived from ordinary one-season phosphorus fertilizer trials, where crop production with and without application of fertilizer phosphorus is established.

From the difference in phosphorus uptake the initial recovery fraction of fertilizer phosphorus and the crop uptake fraction of the labile pool are calculated. The procedure for calculating the input data, the model parameters, and the initial pool sizes to initialize the model and for calculating the phosphorus uptake by the crop, the pool sizes, and the fertilizer phosphorus recovery for successive years after a single fertilizer phosphorus application has been described by Wolf et al. (1987), to which the reader is referred for a complete explanation.

Results of long-term field trials with maize, sorghum, and rice, carried out in Brazil, Australia, and Madagascar were used to evaluate the performance of the model. The calculated and experimentally found residual effects of fertilizer phosphorus were in close agreement, provided the application rates were not too high and seasonal effects (mainly drought) not too strong. It was shown by Janssen et al.(1987) that values of 5 years for the time constant of transfer from the labile to the stable pool and of 30 years for that of the opposite transfer could be used for all locations, irrespective of the method of application and the type of fertilizer. Generally, the net input of phosphorus did not influence the residual effect of fertilizer phosphorus.

TABLE 2. Residual Recovery Fraction (*100) in successive years and Accumulated over 9 years, as dependent on the Initial Recovery Fraction. From Janssen et al.,1987.

Initial recovery fraction [1]	Year after application						
	2	3	4	5	7	10	Total [2]
Superphosphate							
4.0	3.0	2.3	1.8	1.5	1.0	0.7	13.2
8.0	5.7	4.1	3.0	2.3	1.4	0.9	21.5
12.0	7.9	5.3	3.7	2.6	1.6	1.0	26.5
16.0	9.7	6.1	3.9	2.7	1.5	1.0	29.3
20.0	11.2	6.4	3.9	2.5	1.4	1.0	30.4
Phosphate rock [3]							
1.0	0.9	0.8	0.7	0.7	0.6	0.6	6.2
2.0	1.7	1.4	1.3	1.2	1.0	0.9	10.6
3.0	2.4	1.9	1.7	1.5	1.3	1.2	13.7
4.0	2.9	2.3	1.9	1.7	1.5	1.3	15.9
5.0	3.4	2.6	2.1	1.8	1.6	1.4	17.5

[1]) Fraction of applied fertilizer phosphorus, recovered first year after application (*100).
[2]) From second year up to tenth, inclusive.
[3]) It is assumed that the phosphate rock does not contain an inert phosphorus fraction.

Apparently, the effects of soil and climate are taken into account sufficiently via the value for the initial recovery fraction. So, only the initial recovery fraction of fertilizer phosphorus is required to calculate the residual effect in the course of time. For different values of the initial recovery fraction, residual recovery fractions over a number of years after fertilizer application are computed with time constants of 5 and 30 years, both for superphosphate and for phosphate rock, respectively (Table 2).

The total fraction recovered in 10 years increases with increasing values of the initial recovery fraction, changing from 0.17 to 0.50 for superphosphate when the initial recovery fraction increases from 0.04 to 0.20, and changing from 0.07 to 0.23 for phosphate rock when the initial recovery fraction increases from 0.01 to 0.05. At an identical initial recovery fraction, e.g. 0.04, the residual recovery fraction is higher for phosphate rock than for superphosphate, which is due to the larger stable pool built up after application of phosphate rock.

EQUATION

For easily soluble phosphorus fertilizers, such as superphosphates and ammonium phosphates, the contribution of stable phosphorus, built up from fertilizer phosphorus, to the phosphorus uptake by the crop was shown to be quantitatively unimportant during the first years after application (Janssen and Wolf, 1988). In that case the decrease in the size of the labile pool depends only on the uptake by the crop and on the transfer from the labile to the stable pool. The rate of the last process amounts to 20 percent of the labile pool per year, as the time constant of transfer was 5 years.

So, in consecutive years the labile pool, and hence the phosphorus uptake and the recovery fraction of fertilizer phosphorus, decrease annually by 20 percent plus FRL, the crop uptake fraction of the labile pool. If Rt and R1 are the recovery fractions of fertilizer phosphorus in year t and year 1, respectively, the residual effect in the years after application of fertilizer phosphorus can be calculated with

$$Rt = (0.8 - FRL)^{t-1} * R1 \qquad (1)$$

The crop uptake fraction of the labile pool is calculated as the ratio of R1 and the labile fraction of fertilizer phosphorus, being 0.8 for superphosphates and 1.0 for ammonium phosphates (Table 1). So, for superphosphates it holds

$$Rt = (0.8 - 1.25R1)^{t-1} * R1 \qquad (2)$$

and for ammonium phosphates

$$Rt = (0.8 - R1)^{t-1} * R1 \qquad (3)$$

Figure 2 shows that for superphosphates the results obtained with Equations 2 and 3 are close to those of the model during the first years. Compared with the results of model, Equation 2 underestimates the recovery fraction from the second year onwards. Equation 3 overestimates the recovery fraction a little during the first years and underestimates it from year 4 or 5 onwards.

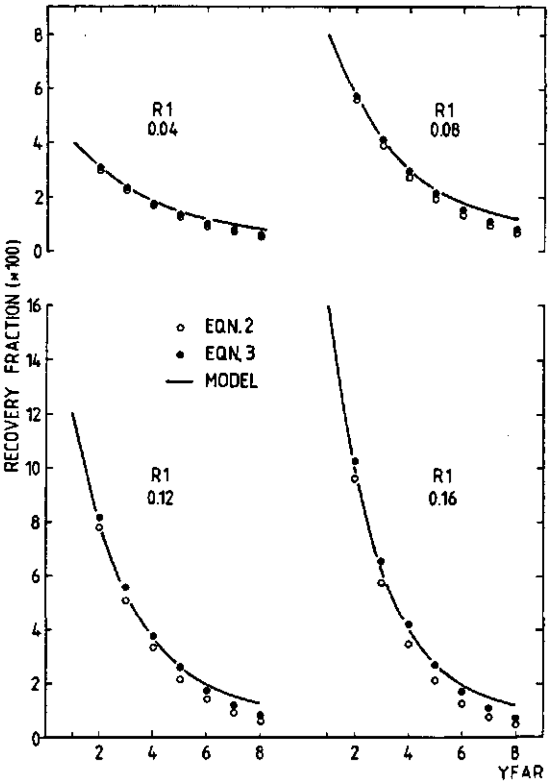

Fig. 2. Course of recovery fraction for superphosphates, calculated with the model and with two equations, for different initial recovery fractions (R1). From Janssen and Wolf, 1988.

It can be concluded that the residual effect of easily soluble phosphorus fertilizers can be calculated with Equation 3 as accurately as with the model for at least the first five years after application. It should be stressed that the equation can not be used for less soluble phosphorus fertilizers, nor for very high applications, and that in such situations the model has to be used.

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AGRONOMIC EFFECTIVENESS OF SEVERAL CROP SPECIES IN UTILIZING ROCK PHOSPHATES

Key words: Acidic uptake pattern Alkaline rock phosphate Alkaline uptake pattern Cowpea Finger millet Maize Rapeseed Relative agronomic effectiveness Rice Soil acidification Velvet bean

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SUMMARY

The relative agronomic effectiveness of six crop species in utilizing rock phosphates was tested in a pot experiment. The effectiveness increased in the order rice< cowpea <maize <finger millet <velvet bean <rapeseed. The processes and crop characteristics responsible for the positions of the species in this sequence vary among species. The low value of rice is an artefact associated with the strong ability of rice to utilize soil P. Cowpea and velvet bean as legumes both display alkaline uptake patterns, but the much higher dry-matter production of the latter crop explains its stronger soil acidifying and rock-phosphate mobilizing capacities. Maize has an acidic uptake pattern hampering the solubilization of alkaline rock phosphates in the rhizosphere. In addition, it absorbs little Ca, in contrast to finger millet which through its high Ca-uptake capacity can bring about a shift in the mass-action equilibrium of alkaline rock phosphates. Rapeseed absorbs even more Ca, has an alkaline uptake pattern, possesses long root hairs promoting the contact between roots and rock phosphate particles, and possibly extrudes organic acids.

INTRODUCTION

The number of known phosphate rock deposits, especially in the tropics, is rising steadily. In 1975, the known reserves were estimated at 82 x 10^9 ton (Notholt, 1975), whereas in 1983 the value had risen to 117 x 10^9 ton (Becker, 1983). Phosphate rock is now produced in over 40 countries ranging from the USA, annually producing 50 x 10^6 tons, to some producing only a few thousand tons per year. However, it is interesting to note that in the past 25 years the number of countries exporting phosphate rock has remained the same at 16, clearly emphasizing the fact that many countries are developing their resources primarily for domestic use.

When for technical or economic reasons, beneficiation of the rock is not feasible it becomes important to examine whether, after grinding, the rock phosphate as such can make a contribution to the P nutrition of crops.

The main factors influencing the availability of P applied as rock phosphate to crops are: soil factors, fertilizer factors, climatic factors, and crop factors. As for the first three factors mentioned, it is generally known that (a) the solubility and plant-availability of alkaline rock phosphates is larger in acid than in alkaline soils, (b) the rock phosphates of sedimentary origin are more reactive and consequently more available to plants than those of igneous and metamorphic origin, and (c) rainfall enhances the agronomic effectiveness of rock phosphates.

In the present publication, main emphasis will be placed on plant factors affecting the agronomic effectiveness of alkaline rock phosphates, and on the residual value of earlier applied rock phosphate. Regarding plant factors, it was earlier stated (Black, 1968) that three characteristics determine the ease with which different plant species can utilize alkaline rock phosphates. These characteristics are 1. the extensiveness and density of a root system, 2. the quantity of P needed for optimal growth of the species, and 3. the degree of ability of a plant species to withdraw Ca from the soil solution.

In recent studies (Aguilar and van Diest, 1981; Bekele et al., 1983; Flach et al., 1987) attention was given to the phenomenon that differences among plant species in quantities of total nutrient cations and -anions they absorb may have important implications for the pH of the rhizosphere and, thus, for the availabilities of rock phosphates.

Excess cation over anion absorption by plant roots would lead to loss of electroneutrality inside and outside the plant root, if not the plant would succeed in compensating any inequality in cation- and anion absorption. The observations made in water-culture experiments with plants absorbing more cationic than anionic nutrients, that the number of equivalents of base needed to restore the original pH is equal to the equivalents of excess cations absorbed, led to the postulation that plant roots are likely to extrude H^+ ions.

A distinction can be made between three situations in which excess cation uptake is to be expected and has been verified experimentally. First, plants absorbing all or most of their N as NH_4 (category 1) usually absorb far more cationic than anionic nutrients[1)] and extrude H^+ ions in the following quantity:

$$H^+ \text{ efflux} = \Sigma\ (NH_4^+, K^+, Ca^{2+}, Mg^{2+}, Na^+)_{absorbed} - \Sigma\ (SO_4^{2-}, H_2PO_4^-, Cl^-)_{absorbed}$$

Second, leguminous plants receiving their nitrogen through a process of symbiotic nitrogen fixation (category 2) also absorb more nutrient cations than -anions, leading to

$$H^+ \text{ efflux} = \Sigma\ (K^+, Ca^{2+}, Mg^{2+}, Na^+)_{absorbed} - \Sigma\ (SO_4^{2-}, H_2PO_4^-, Cl^-)_{absorbed}$$

Third, even in situations of N being absorbed predominantly as NO_3^- (category 3) some crop species absorb more nutrient cations than -anions, which can be expressed as

$$H^+ \text{ efflux} = \Sigma\ (NH_4^+, K^+, Ca^{2+}, Mg^{2+}, Na^+)_{absorbed} - \Sigma\ (NO_3^-, SO^{2-}_4, H_2PO_4^-, Cl^-)_{absorbed}$$

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1) Trace elements, although qualitatively important for each plant, quantitatively contribute too little to necessitate inclusion in these balance-sheet calculations.

In all three categories, the H^+ efflux will result in acidification of the rhizosphere, which will have a positive influence on the solubilization of alkaline rock phosphates.

One of the objectives of the present investigation is to compare the effectiveness of crop species, each belonging to one of the three abovementioned categories, in utilizing alkaline rock phosphates. The other objective is to examine whether any differences exist in the availability to plants of alkaline rock phosphates and triple superphosphate added to the soil either at planting time or five months before planting time.

Earlier work (Devine et al., 1968) has shown that in acid and neutral soil the decline with time in availability to plants of P added as TSP or as alkaline rock phosphate was much larger for the former than for the latter P source. On the other hand, it could be concluded from a number of experiments conducted on acid soils in the South Eastern United States (Ensminger et al., 1967) that the residual effect of rock phosphate was less or no better than that of half as much P originally added as ordinary superphosphate.

MATERIALS AND METHODS

A silt loam loess soil (Typic Hapludalf) was chosen for its low levels of available P and N. Relevant soil characteristics are: pH(H_2O) 6.0; total N 0.1%, total P 42 mg 100 g^{-1}, P extractable in ammonium lactate-actic acid (PAL) 1.4 mg 100 g^{-1}.

Two rock phosphates were used: Zimapan rock phosphate (ZRP) from Mexico and Tilemsi rock phosphate (TRP) from Mali, with total P contents of 14.5% and 13.4%, and P extractable in 2% citric acid 2.6% and 4.5% P, respectively. These materials are listed as low and moderately high in reactivity, respectively (Hammond et al., 1986).

These rock phosphates and TSP were added at a rate of 87.3 mg P kg^{-1} to 6-kg batches of air-dry soil contained in polyethylene bags. Soils and fertilizers were mixed thoroughly. The fertilizers were applied as powder < 0.125 mm. Demineralized water was added to 60% of moisture-holding capacity (MHC) and the soil, including controls without P added, was incubated at room temperature for 150 days, prior to use in the pot experiment.

The enamel pots used contained 6 kg of air-dry soil. Of these pots, 72 were filled with incubated and 72 with nonincubated soil. To the latter, the abovementioned quantity and types of P fertilizers were added at planting time. At that stage, all pots also received 1 g K and 0.24 g Mg, both as sulfates. To pots with legumes 0.1 g N as $Ca(NO_3)_2$ was added to support the early growth of the legumes, before they could start to rely on symbiotic N_2 fixation, for which purpose appropriate strains of Rhizobium had been added. Non-legumes, except rice, obtained 1 g N per pot as calcium ammonium nitrate, while rice received 1 g N per pot as urea, with half of it applied as basal dressing and the remaining half later as topdressing.

The moisture level in the pots was daily or twice daily restored to 60% of MHC, except for the pots with rice, in which the soil was kept flooded. A plastic tube, partly filled with clean quartz sand, was inserted into each pot, except those for rice. Watering and a second addition of K_2SO_4 and $MgSO_4$ were carried out through this tube. The soil was covered with clean gravel to minimize evaporation.

Six plant species were used in the experiment. They were:

Monocots

- *Zea mays*, var. LG 11 (maize), two plants per pot grown for 43 days.
- *Oryza sativa*, var. IR36 (rice), two plants per pot grown for 109 days.
- *Eleusine coracana* (finger millet), eight plants per pot grown for 92 days.

Leguminous dicots

- *Mucuna pruriens*, var. utilis (Bengal velvet bean), two plants per pot grown for 92 days.
- *Vigna unguiculata*, var. IT82D-889 (cowpea), two plants per pot grown for 74 days.

Non-leguminous dicot

- *Brassica napa napobrassica*, var. Jet neuf (rapeseed), eight plants per pot, grown for 90 days.

The growth periods of the non-leguminous crops were determined by the availability of N, except for maize where P was the primary limiting factor. When the crops started to show signs of nitrogen deficiency they were harvested. To accelerate germination, the seeds of the legume species were treated with conc. H_2SO_4 by soaking for one minute.

Of the abovementioned crop species, it was known that lowland rice belongs to the earlier mentioned category 1, Bengal velvet bean and cowpea to category 2, and rapeseed to category 3 (Hedley et al., 1982).

The plants were grown from July on in a greenhouse in which the day temperature was kept at about 24°C and the relative humidity between 70% and 75%. All treatments were present in triplicate in a design in which each crop species occupied a greenhouse table on which the pots were placed in a randomized fashion and changed positions daily.

After harvesting, drying, weighing, and grinding, composite plant samples consisting of representative portions of generative and vegetative plant parts were digested with conc. sulphuric acid, hydrogen peroxide and salicylic acid (Van Schouwenburg en Walinga, 1983). Total N and P were determined colorimetrically, K and Na flamephotometrically, with the use of a Technicon Auto-Analyzer. Ca and Mg were determined by flame emission- and absorption spectrophotometry, respectively. NO_3 and Cl, after extraction with water, were determined colorimetrically and potentiometrically with a chlor-o-counter, respectively. Total S was determined by digesting the plant sample with conc. nitric acid followed by measuring S by inductively coupled plasma-atomic emission spectrometry (Novozamsky et al., 1986). Final soil pH was measured potentiometrically at a soil / H_2O ratio of 1 : 2.5 (Houba et al., 1986).

A method was described (Breteler, 1973) for calculating acid and alkaline excretion by plants. The total number of equivalents of cationic and of anionic nutrients absorbed by NO_3-fed plants is calculated directly from the analytical values of K, Ca, Mg, and Na determinations, and of N, S, P and Cl determinations, respectively. In the case of NH_4-fed plants, the value for organic N is added to that of mineral cations, while the sum of total S, P and Cl is supposed to represent the sum of equivalents of anions absorbed. For plants utilizing symbiotically fixed N_2, nitrogen is not taken into account for ionic balance calculations, except for any N absorbed from soil sources and/or from starter-NO_3 added.

The relative agronomic effectiveness of rock phosphate applied is calculated with the following equation (Engelstad et al, 1974):

$$RAE = \frac{Yrp - Yc}{Ysp - Yc} \times 100\%$$

in which Yrp, Ysp, and Yc stand for average yield or P uptake obtained with the tested rock phosphate, the triple superphosphate and with no P added, respectively.

The percentages of P recovered by plants from applied P fertilizers were calculated as follows :

$$P\ recovery = \frac{Yp - Yc}{Pa} \times 100\%$$

in which Yp and Yc represent amounts of P absorbed from soil fertilized and not fertilized with P, respectively, and Pa stands for the amount of fertilizer P applied.

RESULTS AND DISCUSSION

Monocots

In Fig.1 data are presented on the uptake of P by plants grown on incubated and nonincubated soil. It can be observed that in general the effect of pre-incubation was nonexistent or was slight. In only three instances a significant difference was observed in P uptake from incubated and nonincubated soil. Two of these were found for TSP whose availability to velvet bean and cowpea was reduced by incubation. The third instance was a negative influence of incubation on the availability of soil P to cowpea.

It can therefore be inferred that a 5-month incubation period did not affect the availability of P applied as alkaline rock phosphate to the six crop species grown in the experiment on the neutral soil used, and that the availability of P applied as TSP was negatively affected by pre-incubation only for the two legumes.

In the original experiment, all plant material obtained in the experiment was analysed for its nutrient contents (Bako Baon, 1987). Since not only for P, but also for other nutrients little differences in

TABLE 1. Dry-matter production and nutrient uptake by the three gramineous monocots, as affected by variation in P source.

	P source			
	ZRP	TRP	TSP	Control
	maize			
Dry matter, g pot^{-1}	29.1 c*	38.0 b	85.5 a	26.2 c
Nutrient uptake, meq pot^{-1}				
K	32.1	35.8	31.9	29.4
Ca	9.7	12.9	17.8	8.8
Mg	8.3	11.4	21.9	6.7
H_2PO_4	1.2 b	1.5 b	2.8 a	1.0 b
	rice			
Dry matter, g pot^{-1}	101.9 a	100.6 a	100.8 a	111.3 a
Nutrient uptake, meq pot^{-1}				
NH_4	90.7	93.8	93.8	91.2
K	38.2	37.4	37.0	37.0
Ca	13.2	18.3	17.1	17.6
Mg	10.0	10.1	9.5	9.8
Na	1.2	0.9	1.7	1.7
Σ Cations (C_a)	153.3	160.5	159.1	157.3
H_2PO_4	5.8 a	5.9 a	6.9 a	5.9 a
SO_4	9.4	9.7	9.7	9.1
Cl	5.8	5.4	5.7	5.6
Σ Anions (A_a)	21.0	21.0	22.3	20.6
$\Sigma(C_a-A_a)$	132.3	139.5	149.4	136.7
	finger millet			
Dry matter, g pot^{-1}	141.7 a	144.1 a	149.4 a	123.4 b
Nutrient uptake, meq pot^{-1}				
K	72.3	74.3	71.2	70.9
Ca	75.4	71.5	72.3	65.9
Mg	41.5	46.8	54.0	40.0
N	127.4	133.1	136.6	132.1
H_2PO_4	4.1 c	5.5 b	8.8 a	3.0 d

* values followed by different letters differ significantly ($p < 0.05$) according to Duncan's multiple-range test

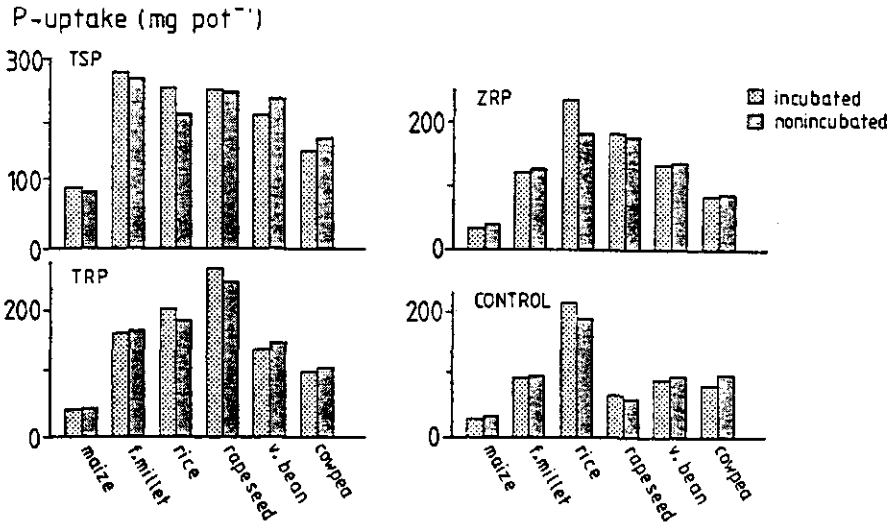

FIG. 1 The uptake of P (mg P pot^{-1}) by the six crop species grown on several phosphate sources with and without pre-incubation.

contents were observed for plants grown on incubated and nonincubated soil, the presentation and discussion of analytical data will in this paper further be confined to those obtained with the use of nonincubated soil.

Table 1 contains information on yield and chemical composition of the three cereals used in the experiment. Large differences were obtained in dry-matter yields. As to be expected, the differences in yield among the three cereals were smallest for TSP as P source. The use of alkaline rock phosphates instead of TSP resulted in large yield declines for maize, and no yield declines for rice and finger millet. The omission of fertilizer P led to yield declines in maize and finger millet, and no yield decline in rice.

The chemical composition of the plant material should be viewed in connection with the yield data, and knowledge on the cation-anion uptake balance sheets should be particularly useful in this respect. Only for rice, such a balance sheet could be calculated with the necessary accuracy. Lack of knowledge on the percentages of total N absorbed as NH_4^+ and NO_3^- prevented a calculation of such balance sheets for maize and finger millet. Fertilizer N was applied to these crops as calcium ammonium nitrate with a 1 : 1 ratio of NH_4^+-N and NO_3^--N. Under aerobic soil conditions, this ratio is bound to change during the growth period, thus preventing an accurate balance sheet of cation- and anion absorption to be calculated. For this reason, the analysis of nutrient contents in millet and maize was restricted to those nutrients which can be determined in the diluted digest in which P is also determined.

The lack of response of rice to P fertilizers and the negative (ZRP) and zero (TRP) values for the relative agronomic effectiveness values of the rock phosphates (Table 2) are to be ascribed to the high level of availability of soil P to rice. This finding is undoubtedly associated with the soil pH increase resulting from inundation of the soil (Table 3). It can be postulated that due to this pH rise enough of the originally present Al- and Fe phosphates became mobilized to meet the P requirement of the rice plants, in spite of the initially very low level of available P measured in this soil.

TABLE 2. Relative agronomic effectiveness of the rock phosphates and apparent ability of the various crop species to recover P applied as rock phosphate.

Crop species	Relative agronomic effectiveness, %		Apparent fertilizer-P recovery, %		
	ZRP	TRP	ZRP	TRP	TSP
rice	-11.1	0	-0.6	0.0	5.2
cowpea	-13.5	20.3	-1.9	2.9	14.1
maize	10.9	27.3	1.1	2.9	10.5
finger millet	18.0	42.7	6.1	14.5	34.0
velvet bean	29.7	41.4	8.2	11.5	27.7
rapeseed	61.5	99.5	21.9	35.5	35.7

The virtual absence of NO_3^- in a flooded rice soil justifies the calculation of a nutrient balance sheet in which all N is considered to have been absorbed as NH_4^+. It can be observed in Table 1 that under such conditions the total cation uptake far exceeds the total anion uptake, giving rise to a strongly alkaline uptake pattern. It appears, however, that the acidifying effect arising from this alkaline uptake pattern is overshadowed by the pH-raising effect of the reduction processes taking place in a recently flooded soil. This pH rise will hamper the solubilization of alkaline rock phosphates, but due to the improved availability of soil phosphate the P nutrition of the rice plant is not affected by this impaired solubilization.

TABLE 3. Final pH values in soil on which the crops with differential P treatments had grown.

Crop species	$pH(H_2O)$ value			
	ZRP	TRP	TSP	Control
maize	5.4	5.4	5.5	5.3
rice	6.7	6.5	6.7	6.5
finger millet	5.5	5.7	5.8	5.5
rapeseed	4.9	5.0	5.3	5.0
velvet bean	5.1	5.1	5.0	5.2
cowpea	5.8	5.7	5.4	5.7

With finger millet, the yields of dry matter obtained with rock phosphates are of the same order of magnitude as obtained with TSP, although the values for yield of P reflect the variations in solubility of P materials included in the experiment. These findings give rise to the thought that especially with the use of TSP some luxury consumption of P might have taken place. Yet, such an assumption must be viewed with caution since, contrary to maize and rice and possibly due to an unsuitable photoperiod, finger millet failed to produce any seed, and the extra P absorbed with the use of TSP may have been needed for seed production, if this would have taken place.

The quantities of P absorbed from the various P sources by finger millet reflect the variation in solubility among these sources (TSP > TRP > ZRP). In this experiment, finger millet is the only cereal absorbing less P from the soil source than from any of the fertilizer-P sources. It is also the crop absorbing far more Ca than the other cereals. A comparison of the Ca concentrations in the cereals can be made with the data supplied in Table 4. The outspoken ability of finger millet to withdraw Ca from the soil solution will facilitate the solubilization of rock phosphate particles, as shown in the equation $pH_2PO_4 = 2pH - 1.6pCa - 1.44$ expressing the concentration of H_2PO_4 in soil solution surrounding rock phosphate particles as a function of both soil pH and Ca concentration in the soil solution (Johnston and Olsen, 1972).

TABLE 4. Ca concentrations in the various crop species under differential P treatments

	Ca concentrations, $meq.kg^{-1}$ d.m.			
Crop species	ZRP	TRP	TSP	Control
maize	332	336	216	332
rice	360	368	343	347
finger millet	532	496	482	534
rapeseed	1100	892	780	1650
velvet bean	850	836	812	828
cowpea	608	614	704	584

It is likely that this capacity to absorb large quantities of Ca is mainly responsible for the ability of finger millet to utilize sparsely soluble rock phosphates. The relatively large withdrawals of K and Mg as well (see Table 1) make it likely, however, that in this experiment finger millet absorbed more nutrient cations than -anions which will have led to an acidification of the rhizosphere and will have promoted a further solubilization of the alkaline rock phosphates. Uncertainty about the NH_4: NO_3 ratio in N uptake, as explained earlier, prevents any definite statement to be made on this issue.

Dicots

Table 5 contains the data on rapeseed, velvet bean and cowpea. Among these crops, rapeseed proves to be the most effective in absorbing fertilizer P and the least effective in absorbing soil P, which characteristics are also reflected in the dry-matter yields. The ability of rapeseed to absorb Ca is even more outstanding than that of finger millet (see also Table 4). It was recently shown with the use of electron probe microanalysis (Jaillard, 1987) that the soil in the immediate vicinity of rapeseed roots is strongly depleted of Ca and, as a result of concomitant pH decrease, shows a high Al concentration. These findings can explain why alkaline rock phosphates are readily available and soil phosphates, in this case mainly Al- and Fe phosphates, are sparsely available to rapeseed. For this crop, several other characteristics have been suggested as being responsible for its unusually high P-absorption capacity, such as long root hairs, an alkaline uptake pattern leading to extrusion of protons (Hedley et al., 1982) and an ability to excrete organic acids (G.R. Findenegg, pers. comm.). This last characteristic, possibly combined with an alkaline uptake pattern, whose existence could not be verified in this experiment, may account for the large soil-pH decline, as found for rapeseed (Table 5).

In comparison with that of rapeseed, the rock phosphate mobilizing capacities of the two legumes are small, but differ considerably among each other. The Σ $(C_a - A_a)$ value of velvet bean is much larger than that of cowpea, which is reflected in lower final soil pH values for the former than for the latter crop. These differences are primarily a

TABLE 5. Dry-matter production and nutrient uptake by the three dicots, as affected by variation in P source.

	P source			
	ZRP	TRP	TSP	Control
	rapeseed			
Dry matter, g pot^{-1}	91.3 b*	98.2 ab	107.2 a	61.4 c
Nutrient uptake, meq pot^{-1}				
K	42.4	42.2	46.2	31.4
Ca	101.0	86.9	83.9	100.4
Mg	22.8	20.2	18.5	19.9
N	101.7	105.5	112.5	89.9
H_2PO_4	5.6 b	7.9 a	8.0 a	1.9 c
	velvet bean			
Dry matter, g pot^{-1}	77.5 b	79.2 b	115.9 a	75.4 b
Nutrient uptake, meq pot^{-1}				
K	42.4	42.2	46.2	31.4
Ca	65.9	66.2	94.1	62.4
Mg	12.4	13.0	18.5	11.6
Na	0.0	0.0	0.0	0.0
Σ Cations (C_a)	120.7	121.4	158.8	105.4
NO_3	7.1	7.1	7.1	7.1
H_2PO_4	4.4 b	4.9 b	7.6 a	2.9
SO_4	11.1	13.3	20.4	9.7
Cl	3.1	2.5	3.2	2.6
Σ Anions (A_a)	25.7	27.8	38.3	22.3
Σ (C_a − A_a)	95.0	93.6	120.5	83.1
	cowpea			
Dry matter, g pot^{-1}	39.8 b	46.3 b	59.7 a	42.2 b
Nutrient uptake, meq pot^{-1}				
K	19.7	24.2	29.1	21.5
Ca	24.1	28.4	42.0	24.6
Mg	10.0	11.0	13.0	9.3
Na	0.5	0.4	0.5	0.3
Σ Anions (C_a)	54.3	64.0	84.6	55.7
NO_3	7.1	7.1	7.1	7.1
H_2PO_4	2.8 c	3.6 b	5.5 a	3.1 c
SO_4	6.3	7.5	10.0	6.5
Cl	3.1	4.3	4.2	3.3
Σ Anions (A_a)	19.3	22.5	26.9	20.0
Σ (C_a − A_a)	35.0	41.5	57.7	35.7

* see footnote of Table 1.

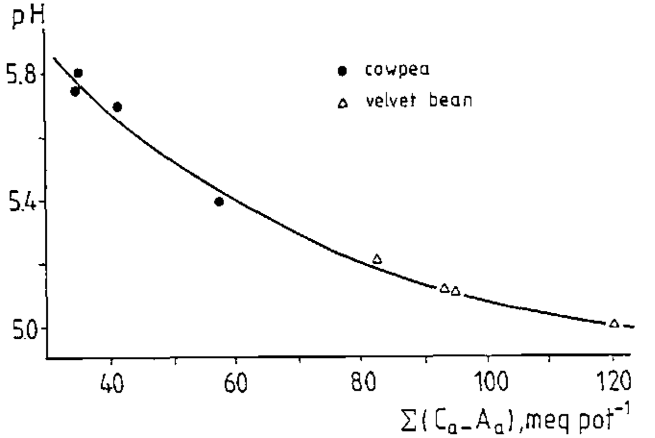

FIG. 2 The relationship between extent of the alkaline uptake pattern Σ (C_a − A_a) and the soil pH decrease brought about by the two legumes grown.

function of the large differences in biomass production: even when P is not a limiting factor (TSP treatment) two velvet bean plants produce about twice as much biomass as two cowpea plants. The relationship between Σ (C_a - A_a) values and soil pH decline is shown in Fig.2, in which the flattening of the curve at lower pH values is to be ascribed to increasing pH-buffering capacity of the soil with decreasing pH values.

The lower soil pH values brought about by velvet bean than by cowpea can account for the fact that velvet bean could solubilize and utilize both rock phosphate materials, whereas cowpea could utilize only TRP and not ZRP. These pH values were not as low as those obtained with rapeseed (Table 4), but it must be realized that in the case of rapeseed the pH lowering might have been due to the combined effects of nitrification of applied NH_4, an alkaline uptake pattern, and possibly extrusion of organic acids.

The relatively high values for agronomic effectiveness and rock phosphate-P recovery in the case of finger millet (Table 2) were ascribed to the ease with which this crop can absorb Ca. It can, however, be observed in Table 4 that the Ca concentrations in the legumes are still higher than that in finger millet. Still, only velvet bean utilizes rock phosphates as easily as does finger millet (Table 2), whereas in this respect cowpea lags far behind. The total amounts of Ca withdrawn per pot are likely to be more important than the Ca concentrations in the plant materials. For finger millet and velvet bean these values are of the same order of magnitude and for cowpea they are much lower, as is to be seen in Tables 1 and 5.

Velvet bean had a strongly alkaline uptake pattern resulting in low soil pH values (Table 3). The pH-lowering effect of finger millet was much smaller, possibly due to an acidic uptake pattern partially neutralizing the pH lowering effect of nitrification of fertilizer NH_4. The fact that nevertheless the rock phosphate mobilizing capacities of these two crop species are about similar may be partially caused by the much finer and denser root system of the monocot finger millet than of the dicot velvet bean.

CONLUSIONS

The results of the incubation experiment indicate that the availability of P in rock phosphates and TSP is not strongly affected by a 5-month incubation period of soil to which these fertilizers were applied. Hence, contrary to general belief, no evidence was present to imply that the availability of P in rock phosphate increases and of P in TSP decreases with increasing length of fertilizer-soil contact period, at least not for the soil and the incubation period used in this experiment.

It is further evident that large differences exist in the agronomic effectiveness of crops in utilizing rock phosphates, and that a number of crop characteristics may influence this effectiveness.

In previous experiments (e.g. Bekele et al., 1983) it was shown that with NO_3 as main N source maize has an acidic uptake pattern leading to a pH increase in the rhizosphere which will hamper the solubilization of alkaline rock phosphates, as was also experienced in the present experiment in spite of an overall soil pH decline due to nitrification of fertilizer NH_4. The same applies to finger millet, but this crop distinguishes itself through its high Ca uptake which enhances the solubilization of alkaline rock phosphates.

The latter also holds for rapeseed. The combined effects of a high Ca uptake rate, a resulting alkaline uptake pattern, the presence of long root hairs, and possibly organic-acid excretion make this crop outstanding in its ability to utilize alkaline rock phosphates.

Through their utilization of symbiotically fixed atmospheric nitrogen, the legumes exhibit an alkaline uptake pattern leading to acidification of the rhizosphere and solubilization of alkaline rock phosphates. In the present experiment, the much higher biomass production of Bengal velvet bean than of cowpea accounted for the fact that the former crop exceeded the latter in soil acidification and in effectiveness of rock phosphate utilization.

It was recently reported (van Eijk-Bos et al., 1987) that in Colombia a cultivar of *Mucuna pruriens* was effective in suppressing the growth of the obnoxious grass *Imperata contracta*. In West Africa, the cultivar grown in the present experiment is used to restrain the growth of Guinea grass (*Panicum maximum*). It can be hypothesized that in Asia cultivars of *Mucuna pruriens* might be useful in suppressing the growth of *Imperata cylindrica*. When the crop is considered for use as a weed-suppresser, it might be advantageous to know, that *Mucuna* is an effective utilizer of alkaline rock phosphates.

In this study, rice assumed a special position. Although the crop is known to be an effective feeder on fertilizer P, the conditions of the present experiment did not allow a proper evaluation to be made of the crop's capacities in this respect. The pH rise occurring in the submerged soil on which the rice was grown, was more conducive to a solubilization of the native Al- and Fe phosphates in the soil than of the alkaline rock phosphates added to the soil.

All crops used in this experiment, with the exception of rapeseed, are grown in the tropics. With increasing use of rock phosphates in tropical countries, it is important to be aware of the differences crops display in their effectiveness in utilizing rock phosphates. The various plant factors favoring the solubilization of these phosphates were met in various combinations in the crops used in this experiment. It would be interesting and useful to examine whether the outstanding ability to utilize rock phosphates, as experienced in rapeseed, will also be met in a crop like *Brassica juncea*, native to the tropics.

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TREND OF SOIL NUTRIENT MOVEMENTS IN TWO DIFFERENT SOIL TYPES AFTER CLEAR-CUT WITH OR WITHOUT BURNT IN KALIMANTAN, INDONESIA

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Abstract

Trends of soil nutrient movements after clear-cut clearing with or without burning was studied within period of 1.5 years on a Red-yellow Podsolic soil (Ultisol) and Podzol (Spodosol) in East Kalimantan, Indonesia. As controls were used soils under the primary and secondary forest of Dipterocarp and Kerangas forests.

The results showed considerable differences the dynamics of soil properties between two different forest types. These dynamics were different between burnt and unburnt treatments in mixed Dipterocarp forest, but both treatments showed a similar pattern in the Kerangas forest. In mixed Dipterocarp forest, soil conditions had more or less returned to the original levels after 1.5 years. In Kerangas forest, soils had considerably degraded in the same period.

It is suggested that forests on extremely poor soils (Podzols) be kept in their natural state, rather than converted into the arable lands.

Introduction

The apparent fertility of tropical soils is principally the result of high levels of organic matter at the surface and rapid mineralization of this detrital pool. Once cleared of forest, the nutritional reserves of the soil decline rapidly and their restoration is dependent of the repopulation by successional plant species, which may vary from one site to another.

The general relationship between soils and vegetation needs to be considered briefly in order to put the observations from different sites in proper perspective. Knight (1975) reviewed literature on soil-vegetation relationships and concluded that in general species composition is relatively insensitive to soil characteristics in tropical forest. In Australia, rainforest distribution has been correlated with soil nutrients, especially phosphorous (Webb, 1968). Soil physical factors were shown to have a much more limited effect (Tracey 1969). Within climatic zones, disturbance by fire reduced the degree of correspondence between vegetation type and soil fertility.

The purpose of the present study is to assess the changes in soil nutrient levels under two different forest types i.e. mixed Dipterocarp forest and Kerangas forest and the effects of clear-cutting with or without burning of forest litter.

Study areas

This study, a part of the Man and the Biosphere (MAB) Project No.I, was carried out in East Kalimantan, Indonesia. The forest, with primary and secondary vegetation, is described in detail by Riswan (1982, 1987a).

The primary mixed Dipterocarp forest (control plot A) was developed on Red-yellow podzolic soils derived from sedimentary rocks formed during

Table 1. Chemical and physical properties of the top soil (0-10 cm) in primary (A) and secondary (B) mixed Dipterocarp forest (MDF) and the primary (P-1 and P-2) and secondary (Q) Kerangas forest (KF)

		A	B	P-1	P-2	Q
A. Soil physical properties.						
Texture (%)	clay	26.4	36.6	3.7	4.0	5.1
	silt	34.2	37.8	1.9	0.9	1.3
	sand	39.4	25.6	94.4	95.2	93.7
Moisture (% d.w.)		0.9	2.1	8.9	3.1	1.0
B. Soil chemical properties.						
pH (1:1)	H_2O	3.4	4.1	3.7	3.5	3.8
	KCl 1N	3.3	3.4	2.4	2.4	2.7
Exchangeable bases (me/100g.)						
	K	0.5	0.7	0.1	0.1	0.1
	Na	0.2	0.2	0.1	0.2	0.2
	Ca	4.2	4.0	1.7	1.6	0.8
	Mg	1.3	2.5	2.1	1.4	1.7
CEC (me/100g)		22.2	13.9	19.9	17.5	15.1
Base saturation (%)		34.1	43.4	22.2	22.1	20.3
Organic C (%)		4.3	2.1	6.4	4.2	4.3
Total N (%)		0.4	0.3	0.1	0.1	0.1
C/N ratio		9.84	8.48	48.85	35.08	39.00
Organic matter (%)		7.5	3.7	10.9	7.2	7.4
Available P (ppm)		8.5	5.3	0.7	1.4	1.2
Total P (ppm)		140.9	131.1	6.1	8.2	6.4

Values are means of 9 samples (plot A) and 6 samples (other plots)

the Upper Miocene Period (Anonymous, 1965), with an altitude between 40-80 m above sea level in an undulating and somewhat hilly topography. The climate is humid, belonging to the rainfall type A with a Q value of 7.4 (Schmidt and Ferguson, 1951). The annual rainfall is 1935 mm with monthly rainfall ranging from 97 mm in August to 206 mm in December (Berlage, 1949).

The secondary forest site was located in the same area about 350 m away from the primary forest. The 1.6 ha primary forest site contained 209 species of tree over 10 cm dbh, which is typical of the species diversity in the West Malaysian Forest Region (Ashton, 1965; Wyatt-Smith, 1966; Poore, 1968; Whitmore, 1975). The Dipterocarpaceae were the most represented, whereas the family with the largest number of species was Euphorbiaceae. Eusideroxylon wageri (Lauraceae) was the single most frequent species.

In the secondary forest (control plot B), developed on an abandoned pepper plantation during a period of 35 years, the number of species was 121 on a plot of 0.8 ha. Here, the family with the greatest total area was Euphorbiaceae. It also provided the highest number of species, although the species concerned were different from those in the primary forest. Pternandra azurea was the most frequent species. Both experimental plots are described in detail by Riswan (1982) and Riswan and Kartawinata (1986).

Similar cases also have been studied in Kerangas forest at Samboja, East Kalimantan (Riswan, 1982, 1987b), located at Gunung Pasir, Samboja, about 57 km north-east of Balikpapan. The word "Kerangas" is a word of the Dayak Iban language, meaning that rice cannot grow on after clear-cutting and burning. On this site, the altitude ranged between 20-40 m above sea level. The soils were podzols developed in white sands derived from sedimentary rocks of the Upper Miocene formation (Anonymous, 1965). The climate was wet, belonging to the rainfall type A with the Q value of 4.4 (Schmidt and Ferguson, 1951). The annual rainfall was 2347 mm, with monthly rainfall ranging from 129 mm in October to 273 mm in April (Berlage, 1949).

Two primary forest plots (control plot P-1 and P-2) of 0.5 ha consisted of 24 and 14 tree species respectively with the dbh > 10 cm. The prevalent tree species were Tristania obovata, Cotylelobium flavum, Eugenia claviflora and Brackenridgea hookerii. The secondary forest plot (control plot Q; 0.5 ha) was located in the same area about 200 m north-east of the primary plot. It consisted of 8 tree species with Rapanea umbellata, Ilex cymosa and Callophyllum pulcherianum as the most prevalent. These trees appear to be the most resistent to disturbances and burning, due to the fact that the recovery process is dominated by vegetative resprouts. In 1.5 years-old experimental plots (both with or without burning), vegetative resprouts such as Tristania obovata and Cotylelobium flavum and other resistant trees were the most prevalent resprouts.

Methods

Composite soil samples (10 x 10 x 10 cm3) were collected from both experimental plots at 20 m intervals from mixed Dipterocarp forest (MDF) and Kerangas forest (KF), at six weeks intervals during the first six months and thereafter every six months.

In MDF 7 soil samples per experimental plot were taken, 9 in primary and 6 samples in secondary forest plot. In KF these numbers were 6, 12 and 5 samples respectively.

The physical and chemical analysis of all soil samples were carried out in the Department of Natural Sciences, Bogor Agricultural Institute. Soil moisture was measured in an oven (Allen, et al, 1974); soil texture by using the Bouyoucos (1926) method; soil pH was determined with the potentiometric method using a Beckman pH-meter; cation exchange capacity (CEC) was determined with NH_4OAc. Exchangeable bases of K, Na, Ca and Mg were determined by flame photometer (K and Na) and EDTA-titration (Ca and Mg). Total N was determined by the Kjeldahl method. Organic carbon was determined with the Walkley and Black (1934) method, available P by Bray and Kurz (1945) and total P by Murphy and Riley (1962).

The soil data collected were analyzed using the PCA (Principal Component Analysis) method, which is an efficient method of summarizing soil variation and it has also proved to be useful in trend seeking. (Orloci, 1973). The PCA-program applied was developed at the University of Kansas, USA and has been modified and implemented by T. Demiray of Computing Centre, Aberdeen University.

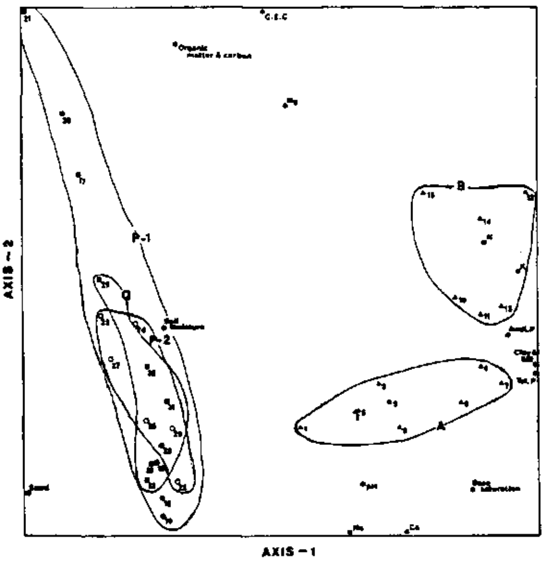

Figure 1. Principal Component Analysis of composition of the topsoils of Podzols (KF) and Red-yellow podzolic soils (MDF), Kalimantan.
A= primary MDF,
B= secondary MDF,
P-1 and P-2= primary KF,
Q= secondary KF.

Results and discussion

Nutrient status in podzol and red-yellow podzolic soils

A Principal Component Analysis of the topsoil (0-10 cm) revealed a clear separation between podzols (Kerangas forest) and red-yellow podsolic soils (Dipterocarp forest) (Fig. 1). The soil under Kerangas forest tended to be associated with low nutrients, sandy texture and low organic matter, whereas the mixed Dipterocarp forest soils had much higher clay and silt contents and richer in nitrogen, phosphorous and potassium (Table 1). Fig. 1 also confirms that soils of the primary Kerangas forest were quite variable.

In contrast the primary and secondary mixed Dipterocarp forest are clearly separated in their soil properties. The soil under secondary mixed Dipterocarp forest is relatively high in nitrogen and potassium, as reported by other authors (Harcombe,1977 and Vitousek and Reiners, 1975).

Only at a stage where the forest ecosystem is recovering, or in a certain stage in the succession where most of the species are secondary or pioneer species, many leguminous plants may occur (Riswan, 1982).

Trend of soil nutrient movement in Kerangas forest

The results of PCA-analysis of soil changes during 1.5 years in podzols revealed following (Fig. 2):

1. In the early stages after clear-cutting with or without burning, there is an increase in pH, exchangeable Mg, base saturation and also total and available P. The clear-cut and burnt experimental plot shows a much bigger effect due to the presence of ashes, where subsequently there is a decline. But for other major soil properties e.g. K, organic matter, a sharp decrease was noted following clear-cutting and burning.

2. After 1.5 years, both treatments still had a high level of soil organic matter, carbon, nitrogen, available and total phosphorus, CEC, exchangeable bases of K and Ca.

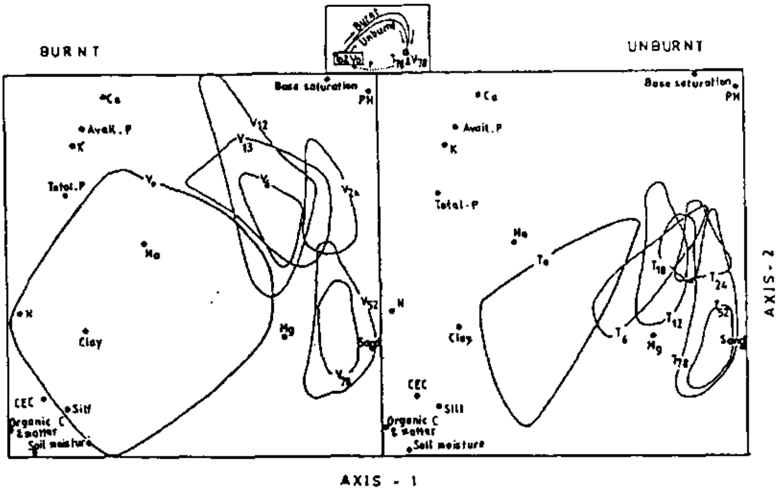

Figure 2. Principal Component Analysis of changes in soil properties after clearcutting with and without burning in podzols (KF).
Legend: T0 and V0= primary KF before treatments
T6 to T78= samples 6 - 78 weeks, unburnt plots
V6 to V78= samples 6 - 78 weeks, burnt plots

Results suggest that clear-cutting with or without burning is not only destroying the overall nutrient cycling of this complex soil-plant ecosystem, but also to washes-out most of nutrient elements stored by erosion and leaching. These last two processes are accelerated by poor vegetation recovery or poor recolonization (Riswan, 1982) and rapid drainage in sandy soils. This seems to be a general feature of KF soils, and the deep-rooting resprouts that recycle leached nutrients may be a good approach to prevent further deterioration of the soil.

Trend of soil nutrient movement in mixed dipterocarp forest

In red-yellow podzolic soils, unlike the podzols, the pattern of nutrient movement in the two sites is quite different (Fig. 3) at the beginning, but after 1.5 years both patterns converse. This means that initially, at least, quite different processes must be taking place.

It seems that the occurrence of ashes in the soil surface causes an increase in the exchangeable K and Ca, pH, CEC and available P. There are also huge numbers of seedlings (Riswan, 1982) which can trap the silt and clay fraction and any nutrients which are released. In the clear-cut and unburnt plot there is little change in the first 6 weeks, but there is increasing silt content. After a period of 52 weeks period the soils on burnt and unburnt sites still are distinct.

The soil condition of the burnt plot already has returned to a position close to the initial situation. However, between 52 and 78 weeks, there are big changes in the unburnt plot which bring it closer to the conditions of the burnt plot.

This means that the general changes have taken place faster in the burnt plot in earlier stage when the influence of ash was still very important. After 78 weeks most soil parameters are returning to levels found prior to treatments.

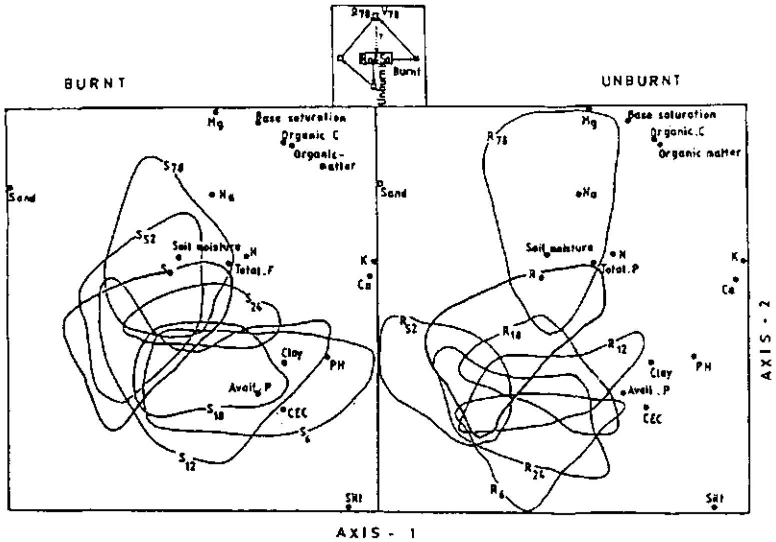

Figure 3. Principal Component Analysis of changes in soil properties after clearcutting with and without burning in Red-yellow podzolic soils (MDF).

Legend: R0 and S0= primary MDF before treatments
R6 to R78= samples 6 - 78 weeks, unburnt plots
S6 to S78= samples 6 - 78 weeks, burnt plots

General discussion

Soil texture and soil organic matter levels remained constant in red-yellow podzolic soils (MDF), but changed in podzols (KF), where considerable decreases in clay, silt and organic matter-levels were observed (Fig. 4 and 5).

In MDF, initial increases in CEC, K and Ca-levels occurred (Fig. 6), which might be related to the very fast recolonization of the bare soil by pioneer trees in MDF, but not in the KF. Thus, it appears that pioneer species have two major roles to fulfill after forest clearing, namely:

1. to protect the soil surface from the destructive effects of rain, wind etc. and
2. to enhance the fertility of the soil surface through litterfall.

Other evidence shows that the leaf nutrient status of pioneer species is very high compared with primary species (Riswan, 1977, 1982 and 1987c). Thus, it would appear that pioneer species are very fast accumulators of nutrients (Riswan, 1982; Riswan and Kartawinata, 1986).

Burning caused changes in pH; pH increased in the first six months and then returned more or less to the original level after 1.5 years, both in Podzols and Red-yellow podzolic soils (Fig. 7). The increased pH was possibly due to the ash on the soil surface which contains large amounts of soluble salts of Ca, Mg, K and Na. These changes in pH occur throughout the soil profile (Riswan, 1982), since leaching takes all the soluble mineral salts down.

Total nitrogen levels declined rapidly after clearing in podzolic soils, but did not show much change in Red-yellow podzolics. In the burnt MDF plot, total N reached the highest level after six months and after that returned to its original level (Fig. 5).

A similar pattern could be observed regarding the levels of total and available phosphorus.

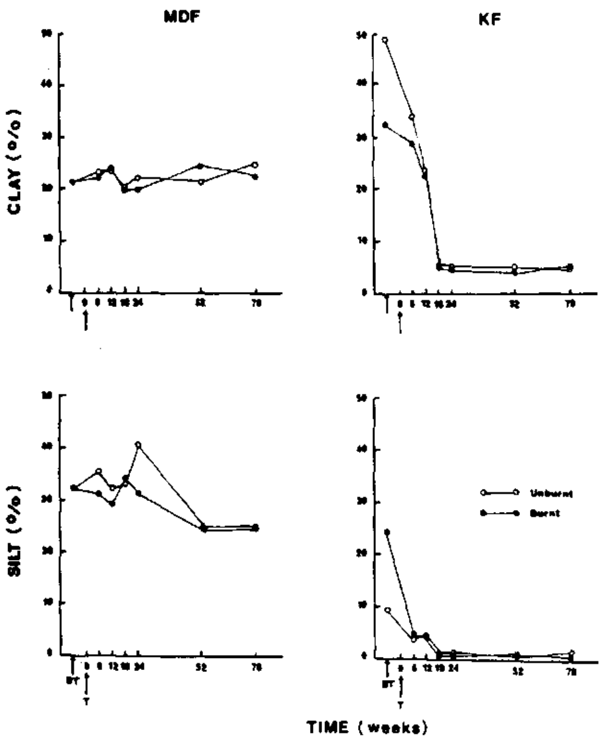

Figure 4. Changes in clay and silt content in top soil (0-10 cm) in experimental plots MDF and KF.
(BT= before treatment, T= treatment)

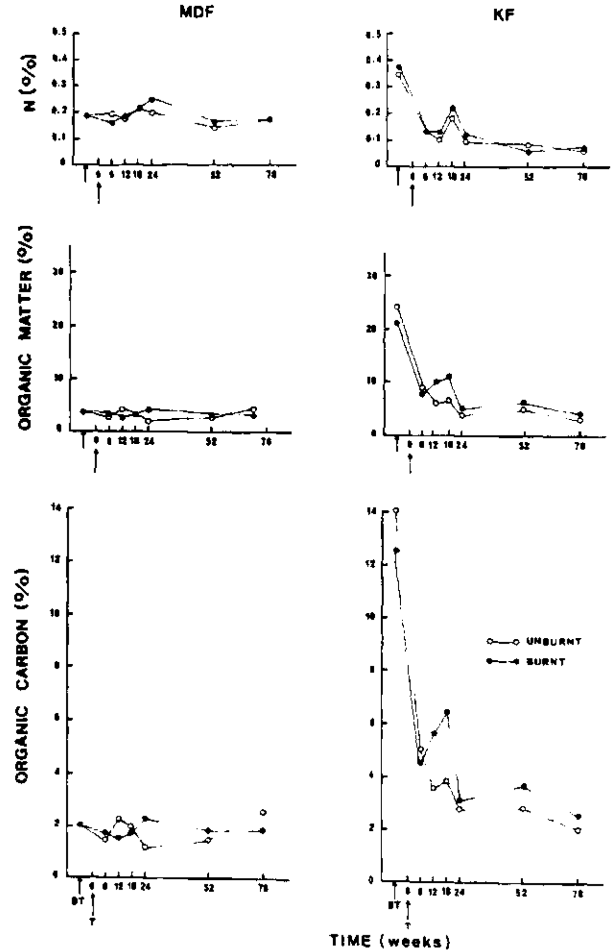

Figure 5. Changes in nitrogen, organic matter and carbon levels in top soil (0-10 cm) of the experimental plots MDF and KF.
(BT= before treatments, T= treatment)

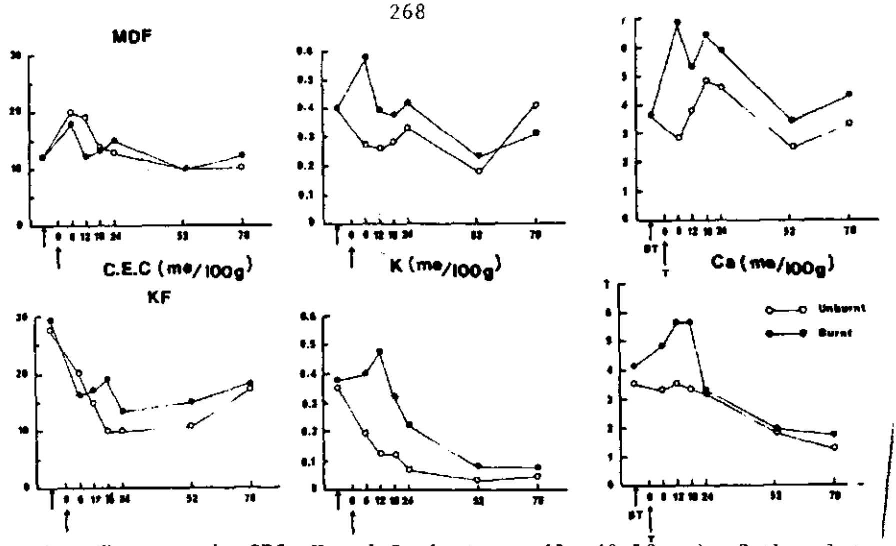

Figure 6. Changes in CEC, K and Ca in top soils (0-10 cm) of the plots MDF and KF. (BT= before treatment, T= treatment)

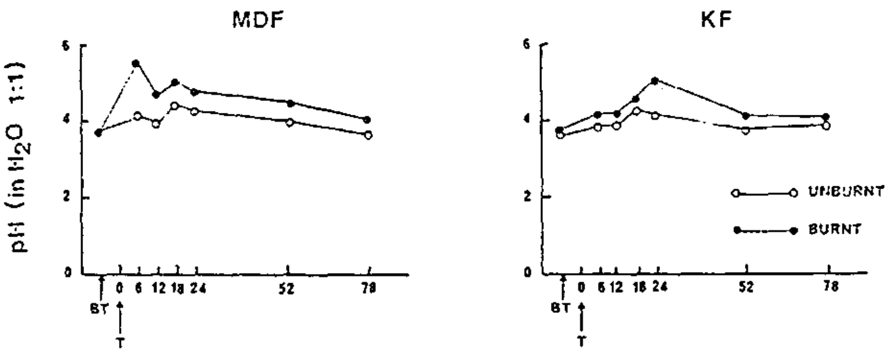

Figure 7. Changes in pH in top soils (0-10 cm) of the plots MDF and KF. (BT= before treatment, T= treatment)

In Red-yellow podzolic soils (MDF), levels increased in the first six months for both treatments and then declined in particular in the unburnt plot. In the burnt plot however available P was still increasing after 1.5 years. Results suggest that recovery process of soils in the burnt plot is faster than that in the unburnt plot on Red-yellow podzolic soils. P-levels in Podzols declined to very low levels in 1.5 years (Fig. 8).

Conclusions

A comparison of the dynamics of soil properties after clear-cutting, with or without burning in two different soil types (podzols and red-yellow podzolic soils) under two different forest types (Kerangas and mixed Dipterocarp forests) show a different pattern between burnt and unburnt plots during 1.5 years in mixed Dipterocarp forest, but are similar in Kerangas forest. In mixed Dipterocarp forest, soil conditions more or less have returned to the original levels, while in Kerangas forest a trend of degradation persists.

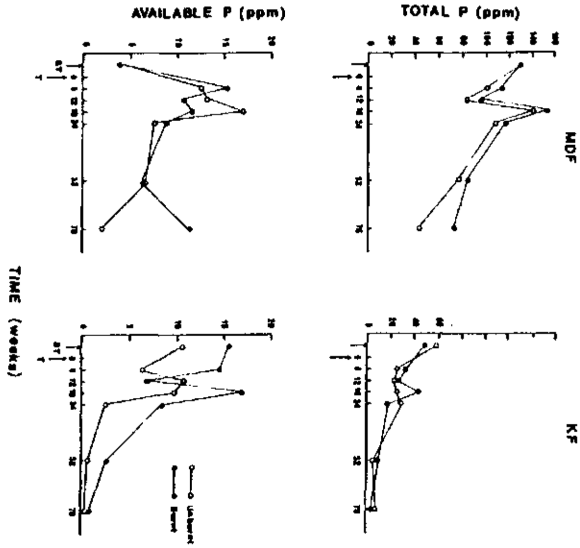

Figure 8. Changes in total and available P in top soils (0-10 cm) of the experimental plots MDF and KF.
(BT= before treatment, T= treatment)

These observations indicate that the misuse of forests on Podzols will lead to soil degradation which jeopardizes the whole ecosystem. One important reason for this is the fact, that the regeneration processes after disturbances on Podzols are very slow, and dominated by resprouts of original plants with no commercial or export value (Riswan, 1982).

Therefore, it is recommended that the rational land-use of KF and other forests on podzol soils will be the following:

1. Keep all KF in natural state and classify as conservation areas.
2. Direct utilization of this forest is only for education, research and recreation.

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THE ROLE OF LEGUMINOUS ALLEY CROPS IN THE NITROGEN NUTRITION OF SELECTED ANNUAL CROPS IN SMALLHOLDER FARMING SYSTEMS OF SRI LANKA.

Key words: Alley Cropping Grain Legumes Maize Mulch Nitrogen Nutrition Sesame

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Summary

A study evaluated the effects of the addition of Leucaena and Glyricidia leaves to selected crops in an alley cropping system. The loppings were either placed on the soil surface or incorporated into the soil soon after crop establishment in the wet season. In addition, three levels of inorganic nitrogen fertilizer were applied to the selected crops.

Plant yields indicated that the addition of leaves of alley crops had a greater effect in the dry season. Amongst the two methods of addition, incorporation of leaves into the soil had a significantly better effect. In terms of nitrogen nutrition, the added leaves did not act as a total substitute for inorganic nitrogen. However, the mulch enhanced yields obtained under all levels of fertilizer nitrogen. The value of the study for the smallholder in terms of increasing production by the use of loppings to enrich the nitrogen nutrition of selected crops is presented.

Introduction

Sri Lanka, a tropical island of 65609 sq. kms, situated 5^o - 9 ^{o}N and 80^o - 84 ^{o}E, is a country with a rich and diverse agricultural sector. Development schemes in the agricultural sector in Sri Lanka excluding the plantation sector have focussed on expansion into the dry zone of the country. The dry zone of Sri Lanka is characterized by its irregular rainfall pattern. The rainfall of this region, which averages around 2000 mm per annum is derived from monsoons. However, approximately 75% of this rainfall is received during the north east monsoonal period in October - February (wet season). This creates a distinct dry season during the south west monsoon in May - August (Land Use Division, 1984). The temperatures rise during this dry season and the humidity goes down, thereby making rainfed arable agriculture difficult during this period. This calls for the provision of irrigation water for both lowlands and highlands during this season.

The most important development scheme in the dry zone of Sri Lanka is the diversion of the Mahaweli river into the north. New lands cleared under this scheme have been allocated to settler farmers for the cultivation of food crops, both irrigated and upland species. The upland allotments of the Mahaweli scheme which are scheduled to be used for food crop production lack irrigation facilities. Hence, methods of upland rainfed agriculture are recommended for this region (Mahaweli Authority of Sri Lanka, 1984).

The settlers of the Mahaweli regions have adopted non systematic cultivation practices. This has resulted in the rapid decline of yields with time. Excessive erosion, weed problems and rapid loss of fertility have been identified as primary causal factors for yield reductions (Weerakoon and Seneviratne, 1982). In addition, a recent survey (Keerthipala, 1987) illustrates that farmers do not use adequate fertilizers in these allotments due to poor yields and uneconomic conditions. Kang and Duguma (1985) also show, that amongst all fertilizers, the use of nitrogen is limited due to high costs and the lack of availability at required times.

Alley cropping is a proven beneficial farming system for non irrigable highlands in the humid tropics (Kang et al., 1981a; Wijewardena and Waidyanatha, 1984). The use of nitrogen fixing leguminous tree species in alley cropping systems further enhances the value of the system due to their fertility regenerating capacity, soil and moisture conservation and reduction of weeds (Wijewardena and Waidyanatha, 1984). In addition, the use of loppings, which is a very old practice (Singh, 1975) adds considerable quantities of nitrogen (Brewbaker et al., 1982). Hence, the low input of high priced nitrogen fertilizer can be offset by the use of leguminous alley crops, which is a system reputed as a stable, low input and productive alternative to the open farming conditions of the smallholder systems of the tropics (Kang et al., 1981a).

Although the use of loppings from alley cropping as green manures is recommended for the drier regions of the tropics, information based on field trials on its usefulness as a source of nitrogen is limited. Few studies in the tropics (e.g. Kang et al., 1981a, b; Pathak and Patel, 1983) have shown the advantages of using loppings in increasing yields of annual crop species. Studies on the use of loppings in crop productions in the dry zone of Sri Lanka are presently being carried out. Preliminary results identify its usefulness as a viable system for smallholder farming systems of the dry zone of Sri Lanka (Ratnayake and Sangakkara, 1987), due to the distinct advantages it offers over conventional open farming systems. However, the usefulness of loppings as a source of nitrogen has not hitherto been evaluated under such farming conditions. Hence, a study was undertaken to evaluate the role of the loppings of two nitrogen fixing leguminous alley crops as a source of nitrogen to selected annual field crops grown in the smallholder farming systems of the dry zone of Sri Lanka.

Setting of the study

The trial was conducted at Girandurukotte ($7^{o}20'$N; 89^{o} E; 96 meters above sea level), situated in the Mahaweli (region C) in the dry zone of Sri Lanka. The environmental parameters of the region are as follows:

Rainfall : Mean annual rainfall in the region is 1950 mm. Of this, approximately 75% falls during the north east monsoon period (October - January), and the balance in the south west monsoon period (May-August).

Temperature : The mean temperature during the wet and dry seasons varies significantly. They lie in the region of 29 ^{o}C and 35 ^{o}C in the wet and dry seasons respectively.

Soils : The soils of the region are Reddish Brown Earths (Alfisols) with a highly erodable surface horizon (Moorman and Panabokke, 1961).

Materials and methods

Site: The experiment was located on a parcel of land situated on a hillock. The parcel of land was divided into three sections. Two nitrogen fixing tree species, namely, Leucaena leucocephala and Gliricidia sepium were planted at a spacing of 1-2 meters along contours spaced 8-10 meters apart in two seperate sections of the land. The third section did not contain any perennial trees to conform to conventional open farming conditions.

The soil (a Reddish-brown earth, Alfisol) was analysed for some physical and chemical properties, and appeared to have a clay loam texture, a pH of 6.52 and a CEC (NH_4OAc - pH 7.0) of 10.89 m eq./100 g.

Crops : The crops were selected on the basis of their suitability to the region (Gunasena, 1974) and from those commonly cultivated by farmers. The crops thus selected were maize (Zea mays) and mung bean (Vigna radiata) during the wet season and cowpea (Vigna unguiculata) and sesame (Sesamum indica) in the dry season.

Crop establishment and management : The alley cropped regions were sprayed with Paraquat (24% EC) prior to crop establishment in both seasons. The control plot was hand weeded at the time of spraying.

Maize and mung bean were established in six prepared plots per crop in the alley cropped tracts and three plots per crop in the control treatment with the onset of rains in the wet season. Sesame and cowpea were established in all tracts in plots that contained mung bean and maize respectively in the wet season. This was done to overcome any detrimental residual effects of a legume crop on a succeeding legume species. All seed rates, plant densities and P and K fertilizer applications were based on local recommendations (Gunasena, 1974).

Plots prepared in the wet season were maintained for the dry season. This was done to evaluate the residual effect of added mulch on crops grown in the dry season.

Treatments :

A. The alley crops were lopped at a height of 1.5 metres soon after crop establishment in the wet season. The leaves were spread as a mulch at the rate of 4 t/ha. within the respective alleys in between the annual crop in all plots. The mulch was incorporated into the soil soon after addition in three plots per crop. The mulch on the other three plots per crop was left on the surface. Mulching was not done in the dry season as the alley crops are not lopped due to the requirement of shade for the annual crops during this season. A mulch was not applied in the open tract to conform to open farming conditions.

B. Three levels of nitrogen fertilizers were used for each crop. These were 0, 50% and 100% of the local recommendation of each crop. Each mulching treatment per crop received the three levels of fertilizer nitrogen. The fertilizer treatment was also applied in the control treatment tract as well. The nitrogen levels adopted are given in Tables 3 and 4. Plots receiving no fertilizer nitrogen in the wet season did not receive any nitrogen fertilizer in the dry season. Similarly, plots receiving 50% and 100% of the recommendation for a given crop in the wet season received similar percentages of the recommended level of nitrogen for the crop grown in the dry season. This was done to minimize residual effects of high levels of fertilizer in the wet season being carried over to low nitrogen plots in the dry season.

Experimental design : A split split plot design with three replicates (Gomez and Gomez, 1983) was used. The main plots were the Leuceana and the Gliricidia plots and the control, subplots were the method of mulch addition and sub sub plots were the three levels of nitrogen fertilizer.

Measurements : The measurements taken were:

A. Soil organic matter and total nitrogen status. This was measured in soils obtained from the maize and sesame plots that received no fertilizer nitrogen, at the beginning and end of each season. A composite sample of soil was taken to a depth of 30 cm, percentage organic matter and total nitrogen were determined by methods described in SSSA and ASA monographs (1986).

B. Crop yields (kg/ha) were determined by harvesting a 1.5 x 4 meter area from each (sub)(sub)plot.

Results and discussion

The soil organic matter contents in maize and sesame plots that received no fertilizer nitrogen are presented in Table 1.

TABLE 1. Soil organic matter levels in plots of maize and sesame at the beginning and end of each season*.

Mulch	Method addition	Wet season		Dry season		St_x
		- - - - - - - - (% C) - - - - - - - -				
A	B	A	B			
Leucaena	Surface	1.48	1.64	1.66	1.47	0.05
	Incorporated	1.47	1.88	1.72	1.53	0.11
Gliricidia	Surface	1.44	1.59	1.53	1.32	0.08
	Incorporated	1.45	1.66	1.58	1.37	0.13
No mulch		1.43	1.24	1.28	1.15	0.09
St_x		0.12	0.16	0.09	0.19	

* A and B were samples taken at the beginning and the end of each season respectively.

At the onset of the experiment, soil organic matter contents in the alley cropped plots were marginally greater than that of the control. The addition of the loppings as a surface mulch or when incorporated into the soil increased soil organic matter content significantly. A comparison of the two methods of addition reveals that the soil organic matter content is greater when incorporated into the soil. This trend is observed in both wet and dry seasons and is in contrast to reports by Read (1982) cit. Kang and Duguma, 1985) which show faster rates of decomposition of leaf material when incorporated into the soil. Kang et al. (1981a) indicate significant increases of soil nitrogen with the addition of prunings of Leucaena. A similar result is observed in this study (Table 2).

TABLE 2. Total nitrogen (%) in plots of maize and sesame at the beginning and end of each season*.

Mulch	Method of addition	Wet season		Dry season		SE_x
		- - - - - - - - (% N) - - - - - - - -				
A	B	A	B			
Leucaena	Surface	0.13	0.17	0.15	0.13	0.02
	Incorporated	0.12	0.19	0.18	0.14	0.01
Gliricidia	Surface	0.12	0.16	0.14	0.12	0.02
	Incorporated	0.11	0.17	0.15	0.12	0.02
No mulch		0.12	0.13	0.11	0.11	0.02
SE_x		0.02	0.01	0.01	0.03	

* A and B were samples taken at the beginning and end of each season respectively.

The addition of loppings increases soil nitrogen considerably over the control. This high soil nitrogen content is maintained throughout the experimental period, although the nitrogen content decreases with time. This decrease can be attributed to the decomposition of the added organic matter, plant utilization of nitrogen and losses of released soil nitrogen.

The addition of Leucaena loppings increases the soil nitrogen content more than when Gliricidia leaves are added as a mulch. This could be considered a resultant feature of the higher nitrogen content in Leucaena leaves (Wijewardena and Waidyanatha, 1984). In addition, the data reveal that soil nitrogen levels are higher when the mulch is incorporated than when left on the surface.

The yields of maize and mung beans obtained from the different treatments in the wet season are presented in Table 3. There was a significant positive response in both species to added fertilizer nitrogen also in the control (under open farming conditions). The response of maize to added fertilizer when mulched was also significant. However, the yield increase of mung bean between the 25 kg N and 50 kg N applications were not significant when mulched with loppings of Leucaena and Gliricidia. This suggests that nitrogen fertilizer rates of this species which is a legume can be reduced in the presence of an organic mulch, irrespective of the method of its placement. However, the data show that a mulch cannot meet the total nitrogen requirements of both crops, but can complement the effects of added fertilizer.

Yields of cowpea and sesame indicate a similar trend in the dry season (Table 4). The yields of both crops are significantly higher in plots mulched in the previous season, than those obtained in control plots. This again indicates the complementary effect of the mulch to added fertilizer even in the succeeding season.

As in maize, sesame yields increase significantly with added fertilizer in all plots. However yield increases of cowpea between fertilizer application of 25 kg N and 50 kg N is marginally significant in plots mulched in the previous season. This again indicates that a mulch applied in the previous season can act as a partial substitute for inorganic nitrogen fertilizer for grain legumes. However, the beneficial effect lessens with time, as seen by the differences in mung bean and cowpea yields at the highest level of nitrogen fertilizer.

TABLE 3. Effect of type and method of placement of mulch and nitrogen fertilizer on yields of maize and mung bean in the wet season.

Mulch	Method of addition	Yields (kg/ha) Nitrogen rate (kg N/ha)			SE_x
		0N	40 kg N	50 kg N	
		Maize grain yield (kg/ha)			
Leucaena	Surface	542	1123	1785	184
	Incorporated	613 (13%)	1425 (26%)	1923 (7%)	142
Gliricidia	Surface	519	1125	1843	317
	Incorporated	559 (7%)	1251 (11%)	1910 (3%)	285
No mulch		552	1025	1711	231
SE_x		31	48	45	
		0N	25 kg N	50 kg N	
		Mung bean grain yield (kg/ha)			
Leucaena	Surface	469	891	968	73
	Incorporated	508 (8%)	976 (9%)	1024 (5%)	91
Gliricidia	Surface	438	834	919	53
	Incorporated	455 (3%)	883 (5%)	951 (3%)	62
No mulch		395	783	892	58
SE_x		41	23	58	

Figures in parantheses indicate percentage yield increase due to incorporation of mulch.

TABLE 4. Effect of type and method of placement of mulch and nitrogen fertilizer on yields of sesame and cowpea in the dry season.

Mulch	Method of addition	Yields (kg/ha) Nitrogen rate (kg N/ha)			SE_x
A. Sesame		NO N	30 kg N	60 kg N	
Leucaena	Surface	294	425	684	104
	Incorporated	351 (19%)	573 (34%)	735 (7%)	75
Gliricidia	Surface	271	394	645	181
	Incorporated	301 (11%)	446 (13%)	693 (7%)	126
No mulch		245	340	599	91
S_x		58	64	34	
B. Cowpea		NO N	25 kg N	50 kg N	
Leucaena	Surface	326	524	667	87
	Incorporated	359 (10%)	589 (12%)	718 (8%)	94
Gliricidia	Surface	299	477	619	69
	Incorporated	321 (7%)	519 (8%)	651 (5%)	108
No mulch		258	441	619	76
SE_x		49	58	34	

Figures in parantheses indicate percentage yield increase due to incorporation of mulch.

Plots receiving Leucaena mulch in the wet season show greater yields than those receiving Gliricidia mulch, in both seasons. This again could be attributed to the higher nitrogen content of Leucaena leaves.

Evaluation of the effect of placement indicates that incorporation of a mulch in the wet season increases yields of all crops over surface mulching in both seasons. This, as suggested by Kang and Duguna (1985), could be attributed to the more effective decomposition of the mulch when incorporated into the soil. In addition, incorporation seems to give a better residual effect in the dry season then surface mulched.

A primary objective of this study was to evaluate the effect of the type of mulch and its method of application in the wet season on yields of species in both wet and dry seasons. Hence, a comparison of percentage decrease or increase in yields was made as direct comparison of yields do not act as a guide due to different yielding abilities.

A comparison of percentage in yield increases were made within the nitrogen fertilizer treatments when the mulch was added to the surface or was was incorporated into the soil in the wet season. Incorporation of the mulch increased yields of maize at all levels of nitrogen fertilizer. The highest increase (26%) was observed when Leucaena was incorporated into the soil and the plots were fertilized with 40 kg N (Table 3). Similarly, higher yields of sesame were observed in plots with incorporated mulches. Again the highest percentage yield increase (34%) (Table 4) was seen in the plots with the incorporated Leucaena mulch and fertilized with 30 kg N. In addition, the percentage yield increase of sesame in all plots with the incorporated mulch was greater than maize yields. This suggests that the incorporated mulch has a greater beneficial effect on sesame planted in the dry season than on maize planted in the wet season.

Evaluation of the residual effects of applied mulches show that the percentage yield increases with mulch incorporation is greater in the dry season (Tables 3 and 4). This is observed with both types of mulches and the data suggest a higher effect of the mulch in the succeeding dry season than in the season of incorporation.

The beneficial effect of a mulch on crop growth is brought about by the provision of nutrients and possibly by the improvement to soil characteristics such as its water holding capacity. The results of this study indicate improvements of yields due to mulches at all levels of inorganic nitrogen fertilizer, although the differences are less marked in the two legumes. These increases have been attributed to the supply of nitrogen by the mulches which have relatively high percentages of this element. However, the effects of the mulch in increasing the moisture retention capacity of the soil especially in the dry season cannot be ignored although it was not quantified in this study. This becomes especially important as the beneficial effects of the mulch when incorporated are greater in the dry season.

Smallholder farmers strive to achieve maximum production levels from making better use of available resources in subsistance farming. The data of this study indicate the beneficial effects of mulches obtained from two leguminous trees Gliricidia and Leuceana. The addition of mulches in the wet season has beneficial effects in the wet and the succeeding seasons, especially if incorporated into the soil. The requirements of inorganic fertilizers, particularly of expensive nitrogen fertilizer, can be reduced. Thus, alley cropping with multipurpose leguminous trees can be useful, in particular for smallholder farmers.

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NUTRIENT MANAGEMENT FOR SOME FIELD AND PLANTATION CROPS PRODUCTION IN PHILIPPINE FARMING SYSTEMS.

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Introduction

Roughly about 70 percent of the agricultural lands in the Philippines is rainfed or non-irrigated. It is in these areas where most of the population is located. This suggests that non-irrigated farming systems have tremendous potential for food production to meet the needs of a population that is predicted to double by the year 2000.

The Philippines has a total land area of approximately 30 million ha, of which 57 percent is forest land and 43 percent is alienable. A total of 13,876,959 ha is devoted to agriculture and 9.8 million ha (71%) are planted to food crops. Of this, 4 million ha are occupied by commercial crops; 3.5 million ha by rice and 3 million ha by corn. About 53 percent of the total land area planted to rice is rainfed. This is further subdivided into lowland rainfed (1.4 million ha) and upland rainfed (0.4 million ha).

The southeast moonsoon climatically divides the year into distinct wet (> 100 mm/mo) and dry (< 50 mm/mo) seasons in the greater part of the country. Together with soil texture and physiography, rainfall determines the start, duration, and end of growing periods. Such factors as rainfall, crops and soil also play very important roles in the management of plant nutrients in the tropics. The timing, amount, frequency and method of application of fertilizers are all dependent on the above factors.

Fertilizer use

The amount of inorganic fertilizers applied in the country in 1983, when fertilizer cost was not very prohibitive, gives the picture of nutrient usage in Philippine agriculture (table 1).

The average nutrient consumption in the Philippines is still at a low level, viz, 18 N, 5 kg P_2O_5, and 6 kg K_2O per hectare.

One of the major reasons is that 75 percent of the cultivated lands is non-irrigated where the risk of crop production losses is very high. Here, typhoon and flooding losses are common during the wet months and losses due to drought during the dry months. Hence, farmers are dissuaded from investing the maximum or even the optimum production inputs.

A serious challenge that confronts us today is how to make farmers accept the risk of investment on fertilizers notwithstanding its prohibitive cost.

Perhaps, government programs on agricultural credit, fertilizer subsidy, and market support should be made available to farmers, coupled with affective transfer of technology and research support on fertilizer usage.

TABLE 1. Kinds and amounts of inorganic fertilizers used in 1983[2].

Kind	Quantity (m.t.)
A. Finished fertilizers	
1. Urea	318,800
2. 20-0-0	172,070
3. 0-18-0	2,863
4. 0-40-0	4,104
5. 50-50-0	16,500
6. 16-20-0	130,899
7. 12-12-12	1,796
8. 14-14-14	117,610
9. 6-10-4	1,058
10. 0-0-60	81,000
11. 0-0-48	5,882
12. Kieserite	1,605
B. Raw materials	
1. Sulfuric Acid	23,800
2. Anhydrous Ammonia	17,930
3. Phosrock	135,250
4. Dolomite	180
C. Speciality Fertilizers	
1. Zinc Sulfate Heptahydrate	360
2. Zinc Sulfate Monohydrate	80
3. Sulfate of Potash Maagnesia	1,215
4. Solubor	12
5. Iron Sulfate Heptahydrate	1,197
6. Mangesium Sulfate Heptahydrate	180
7. Magnesium Chloride Dihydrate	2
8. Foliar NPK	10
9. Gypsum	26
10. Foliar (5-8-10)	15,000 liters
11. Foliar (18-18-18)	15
12. Complehumus (8-8-8-3)	120
13. Calnitro	144

2. Fertilizer and Pesticide Authority, 1983.

Fertilizer research

A review of the fertilizer researches in the country (Paningbatan and Reyes, 1981) showed that out of 477 studies on fertilization, 25 percent was done on rice, 10 percent on corn, and the 65 percent on other crops. Of these studies, 50 percent tested crop response to N; 23 percent to N-P-K; 9 percent to P; 5 percent to K; 8 percent to organic materials; 2 percent to lime; and the rest to other elements. Using the elements and their various combinations to different crops, 70 percent dealt with nutrient sources and rates, and the 30 percent on other aspects such as time of application, methods of application, spacing, density, variety and soil.

In studies of the nutrient status of Philippine soils, done 1974-1987 by the Bureau of Soils and the FAO, and 1975-1980 in a FAO/UNDP fertility survey project, the status for macro and micronutrients of major Philippine soils was determined (Sillanpaa, 1982, Arnott, 1978).

Significant responses of crops to various fertilizer treatments have been obtained from field experiments in the country. They show yield increases due to added nutrients with attractive cost/benefit ratios when applied at the appropriate rate, time or method along with varieties and improved cultural practises. These fertilizer technologies, however, are for most part location-specific. This suggests the need for a vehicle to extrapolate these technologies. This can be done by using soil properties and environmental conditions in other locations where the technology is more likely to succeed.

Soil classification systems such as Soil Taxonomy (USDA, 1975) have demonstrated to be an effective vehicle of agrotechnology transfer at the soil family category (Uehara, 1978). In other words, the soil of the experimental site should be classified into an extrapolable soil classification system. Classification by Soil Taxonomy, which is virtually a quantitative system of classification, is very expensive and can hardly be afforded by developing countries. A faster and similarly reliable means of transfer could be the use of a minimum set of site parameters such as soil and plant analysis.

Phosphorus fertilization

The analytical method for estimating available P considers the form of soil P which is the source of available P for the plant. The Olsen method (0.5M $NaHCO_3$, pH 8.5) is used for calcareous soils including the slightly weatered soils. Bray 1 (0.025M HCl + 0.03M NH_4F) is employed for soils high in Aluminium-P because of the strong complexing action of F for Al (Kamprath and Watson, 1980). It also extracts calcium-P. The adequacy levels of soil P are given in table 2 for some non-irrigated crops.

TABLE 2. Adequacy levels of P in the soil for plant growth (Recel, et al., 1986; Paningbatan & Reyes, 1981).

Analytical method	Crop	Adequacy level ppm P	Soil
Truog	Sorghum	23	Inceptisols
Bray 2	Sorghum	35	Inceptisols
Ayres-Hagira	Sorghum	95	Inceptisols
Olsen	Corn	42	Inceptisols
Ayres-Hagira	Corn	20	Inceptisols
North Carolina	Corn	8	Inceptisols
Olsen	Banana	33	Inceptisols
Olsen	Cacao	150	Andisols
Olsen	Cacao	20	Inceptisols
Olsen	Rice	5	Vertisols

Potassium fertilization

The amount of K available for various crops is closely correlated with the amount of exchangeable K in the soil. Several adequacy levels were found in different crops and soils. The adequacy level is relatively higher in soils having three layer clay minerals that have stronger affinity for K than two layer clay minerals (Hipp and Thomas, 1967).

Exchangeable K as determined in NH_4OAc at pH 7 by a Flamephotometer or an AAS gave a good measure of plant available K. The Hot H_2SO_4-extracted K is also well correlated with NH_4OAc K. Some established adequacy levels of K for certain crops are shown in table 3 (Recel, et al., 1986; Ponnamperuma, 1985).

TABLE 3. Adequacy levels of K in soil and in the plant.

Analytical method	Crop	Soil K	Leaf K
NH_4OAc, pH 7	Corn	0.57 meq/100 g	-
	Banana	400 ppm	0.20%
	Cacao	350 ppm	0.5%
	Rice	0.5 meq/100 g	-
Hot H_2SO_4	Rice	175 ppm	

Nitrogen fertilization

Soil organic matter content is a simple and inexpensive guide to fertilization (table 4).

TABLE 4. Adequacy levels of Organic Matter or leaf N.

Analytical method	Crop	% OM	% leaf N
Acid-dichromate digestion	Rice	2.0	-
	Banana	1.5	2.8
	Cacao	3.5	3.4
	Corn	2.0	-

Time of fertilizer application

In the north, where there are distinct wet and dry seasons, the predominant crops in the rainfed lowlands and uplands are annuals such as corn, sweet potato, tobacco, cotton, etc. Here, the basal fertilizer is applied at planting time. P and K are all applied with split N. The rest of the N is topdressed or sidedressed at a certain growth stage of the crops, usually before or during flowering. The time varies depending on available soil moisture. During the wet season, sidedressing is done immediately after rains at the appropriate stage of development.

During the dry season, the split N is applied while the soil is still moist. Side or topdressing however is seldom applied due to inadequate soil moisture.

In Mindanao where the rainfall is well distributed throughout the year and where most of the plantation crops are grown, fertilizers are applied at various frequencies depending on the type of crop, soil texture and costs. N and K are applied monthly, while P is applied every other month or even quarterly for banana. These high frequencies are intended to avoid total loss of the fertilizers when the application is immediately followed by high intensity rains that results to a total loss through run-off.

The frequent pruning of cacao results to a thick leaf mulch on the soil surface. Here, fertilization frequency is less. N and K are applied once in two months and P, twice a year. The natural leaf mulch neutralizes rapid surface run-off and thus reduces the loss of applied nutrients.

Ramie, a perennial fiber crop, is another important crop in the south which is heavily fertilized. The frequency of application, which is done after every cutting, is twice that of N, P and K.

Placement of fertilizer

The choice between broadcasting or placement of fertilizer depends (various factors, mainly rainfall, the kind of crop, soil texture, top(graphy and cost, that differ from one region to another.

In regions having distinct wet and dry seasons, fertilizers a deep-placed during the rainy season to prevent run-off losses. De placement during the dry season is intended to bring the fertilizers contact with soil moisture and thus into the soil solution.

There are many techniques of fertilizer placement that are practic by Filipino farmers. For small grain crops, like corn and sorghum, fu rows are made with an animal drawn plow to a depth were soil moisture adequate to germinate the seed. The fertilizer is applied continuously a band at the bottom of the furrow. A light wooden harrow is passed cover the fertilizer and after which seeds are dropped by hand an cover by passing again the wooden harrow for the second time. Sometimes, t fertilizer is dropped at the side of the seed inside the furrow and bc covered with soil by the foot.

In rolling areas, where soil moisture is deeper and it is more di ficult to make the furrows, the fertilizer is drilled manually to whe the soil is moist, covered lightly with soil and either followed in t same hole with the seed above it or the seed is drilled beside t fertilizer.

For crops that are planted as seedlings, like tobacco, cabbage, etc the fertilizer is dissolved in water and applied around the newly plant seedlings. As soon as the seedlings are established and have grown about a foot high, the rows are bared with an animal drawn plow and t fertilizer is applied in bands in the furrow, after which the plow passed again upwards the slope.

Another way of doing this is preparing the land in deep furrows . planting the seedlings at the side of the ridges. The seedlings are a started with fertilizer solution that is watered around the base of plant. As soon as it is established to about a foot high, fertilizer dropped in the bottom of the furrows and covered by plowing.

Crop removal

The amount of nutrients taken out of the land through the harves parts is another point to consider in deciding the rate of fertili application. More studies along this line have been done for plantat crops where research support is availed by the private sector.

In banana and cacao for example, the mineral composition of the cr are shown in tables 7 and 8 (Recel, et al., 1986).

TABLE 7. Average mineral content of a banana crop of 30 t/ha kg/ha.

	N	P_2O_5	K_2O	CaO	MgO
A. whole plant (kg/ha)	209	57	721	190	157
B. bunches (g/kg)	1.9	0.55	6.9	0.60	0

TABLE 8. Average nutrients removed from the soil annually in kg by a cacao crop of 1 T/ha beans.

	N	P	K
Beans	26	6.8	25
Husks	23	2.5	52
	49	9.3	77

General fertilizer recommendations

General fertilizer recommendations in the Philippines are formulated based on considerable field fertilizer trials.

1. Rice and wheat
   Basal : 0-30-30
   Topdress: Rice: 10-15 DAE - 45 N
   30-35 DAE - 21 N
   45-50 DAE - 12 N
   Wheat: 10-15 DAE - 45 N
   30-35 DAE - 42 N
2. Corn and sorghum:
   Basal : 60-30-30
   Sidedress: (Applied 2-3 inches from base of plant during hilling-up 20-30 DAE)
   30-0-0
3. Sweet potato
   Basal : 60-60-60
   Sidedress: (Applied 2-3 inches from the base of the hill) 30-0-0
4. Peanut, soybeans, and mungbean all basal: 45-30-30

CONCLUSIONS

1. Fertilizer nutrient usage in the Philippines is far below the recommended nutrient levels. This is mainly due to the prohibitive cost and the risk in investment as a result of unpredictable climatic hazards and undertain soil moisture.

2. Organic carbon or organic matter could be a good index of the need for nitrogenous fertilizer.

3. If the organic matter content of the soil is less than 2.0%, responses to N are likely in rice and corn. This critical level is 1.5% in the case of banana and 3.5% in the case of cacao. Similarly if N is 2.8% in the third leaf of banana or N is 3.4% in the newly matured leaf of cacao, nitrogen fertilizers should be apllied.

4. If the P-Olsen in soil is less than 5 ppm, the likelihood for a significant response of rice to P fertilization is very high. This may occur at levels less than 42 ppm in the case of corn, less than 33 ppm in the case of banana; and less than 20 ppm (inceptisols) or less than 150 ppm (andisols) in the case of cacao.

5. A soil K by NH_4OAc extraction at pH 7 of 195 ppm suggests the need for K fertilizers in rice; less than 222 ppm in the case of corn; less than 350 ppm in the case of cacao, and less than 400 ppm in the case of banana.

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PRELIMINARY STUDIES IN NUTRIENT CYCLING WITHIN THE FARMING SYSTEMS OF THE SOLOMON ISLANDS

Key words: Agroforestry Nitrogen Nutrient cycling Phosphorus Potassium Rain forests Shifting Cultivation Solomon Islands Sustainable agriculture

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SUMMARY.

The paper reviews the status of the major soil groups found in the Islands, particularly in relation to vegetation and climate which have influenced their pedogenesis, and the impact that present systems of agriculture (mainly shifting cultivation) are having on these soils, with particular regard to the nutrient cycles of nitrogen, phosphorus and potassium. The inter-relationships between soil fertility and the various parameters which are characteristic of these traditional systems are discussed, particularly length of cropping and fallow periods, effects of clearing and burning, influence of crop species and intercropping practices. A brief description is made of the present investigatory programme, where the aims are to improve the availability of the major plant nutrients, particularly potassium, enhance the sustainability of the present systems, and including those on sloping land. In this respect agroforestry, in the form of alley cropping, is being evaluated as a way of enhancing all of these aspects.

INTRODUCTION

The traditional method of agriculture adopted by the farmers in the Solomon Islands, like most other lowland areas of the humid tropics, is shifting cultivation. In this system the farmer clears an area of natural vegetation, burns the residues and plants food crops into the ash-enriched soil. The land is then cropped for a number of cycles and then allowed to revert to natural secondary regrowth, while the farmer initiates a new 'garden' elsewhere. The fallow period, provided it is long enough, allows the available nutrients in the soil to be replenished. These highly fragile farming systems are now being put under stress, due to increases in population and the resultant pressure placed on the available land resources. This situation is further exacerbated by the fact that the ecosystems which are present, are mainly rain forests on strongly weathered nutrient poor soils, with most of the available nutrients associated with the humus and root layer on top of the mineral soil.

In order to devise farming systems that are sustainable with regard to the maintenance of soil structure, nutrient status and erosion, it is essential to determine the interactions within the soil/plant ecosystems under natural rainforest and to what extent these are altered by the influence of man. In this context the situation as it stands in the Solomon Islands is reviewed against known values and hypotheses from elsewhere in the humid tropical zone, particularly where important facts are not available for this country

NUTRIENT CYCLING WITHIN THE SOLOMON ISLAND ENVIRONMENT

Tropical Rain Forest

The Solomon Islands falls within the humid tropical zone with a mean ambient temperature of 26.6 ^{o}C and an overall average rainfall of between 3000-5000 mm/yr reasonably well distributed throughout the year. Higher precipitation in excess of 8000 mm/yr is found on the high mountain areas of some of the high islands, such as Guadalcanal and Makira, while in north Guadalcanal there is a seasonally dry rain shadow area with only 2000 mm/yr. The climate of this latter region has had a marked effect on the vegetation and soils.

The vegetation found on the Solomons is remarkably uniform (Whitmore, 1969) with very little variation between islands. Factors which have affected plant distribution, and hence given rise to vegetation differing from the climax vegetation, are the occurrence of cyclones, the impact of man, the relationship between species change and topographic features, the influence of climate (mainly rainfall, in the seasonally dry area of north Guadalcanal) and the influence of soils derived from basic parent material. All these factors have affected both the range and types of species present and the size of the biomass.

Over most of the islands lowland rain forest is the climax vegetation. It is a species-rich formation (approximately 4500 species) which in many ways is floristically similar to that of Malaysia but having fewer families, genera and species, and containing distinctive groups of Pacific and local Melanesian genera. In this forest type there are only twelve big tree species (Calophyllum peekalii, C. pseudovitiense, Elaeocarpus sphaericus, Endospermum medullosum, Gmelina moluccana, Maranthes corymbosa, Parinari salomonensis, Pometia pinnata, Dillenia salomonensis, Schizomeria serrata, Terminalia calamansanai and Campnosperma brevipetiolatum) found among the canopy. There is a low degree of homogeneity among these forests, and over large areas it is locally broken with regrowth species filling gaps caused by the influence of man and cyclones. Two species which indicate past disturbance and are common in this ecosystem are Vitex cofassus and Canarium spp.. The lower tree and shrub layers are made up of species such as Barringtonia papeh, Boerlagiodendron spp., Leea indica, Areca catechu etc. Below this the herb layer is irregular and patchy, and where gaps appear in the canopy Calamus spp., bamboos and gingers predominate. Climbers and epiphytes are abundant especially at higher altitudes with greater rainfall.

One of the major factors that influences the forest flora is the impact of shifting cultivation, where after gardens are cultivated for one sometimes two years, they are abandoned and allowed to revert to forest. These old gardens rapidly become recolonised by secondary species. Herbaceous regrowth rapidly establishes itself as soon as weeding ceases, with the grass species Paspalum conjugatum predominating. Imperata cylindrica and Pennisetum macrostachyum are found to occur only on intensively used gardens with short fallows. As long as the cropping cycle has been of normal duration and the soil has not been unduly degraded, the herbaceous growth phase is rapidly superseded by woody regrowth. The pioneer species of the typical secondary forest are light-demanding species which include Macaranga urophylla, M. tanarius, M. alauritoides, Melochia umbellata, Scheinitzia insularis, Pipturus argenteus, Acalpha grandis and Alphitonia incana with a mixture of Musa spp. and Heliconia spp.

As the fallow progresses these initial species loose their dominance as other species (Kleinhovia hospita, Trichspermum psilocladum, Ficus ssp., Albizia falcata, Rhus taitensis and Canaga odorata) more typical of older secondary regrowth begin to compete. The breadfruit Artocarpus altilis is nearly always found in the regrowth forest and to a lesser extent Mangifera indica. At around this stage in the cycle tree ferns (Cynathea lunulata and C. brackenridgei) are re-established, particularly in the hill areas of the larger islands, as also are the palm species Areca catechu and Caryota rumphiana, and gingers in the shrub layer. Subsequent to this some of the large tree species become apparent, namely Pometia pinnata and Vitex cofassus.

In an undisturbed tropical rain forest, the ecosystem is in equilibrium with the bulk of the nutrients within the vegetative component, in contrast to temperate forests which have a larger total nutrient content within the soil fraction; due to the younger and less weathered soils of these regions (Ewel and Conde, 1978). Data for biomass and nutrient content of tropical rainforest ecosystems is very varied, partly due to the differing parameters which have been used in their determination. However, an approximation for this type of forest can be detailed in order to put them in to perspective with other data. Total biomass of a tropical rain forests can range between 350-450 t/ha of dry matter. Further to this, the total nutrient content of the whole forest ecosystem (soil, vegetation and litter) has been determined, and is found to fall within the following ranges 2.1- 2.8 t N/ha, 0.08-0.24 t P/ha and 0.55-1.3 t K/ha (Nye and Greenland, 1960), with a much larger proportion of N in the soil and litter, as compared to P and K which predominate more in the vegetation. With rainwash included, it has been estimated (Cole and Johnson, 1978) that about 13%, 11% and 33% of the N, P and K respectively, are recycled every year, showing that large amounts of nutrients are in constant and rapid circulation in the rainforest. With water not usually limiting, the shallow rooting forest vegetation can largely depend on the nutrients in the cycle and is rather independent of the poor subsoil as long as the topsoil remains shaded, moist and undisturbed.

This recycling process for most of the forests in the Solomons is continuous, with leaf replacement, litterfall and litter decomposition, by soil micro-organisms, going on all the time. It is only when there is an excessively long dry period, or a dry season as found in north Guadalcanal, that these dynamics are changed. In this case litter fall continues, however, decomposition is negligible resulting in an accumulation of nutrients in the litter layer. A study by Swift et al (1981) in sub-humid tropical Nigeria on regenerating secondary rain forest, found that during the first 8 weeks of the rainy season most of the nutrient reservoir was released from the leaf litter. During the initial period of decomposition, leaching was an important component of weight loss, with K in particular found to be excessively leached.

Not only is the quantity of the biomass and nutrients important, but the quality,in determining the nutrient status of a particular forest ecosystem. Differences in above-ground accumulation of nutrients are affected enormously by differences in nutrient concentrations of tropical forest species. The range of nutrient content found within species from different locations is 0.18-1.78 N%, 0.01-0.14% P% and

0.10-1.01 K%. (Brazilevich and Rodin, 1966; Stark, 1971). Similar differences have also been found between species within a single location, which suggests that the nutrient content of tree species is regulated as much by inherent characteristics than by climate and soil factors. It is possible that the nutrient characteristics of secondary forest regrowth, with the high proportion of herbaceous and pioneer species, that nutrient additions are not only lower in actual amount than those that would be found in undisturbed rain forest, but the relative concentrations of N, P and K of a different order. Further to this, the presence of leguminous plants and N- fixing epiphytes within forest will influence this balance, by providing substancial N inputs (range 40-110 kg N/ha/yr) into the ecosystem (Nye and Greenland, 1960).

Soils.

According to Wall et al (1979), who were using the USDA (1975) Soil Taxonomy classification system, there are seven soil orders and a total of 32 great groups represented in the Solomon Islands (Table 1). Of these only five great groups can be classified as widespread, accounting for over 50% of the land area; also the strongly weathered Oxisols and Ultisols are found to make up well over a third of all soils. Within the Tropept suborder of the Inceptisols, which occupy large areas of the central hills and mountains of all the main islands, the Dystropepts and Eutropepts are most common especially on the steeper slopes of ridged terrain where surface erosion is active, the former derived from metamorphic rocks or old volcanos and the latter calcareous strata. While the Humitropepts are found on the higher cooler areas on the tops of ridges. The Ustropepts, a minor soil overall, occur on the agricultu-rally important seasonally dry north Guadalcanal plains. Over the base-rich parent rocks, such as fine-grained calcareous sedimentary rocks, limestones of terraces and young basaltic lavas, are found the important soils from the Alfisol order, more particularly the Tropudalfs. Another extensive suborder is Humult, associated with sedimentary rocks (particularly over the non-calcareous sediments of Guadalcanal, Choisel and Makira), occupying stable slopes and ridge tops. The other suborder of importance is Orthox, with the widespread Haplorthox occurring mostly on stable ridge summits and undissected lava of old and young volcanic areas. In contrast the Eutrorthox are found only on limestone terraces, raised atolls or fine-grained calcareous sediments.

Overall, the soils are physically good, reasonably well drained (away from floodplains) and sufficiently deep to allow free rooting. The textures of the upland soils are predominated by a high clay content, aeration however, is unimpeded. In contrast the fertility of the soils (Table 2) is more variable, with many deficient in some or all of the major plant nutrients, and others with imbalanced nutrient composition. Of great importance in the nutrient status of all the soils in the Solomons is the organic matter content of the topsoil. This commonly thin surface horizon, holds the bulk of the soil nutrients and hence the majority of the plant feeding roots. With the exception of the Hemist and Humox suborders, the organic matter is well decomposed, with C:N ratios of 7-13 and weakly acid. Subsoils range from those that are weakly weathered and leached to those that are almost devoid of nutrients and are almost totally inactive and therefore incapable of yielding or retaining nutrients. Further to this, even some of the

TABLE 1: Soil classes (USDA Soil Taxonomy) in the Solomon Islands *1

Order	Suborder	Great Group	Estimated *2 Distribution	Soil Description and Fertility Status *3	Parent Material
Alfisol	Aqualf	Plinthaqualf	L	Deep, strongly mottled clays, impeded drainage, base saturation high; V.	Conglomerates in N. Guadalcanal.
	Udalf	Tropudalf	W	Deep, moderately to strongly weathered, brownish to red clays on stable sites; IV & V.	Mostly calcareous rocks.
	Ustalf	Haplustalf/ Paleustalf	L	Deep, moderately weathered, brownish to red clays, base saturation high; II.	Conglomerates and sandstones in N. Guadalcanal.
Entisol	Aquent	Sulfaquent	L	Deep, gleyed, peaty clays rich in sulphides; Nil.	Alluvium in tidal swamps.
		Tropaquent	L	Deep, gleyed, mixed-textured soils of varied chemical status; III.	Alluvium.
	Fluvent	Tropofluvent	L	Varied-depth, mixed-textured, varied chemical status; III.	Alluvium.
	Orthent	Troporthent	L	Shallow,generally coarse-textured of low fertility; Nil.	Coral reefs or rocky steep slope.
	Psamment	Tropopsamment	L	Deep, pale to dark sands with poor base status; I & II.	Coral detritus or mineral sand.
Histosol	Folist	Tropofolist	L	Shallow, well-drained accumulations of organic matter over rock; Nil.	Limestone.
	Hemist	Sulfihemist	L	Deep, very poorly drained peats rich in sulphides; Nil.	Inter-tidal areas.
		Tropohemist	L	Varied depth, very poorly drained peats dark in colour; II.	Alluvial, coral & high altitude.
Inceptisol	Andept	Hydrandept	L	Moderately deep weakly weathered, very friable dark brown clays; III	Volcanic ash on coral terraces.
		Vitrandept	L	Moderately shallow to deep, brownish clays; III.	Volcanic ash on volcanic rocks.
	Tropept	Dystropept	W	Moderately shallow to deep, weakly weathered, yellowish to red loams and and clays on unstable slopes; IV.	Mainly volcanic.
		Eutropept	W	Shallow to deep, weakly weathered brown loams and clays, high base saturation; III.	Calcareous strata.
		Humitropept	C	Shallow to deep, weakly weathered, humus-rich, brownish loams and clays; III.	Non-calcareous sediments/volcanic rocks, upland.
		Ustropept	L	Deep, imperfectly drained, base-rich, weakly weathered, brownish loams and clays; III.	Alluvium on N. Guadalcanal plains.
Mollisol	Rendoll	Rendoll	L	Shallow, dark, carbonate-rich clay, deep penetration organic matter; IV.	Limestone.
	Udoll	Argiudoll/ Paleudoll	L	Varied-depth, brownish to reddish clay, carbonate-rich, deep penetration organic matter; IV.	Limestone.
		Hapludoll	L	Shallow to deep, yellowish brown to brown carbonate-rich clays, deep penetration organic matter; IV.	Limestone.
	Ustoll	Haplustoll	L	Shallow to deep, moderately weathered, brownish carbonate-rich clays, deep penetration of organic matter;IV.	Limestones in N. Guadalcanal.
Oxisol	Humox	Haplohumox	L	Deep, yellowish red to reddish brown, humus-rich clay, strongly weathered and desaturated; V.	Volcanic rocks
	Orthox	Acrorthox	L	Deep, yellowish red or red clay, very strongly weathered and desaturated; V.	Ultramafic rocks
		Eutrorthox	C	Deep, strong brown to reddish clay, strongly weathered with relatively high base status; IV and V.	Limestones, chalks and marls.
		Haplorthox	W	Deep, brown to red clay, strongly weathered and desaturated; V.	Various rocks, volcanics mainly.
	Ustox	Haplustox	L	Deep, strongly weathered, desaturated dark loams over mottled clays; V.	Conglomerates in N. Guadalcanal.
Ultisol	Humult	Tropohumult/ Palehumult	W	Deep, yellowish red to red, humus-rich clay with low base saturation; VI & V.	Sedimentary rock.
	Udult	Tropudult/ Paleudult	C	Deep, strongly weathered, yellowish red to red clays, low base saturation; IV & V.	Mostly calcareous rocks.

*1 Source: Wall et al(1979); Chase (1981).

*2 Widespread (W) >10%; Common (C) 5–10%; Local (L) <5% of land area.

*3 Fertility status, soil characteristics: I – Weakly weathered, alkaline, moderate P and low K status.
II – Weakly weathered, weakly acid, moderate P and moderate K status.
III – Weakly weathered, weakly acid to alkaline, good P and moderate K status.
IV – Moderate to strongly weathered, acid, moderate/good P and low K status.
V – Strongly to very strongly weathered, acid, low P and low K status.

weakly weathered Inceptisols are found to be nutrient poor when they are derived from certain rocks deficient in these elements. The importance of the influence that parent rock has on subsoil fertility can be overridden by topography, which controls the degree and intensity of pedogenic processes; to this extent the Oxisols show the least influence of parent material on their mineral composition.

TABLE 2: Soil Analytical Data for the Important Great Groups in the Solomon Islands

Great Group	Profile Depth*	pH (water)	C:N ratio	Organic C %	Total N %	Total P ppm	Avail P ppm (Bray)	Total K ppm	Exch. K meq%
Tropudalf	ts	6.3	11	6.1	0.54	670	15	840	0.4
	ss	6.1	10	1.3	0.13	500	13	880	0.2
Dystropept	ts	5.3	11	4.8	0.44	540	9	1140	0.3
	ss	5.2	10	0.6	0.04	310	6	1520	0.1
Eutropept	ts	6.1	14	5.5	0.40	710	13	2020	0.5
	ss	6.1	10	0.8	0.08	550	14	2560	0.3
Humitropept	ts	5.3	14	9.4	0.68	790	12	1660	0.3
	ss	5.2	11	1.6	0.14	670	9	2160	0.1
Eutrorthox	ts	6.0	13	6.8	0.54	2330	13	690	0.3
	ss	6.1	7	0.7	0.10	2050	15	660	---
Haplorthox	ts	5.2	11	4.6	0.42	460	6	730	0.2
	ss	5.2	11	0.9	0.08	300	4	870	---
Tropohumult	ts	5.2	16	10.5	0.67	770	11	920	0.3
	ss	5.0	9	0.7	0.08	560	7	1330	0.1
Tropudult	ts	4.9	7	3.9	0.53	270	6	960	0.2
	ss	5.0	10	0.6	0.06	180	5	1570	0.1

* Topsoil (ts) <20 cm; Subsoil (ss) >20 cm to 1 m.

<u>Nitrogen and Soil Organic Matter</u>: The Solomon Island soils have a wide range of total N and organic C in the topsoil, where the average values of both are high when compared to global figures. The average organic C content is 6.4%, with high levels in several soil groups (Hydrandept, Ustropept, Haplohumox and Tropohumult). The accumulation of organic matter in the Humox and Humults is as a result of high rainfall and low base saturation of many of these soils, which together produce acid conditions which limit microbiological activity. In other soils its accumulation is encouraged by impeded drainage and/or low temperatures. Within the 8 most common great groups of soils, the relatively high total N contents for the profile down to 1 m (Table 3) is misleading, as only a fraction of this is available at any one time. Mineralisation rates of around 1.5% per year have been taken as standard for the tropics, however, this has been found to vary according to conditions (Birch, 1958). The consequence of these levels of available N will be seen, when the impact of traditional farming systems is discussed.

TABLE 3: Estimates of the quantities of total and theoretically available nitrogen, phosphorus and potassium in the important Great Soil Groups of Solomon Islands. *1

Plant Nutrient	Profile *2 Depth	Total Wt t/ha		Available Wt kg/ha *3	
		Range	Mean	Range	Mean
Nitrogen	ts	6.0 - 10.2	8.1	90 - 153	122
	ss	4.3 - 10.1	7.2	65 - 152	109
	tp	10.3 - 20.3	15.3	155 - 305	231
Phosphorus	ts	0.4 - 3.5	2.0	9 - 23	16
	ss	1.3 - 14.8	8.1	29 - 108	69
	tp	1.7 - 18.3	10.1	38 - 131	85
Potassium	ts	1.0 - 3.0	2.0	12 - 30	21
	ss	4.8 - 18.4	11.6	0 - 84	42
	tp	5.8 - 21.4	13.6	12 - 114	63

*1 For Great Groups refer to Table 2.
*2 Topsoil (ts) <20 cm; Subsoil (ss) >20 cm-1 m; Total Profile (tp) 0-1 m.
*3 Estimates calculated using following criterion: Nitrogen - 1.5% mineralisation rate/ha/yr; Phosphorus - Available P ppm (Bray); Potassium Exch. K meq%.

<u>Phosphorus</u>: Phosphorus content is extremely variable in both topsoil and subsoil. The surface horizons of Oxisols derived from ultrabasics contain <100 ppm total P, in contrast to those Oxisols on atolls (Rennell Island) with >100,000 ppm. The modal value for all topsoil is 500 ppm (50% soils in range 200-750 ppm), whereas, for subsoils it is 170 ppm (84% soils in range 50- 750 ppm). As would be expected, as weathering increases P levels are found to decline with Eutrorthox, Haplorthox and Acrorthox all having very low levels, especially those on igneous rocks, in contrast to those on limestones with slightly greater amounts (2000 ppm total P). As mentioned above smallest P contents in the subsoil (<50 ppm) are usually associated with ultrabasic parent material, however the surface horizons on these P deficient soils, are found to be considerably enriched in P as a result of uptake by plants and accumulation in the litter. Thus emphasising the importance of organically bound P in strongly weathered tropical soils, and the fact that it is essential where initial reserves of total P are small that the reserves bound in the soil organic matter and litter (possibly more important) are not lost.

<u>Potassium</u>: The range for total K is 50-26,250 ppm, with amounts generally small (modal value 550 ppm) due to lack of K rich rocks. Further to this, in most of the profiles total K levels decrease rapidly immediately beneath the topsoil, then decline more slowly or remain constant with increasing depth, but increase again, sometimes quite sharply, at the base of the profile where the parent rock is encountered. In a similar manner to P, the amounts in the topsoil reflect uptake by plants and accumulation in the litter, and changes lower down the profile the intensity of weathering that the subsoil has undergone. The generally small amounts of total K are reflected in the low levels of exchangeable K, and even in some of the K rich soils these

amounts are small (Table 3). An indication that most of the K occurs in fairly resistant minerals, such as alkali feldspars, from which little is released by weathering and retained in the exchange complex. This is further compounded by the fact that large amounts of the K released from decomposing organic matter, particularly after forest clearance, are lost by leaching in most of the soils.

THE EFFECTS OF TRADITIONAL SUBSISTENCE AGRICULTURE ON NUTRIENT CYCLES.

The type of subsistence agriculture presently being carried out in the Solomons, varies from the simplest form of true shifting cultivation now confined to inland parts of Malaita and Guadalcanal, where farmers and their village frequently move, to the continuously cultivated and mulched crops of the Polynesian outlying islands and atolls. For the most part however, settlements are permanent and the farmer rotates or shifts around a given area of rain forest. When selecting a site for a food garden the farmer has to consider both the 'custom' (rights of the individual to use the land) and technical availability of the land. With the latter, site selection can be dependent upon such factors as accessibility, drainage and, possibly of greater importance, the appearance of the vegetation on the site. Also most farmers will recognise the suitability of different soil types for particular crops, therefore site selection will depend upon the crop to be grown.

The choice of fallow ground for a new garden is not determined by the age of the fallow, but by the size of the regrowth and the presence of plant associations not found in young secondary regrowth or on exhausted land. The actual length of the fallow is dependent upon both the inherent soil fertility and the availability of land. Where land is freely available and population pressure is low the optimum period appears to lie within the range 7-20 years. On north Malaita, population pressure and the planting of cash crops has severely restricted the choice of garden sites, so that optimal conditions for new gardens cannot always be fulfilled. The period of cultivation is usually from one to two years, or the equivalent of up to three crops of sweet potato (Ipomoea batatas). The cultivation factor, R (the number of years under cropping expressed as a percentage of the total cropping/noncropping cycle), ranges from <10% to >33%. Decline in productivity is the main factor influencing the decision to abandon a garden, however, the exact causes of this decline are not fully understood. As a general rule, there is a drop in yield from the second crop onwards, although the percentage decrease is greater between the first and second crops than between second and subsequent crops. Further to this the lower yield, in itself insufficient reason to abandon the land, because even though yields are reduced they still provide a good return for a minimum labour input. Other factors can be the build-up of soil-borne diseases, increases in insect attach and weed infestation. In addition, many cut stumps and roots sucker strongly so that the need to weed amongst the growing crop occupies increasing amounts of time.

Effects of Clearing and Burning.

The new garden site is cleared by hand, with all the larger trees felled, unless they are of economic importance, eg. Canarium spp. and sago palms, the trash is left to dry, and is eventually heaped around the remaining trees and burnt, leaving the dead stumps standing in the garden. In a number of cases the boundary of the garden is delineated, initially by logs and lines of trash, and subsequently by small crotons, Cordyline spp. and occasionally planted fruit and nut trees. The effects of forest clearing on the nutrient cycle and soil properties is quite dramatic, with cycles both of organic matter and nutrients broken, extremes of soil surface temperature and moisture, and an increase in leaching and surface erosion. Burning results in the volatilization of C, N and S, and a one time large addition of plant nutrients, in the ash and unburnt residue, that can range from 150-250 kg N/ha, 30-120 kg P/ha and 300-800 kg K/ha (Nye and Greenland, 1964; Brickmann and Nascimento, 1973; Sanchez, 1976). It also causes a temporary increase in pH and base saturation, the irregular distribution of nutrients as a result of stacking and burning, localised irreversible dehydration of soil colloids as a result of the high temperatures. Of importance to the nutrient cycles of N and P, is the steep decline in microbial activity due to partial sterilization caused by burning; this is then followed by a short flush and with time, a gradual decline in population (Cole and Johnson, 1978).

During the cultivation period there is a gradual decline in CEC, exchangeable K and mineral N. Cultivation after burning results in significant leaching and erosion losses of cation nutrients, coupled with a large loss of C and N due to decomposition of soil organic matter. Organic matter breakdown does not increase after clearing (Ewel, 1976) owing to the less than optimal environment for the micro-organisms responsible for its decomposition. The decline in soil organic matter is brought about by fact that inputs of litter have been terminated. The drop in CEC after clearing releases nutrients into soil solution, where they are subject to loss through leaching and surface runoff.

Regrowth and Fallow Regeneration.

Not all of the nutrient loss due to leaching is permanent, studies have shown that the nutrients immobilized in regrowth and fallow soil can quickly approach the levels found under mature forest (Golley et al, 1975). Some of the leached nutrients are retrieved by deep-rooted plants particularly on sandy well drained soils. However, this type of uptake may be less likely on the fine-textured, strongly weathered soils, typical throughout the Solomons. In this case nutrients leached deep into the profile are probably irretrievable, especially where the bulk of the species growing on these soils are shallow rooted. Where regrowth is rapid, however, many of the released nutrients will be available for new regrowth, thus ensuring quick establishment of vegetation. Further to this, it is anticipated that under conditions present in the Solomons that the changing botanical structure of the regrowth, from herbaceous through quick growing woody pioneer species, to heavy secondary regrowth forest species, that the relative proportions of the nutrients within the vegetation will alter with species change.

The recovery of the soil nutrient status after a period of cultivation is dependent on the particular nutrient. Nitrogen has been found to decrease for a period of 4 years while cultivation was carried out, but it recovered to initial values after 10 years natural fallow, due in part to N fixation (22-56 kg N/ha/yr; Cornforth, 1970).

In contrast, even though available P increased immediately after burning, total P decreased for 7 years and never recovered its initial values. In a similar manner K followed the same pattern with an initial increase in available K, which was then subsequently lost over the next 4 years.

Intercropping and Crop Removals.

Intercropping is a common feature of subsistence agriculture in the Solomon Islands, with one or more staples dominating a garden, together with a variety of other crops which are grown to mature with or after the staple. Throughout all the islands root crops form the staple, with sweet potato (Ipomoea batatas) accounting for 60-70% of all the staples grown. Next in importance are yam (Dioscorea alata), pana (Dioscorea esculenta), and taro (Colocasia esculenta), followed by cassava (Manihot esculenta), and other aroids Cyrtosperma chamissonis, Alocasia macrorrhiza and Xanthosoma spp. Commonly cultivated with these staples are the following crops, Hibiscus cabbage (Hibiscus manihot), pineapple, pawpaw, banana, corn, and to a lesser degree groundnuts, Chinese cabbage, beans, sugar cane and melons.

All the staples can be classified, on the basis of their K:N ratio in nutrient uptake, as K dominant or demanding species, and fall in the same category as banana, oil palm, pineapple, coconut and sugar cane. In contrast the N dominant species are corn, groundnut and beans. In the case of sweet potato the levels of available P in most soils in the Solomons, is sufficient to produce reasonable yields of tubers, the situation with regard to N and, more importantly K, is much more critical. The very low levels of exchangeable K in these soils and the high requirement by sweet potato for the nutrient, results in K deficiencies within the crop. Responses to fertilizer K up to 86% yield increase have been found on K deficient Tropudalfs in Malaita (Gollifer, 1972). In this respect for all the staples K is the first limiting plant nutrient, and its deficiency must be corrected before other deficiencies can be identified.

Field experiments on Guadalcanal and Malaita, and other trial work in Papua New Guinea, have indicated with sweet potato, that high levels of N encourages vine growth and inhibits tuber development, whereas potassium increases tuberous root yield by encouraging tuberization (Bleeker et al,1984). From this it would seem that the K:N ratio of the soil, particularly the available nutrients, will have a direct bearing on the yields of crops which are heavily dependent on K. This would be the case for all the staples grown in the Solomons.

The average yields of staples is moderate to low (sweet potato 10 t/ha, yam 7 t/ha, taro 8 t/ha and cassava 12 t/ha), resulting in fairly low nutrient removal data (Table 4). It is assumed for these calculations of estimated crop removals, that the tuber/corn is the only plant tissue removed from the garden area, and that the vegetative tissues are left in situ. Despite the fact that these removal figures are relatively low, it would not take long, where a succession of crops are cultivated on the same garden, for K deficiencies to become apparent. Particularly when the readily available K, in the residues left behind after fallow clearance and burning have been leached away, and the crop has to rely on the exchangeable K present in the subsoil.

TABLE 4: Nitrogen, phosphorus and potassium concentration and removal data for major root crops grown in the Solomon Islands.

Crop Species*1	Conc. in tubers (% dry wt)*2			Nutrient Removal kg/ha*3					
	N	P	K	N		P		K	
				Range	Mean	Range	Mean	Range	Mean
Sw.Potato	0.66	0.19	1.04	10-58	19	3-17	6	15-91	30
Taro	1.43	0.25	1.82	14-53	28	3-10	5	19-70	37
Yam	1.10	0.13	1.01	16-39	22	2-5	3	15-35	20
Cassava	0.46	0.09	1.14	16-51	24	3-10	5	41-127	61

*1 Sweet potato Ipomoea batatas, Taro Colocasia esculenta, Yam Dioscorea alata and D. esculenta, Cassava Manihot esculenta.
*2 Source for analytical data FAO (1972).
*3 Mean crop removal of tubers/corms is the considered norm for these crops.

THE NUTRIENT CYCLING RESEARCH PROGRAMME AND DISCUSSION.

Before new or improved farming systems can be devised, particularly when considering changes to traditional shifting cultivation, it is essential to understand from the original system, what are the important changes that are taking place to the nutrient cycles of the major plant nutrients (N, P and K). Firstly it is apparent that when rain forest is cleared and burnt, there are considerable losses of nutrients which are locked up in the biomass; N and K particularly, sustain very heavy losses due to volatilization and leaching. Secondly, the forest biomass and its relative concentration of its component nutrients, will only have a one time beneficial effect to the crops subsequently planted on the cleared land, after which they will have to rely on the residual organic matter and subsoil status.

The nutrient status of the Solomon Island soils is very variable, particularly in regard to their relative nutrient contents, however, useful generalizations can be made. For the most part total N levels in the topsoil are relatively high, so that during the fairly short cultivation cycle they are considered not to pose a serious problem as regards potential deficiencies in N supply. It is only where leaching and erosion losses have been high that its deficiency would become apparent. Levels of available P for the most part are low, despite the varying levels of total P in the topsoil and subsoils, with low pH the main reason for these low levels. However, the low P status of these soils does not appear to be critical, possibly because of the low P requirement of the staple food crops grown. The majority of the soils are deficient in exchangeable K, a situation which is further exacerbated by high K requirement of the crops grown. This will under particularly low K status situations, result in the fairly rapid reduction in crop yields due to K deficiency. The atmospheric input of K which is deposited in the rainwater, has been determined for the Solomons to be in the region of 40-68 kg K/ha/yr, and even this level of input does not seem to alleviate the shortage of this nutrient. The high leaching and runoff losses being responsible for this.

As mentioned earlier, the length of the regrowth period is of paramount importance in rejuvenating soil fertility. In the case of the more fertile soils with reasonable levels of P and K, and high levels of organic matter (eg. Hydrandept, Tropaquent, Eutropept, Humitropept and Ustropept), this period can be as short as 7 years, in contrast to the more strongly weathered soils, within the Oxisol and Ultisol orders, where >20 years is required. If these periods are shortened then the total biomass of the regrowth will be lower. In addition to this the nutrient composition of this immature regrowth will be different due to the higher percentage of herbaceous and pioneer species present in the vegetation.

The main aim of the farming systems research programme is to design stable sustainable systems which in one way or another increase the R factor. This can be either as (a) continuous cultivation on the more fertile soils, or (b) an extension of the cultivation period coupled with a reduction of the fallow period, on the poorer soils. With this in mind the various aspects of the research programme are as follows:

a. The collection of nutrient cycling data for N, P and K, from primary and secondary forest, cultivated land and crop species, on the major soil groups. The aim of this is to augment the data available from elsewhere, outside the Solomons, in order obtain a better understanding of the existing ecosystems and the effects of shifting cultivation.
b. Through a series of field experiments, assess the impact of agroforestry techniques on standardised farming systems. The aim of these trials is to assess the sustainability of alley cropping systems, a proven technique elsewhere, in relation to additions of inorganic fertilizers and the nutrient cycling characteristics within the soil/plant system.
c. Studies on methods of stabilising agriculture on sloping land. As a large majority of the food gardens are on sloping hill sites, where runoff and erosion is high, these investigations are designed to ascertain the feasibility of techniques such as mulching, alley cropping, cover crops, cultivation of tree crops etc.
d. An assessment of the potential of both indigenous andexotic fast growing NFT and non-NFT species for use in alley cropping systems as nutrient cycling species, for shade or for the production of fuel wood.

As this programme was only initiated in 1986, and takes the form of long term investigations, studying nutrient changes over a period of time, no formal results can be quoted at this juncture. However, a few preliminary observations can be made.

1. The practice of alley cropping using the species <u>Gliricidia sepium</u> as the hedgerow NFT is proving to be successful in maintaining soil organic matter levels, protecting slopes from erosion and providing a substantial input of nutrients into the system. Initial data indicate dry matter figures for prunings in excess of 8 t/ha/yr, depositing 184 kg N/ha/yr and 136 gk K/ha/yr, sufficient to sustain continuous cropping of root crops.

2. A spacing of 4 m between rows of Gliricidia is the optimum spacing, the rows must be orientated in an east-west direction where possible, and pruning is required 3 to 4 times per year.
3. The practice of including more N demanding crop species is advocated in order to rectify the inbalance between N and K. A favoured rotation would be the planting of root crops after fallow clearance, so as to take advantage of the high K levels at that time, followed by corn, beans or groundnuts.
4. Where practicable carry out as little burning as possible on during clearing, and establish the hedge row species at the same time as the first crop to be planted. This ensures rapid establishment of the tree, again taking advantage of the initially high values of nutrients in the soil, and hence enabling extensive root systems to be developed. This is important later, particularly with K, where the mining of K from the lower subsoils near the parent material may provide the only additional source of the nutrient during an extended period of cultivation.

Finally, it will be important to delineate within the soils of the Solomon Islands, those which can be cultivated intensively and those which cannot. Only by having the knowledge of the fertility status of these soils, coupled with that for the nutrient status of the vegetation growing on them, can any real improvements be made to the traditional systems of shifting cultivation presently being carried out the country.

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HILL PADI-BASED CROPPING SYSTEM IN SARAWAK, MALAYSIA

Key words: Ammophos Basal Dressing Bench Terrace Bush Fallow Hill Padi Seed Dressing Shifting Cultivation Topdressing Varietal Selection

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Abstract

The hill padi-based cropping system in Sarawak and the physical environment in which it is practised are described. The traditional way of utilizing and managing nutrients through cycles of forest fallow, clear-and-burn and cropping is also briefly discussed. The emphasis is on the review of experimental data collected through many years of studies on ways of improving or complementing the traditional practices. Seed dressing with ammophos seems to be most promising in view of the cost: benefit ratio and the practicality. Topdressing in addition to seed dressing is generally not necessary. When fertilizers are broadcast as basal dressing, yield responses are usually obtained for N and P, but not K; split application and the use of more soluble nutrient sources seem to be more efficient. However, the responses were inconsistent due to variations in other yield-controlling factors such as cropping history, soil type, slope and effectiveness of burn. The local varieties appear to be well adapted to conditions of low fertility. The use of bench terraces has also been tested, but the results have not been very encouraging.

Introduction

Hill padi-based cropping systems, commonly called shifting cultivation are widely practised in Sarawak, Malaysia. It has been estimated that at least 50,000 households are engaged in this form of agriculture. The Iban, Bidayuh (Land Dayak) and other indigenous tribes, who together comprise about 42% of the total population, form the bulk of the shifting cultivators.

From planimetric measurement of the most recent land-use maps of Sarawak, it was estimated that 2,674,544 ha of land are either currently used or have been slashed and burned at least once for hill padi cultivation; this represents nearly 22% of the total land area in Sarawak (Maas et al., 1986).

Mayan and Ngiam (1985), on the other hand, estimated that 84,853 ha were cleared, burned and planted with hill padi in the 1984/85 season. The annual figure is, however, extremely conservative and may in fact be as high as 150,000 ha (Hatch, 1982) giving a more reasonable forest fallow period of 15-20 years.

In this paper, hill padi-based cropping system in Sarawak is briefly described and examined in relation to the physical environment and the traditional way of utilizing and managing nutrients. The main emphasis is however on the review of research attempts to improve or to complement the traditional practices.

The physical environment

Sarawak lies within the tropical monsoon belt. The climate as a whole is typical of humid tropical lowlands. The mean annual rainfall is high, varying from 3050 to 5590 mm, and seasonal fluctuation of temperature (mean of 26 ^{0}C) is negligible. In addition, the rainfall intensity can be very high, commonly exceeding 100 mm/hr. However, dry periods of 10-19 days can occasionally occur in almost any month of the year (Scott, 1985). The seasons are not clearly defined, but during the North-East Monsoon from October to February, the rainfall is higher than average; it is during this period that the hill padi is grown.

The hill padi-based cropping system is most widely practised on the so-called Red-Yellow Podzolic soils (Dystropepts, Tropudults or Paleudults) which represent the most important soil group on the low hills and in the mountainous interior of Sarawak. The low hills and the mountains occupy about 80% of the land area; they are characterised by steep, dissected terrain with slopes commonly in excess of 25 degrees.

Although Red-Yellow Podzolic soils are relatively more fertile than some other upland soils like Podzols, they all have a low to very low supply of most plant nutrients. This is because they are highly leached and are derived from parent materials relatively low in weatherable minerals. Table 1 shows the means of some selected properties of the more important soil series at two depths (0-20 and 40-60 cm). The soils show some variation according to the texture, but in general they are characterised by a base saturation of less than 10% and low pH levels of 4.0-5.0. Level of organic carbon decreases very sharply from about 1.5-2.0% in the friable topsoils to less than 0.5% in the lower horizons where the structure is usually weakly developed. Cation exchange capacity is generally above 24 me/100 g clay in the upper subsoil, but some soils do have values ranging from 16 to 24 me/100 g clay.

Phosphorus levels are very low; available phosphorus is almost zero below the A horizon, and most soils have a high phosphorus fixing capacity.

The small amounts of plant nutrients that are available are mainly concentrated in the topsoils. This shows the importance of the standing vegetation in recycling the nutrients through a well-developed root system and the litter fall. It also indicates the importance of conserving topsoils for sustained productivity.

The hill padi-based cropping system.

The hill padi-based cropping system in Sarawak is a form of shifting cultivation characterised by the rotation of fields rather than crops, by low cultivation factor (1-2 crops alternating with 10-20 years of forest fallow) and by slash and burn with almost exclusive use of human energy and simple implements. To the indigenous tribes, the whole practice is not merely a system of growing food but is one that permeates nearly every aspect of their social organisation, custom and religious belief (Freeman, 1970).

TABLE 1. Means of selected properties of the three main series of Red-Yellow podzolic soils in Sarawak.

Properties*	Naylau (9 profiles)		Bekenu (13 profiles)		Merit (10 profiles)	
	Soil Series					
	Depth (cm)					
	0-20	40-60	0-20	40-60	0-20	40-60
pH (H_2O)	4.7	5.0	4.7	4.8	4.5	4.5
Clay (%)	12	15	22	26	33	39
Organic C (%)	1.47	0.27	1.45	0.35	1.83	0.46
Total N (%)	0.10	0.04	0.13	0.04	0.17	0.07
CEC (me/100g soil)	7.2	3.5	9.4	6.9	16.6	11.7
CEC (me/100g clay)	-	25.8	-	25.7	-	30.8
Exch. Ca (me/100g)	0.27	0.20	0.19	0.21	0.51	0.51
Exch. Mg (me/100g)	0.19	0.05	0.12	0.07	0.20	0.14
Exch. K (me/100g)	0.11	0.05	0.14	0.06	0.45	0.09
Base saturation (%)	10	10	6	7	9	8
P retention (%)	29	32	37	28	53	53
Available P (ppm)	5	1	6	1	7	1
"Reserve" P (ppm)	101	65	111	75	260	129
"Reserve" K (ppm)	574	737	1513	1563	3139	3609
"Reserve" Ca (ppm)	51	32	95	65	298	123
"Reserve" Mg (ppm)	398	504	741	898	1438	1854

* CEC by 1 N NH_4OAc at pH 7.0
Available P by Kurtz and Bray 2
"Reserve" by ignition at 800 ^{0}C and then extraction with conc. HCl

The annual cycle of hill padi cultivation in Sarawak begins in the drier months of June and July when either primary jungle or secondary re-growth is cleared and felled. The felled vegetation is left to dry for about a month and then burned. The larger logs and branches which are not completely burnt are left lying in the field. Sowing of the padi immediately follows the burn, and invariably other crops like maize (Zea mays), tapioca (Manihot esculenta) and local vegetables (e.g. Cucurbita spp., Cucumis spp. and Solanum spp.) are planted as inter-crops or in relay. Hill padi seeds are sown directly into holes randomly dibbled by a stick; the planting distance varies from 30 to 46 cm.

At least one round of weeding is normally done and this usually commences one or two months after planting. Chai (1983) concluded that it is best to start weeding 40 days after sowing. Hand weeding is the normal practice, but the use of weedicide seems to be increasing.

The padi matures in about 160 days and harvesting is usually done in February or March the following year. After the harvesting of padi, a crop of tapioca is usually taken in the second year before the land is left fallow. If the padi yield is exceptionally good, however, a second hill padi crop may be grown in the second year.

The fallow period depends to a large extent on the availability of land. In areas where the demographic and land pressure is high, the bush-fallow period has been very much shortened. From the recent socio-economic surveys, Hatch (1982) summarized that about 50% of the shifting cultivators are farming lands which have been fallowed for ten years or less, about 40% with longer fallow periods (10-24 years or more) and less than 10% are clearing primary jungle.

The varieties of hill padi planted are all local ones selected through generations of cultivations. There seems to be a large number of varieties in use throughout Sarawak but it is likely that many of them are in fact the same variety but with a different local name. All these varieties are long-term, and each household normally plants a few varieties in a single field.

Material input in terms of fertilizer and agrochemicals is practically nil. This is an inherent feature of the cropping system which depends on a good burn for the supply of plant nutrients. Labour input is high; operations like land clearing, weeding and harvesting are all labour intensive. It has been estimated that the labour requirement is about 203 mandays per ha per crop (Department of Agriculture, 1985), the most laborious being harvesting which accounts for nearly one-third of the total requirement; land preparation and weeding take up another 17% each. The padi yield varies considerably from total crop failure to 2.86 t/ha (Hatch, 1982). The very high yields are nearly all derived from farms made from virgin jungle or very old secondary forest. Total crop failure is usually the result of a severe pest attack. The State's average yield is 735 kg/ha (Department of Agriculture, 1975-84).

Traditional way of nutrient utilization and management

The main plus for the shifting cultivation system in Sarawak is that it works, albeit at a subsistence level, provided that the population and land pressure is not great and the bush-fallow period is adequate. In his review, Hatch (1982) concluded that shifting cultivation in Sarawak "is not a temporary form of totally exploitative agriculture but is rather a very sophisticated and rational system of land use". Although it may be criticised as wasteful and unproductive by standards of modern agriculture, it is apparently well adapted to the marginal land resources and the prevailing socio-economic environment in the interior areas.

Under the traditional methods of cultivation, the crops rely entirely on the natural fertility of the surface soils and the release of nutrients from the burning of the felled forest vegetation. Since the level of most nutrients in the highly leached Red-Yellow Pozolic soils is low to very low, the practice of clear-and-burn is in fact the main source of nutrients for the hill padi and the associated food crops. Andriesse (1987) found that immediately after the burn, the increase in total N, available P and exchangeable K, Ca and Mg within the top 25 cm is 1264, 4.4, 329, 540 and 117 kg/ha respectively. The shifting cultivators capatilize on this release of nutrients from the biomass to produce an adequate crop or two before moving on to another site.

Where the primary jungle or very old secondary regrowth is cleared and burnt for hill padi cultivation in Sarawak, yields in excess of 2 t/ha have been recorded. In more densely populated areas, there are increasing incidences of land being re-used after only 3-5 years of fallowing and in such cases, yields have fallen to very low levels of 300-400 kg/ha. The relationship between yield and duration of bush-fallow is not always consistent and straight forward because yield is also affected by many other factors like the effectiveness of the burn, soil type, rainfall distribution over the season, time of planting and disease and pest incidence. However, most workers do agree that the duration of the fallow period is of critial importance in maintaining yield, whether this be through restoring soil fertility (chemical and physical), reducing weed competition and pest problems, restoring biomass or reducing the severity of soil erosion. Andriesse (1977) reported that a bush-fallow period of 20 years is required to accumulate sufficient plant nutrients in the living vegetation to sustain one crop. More recent observations suggest that this will vary according to soil type, slope and cropping history but the fallow period should not fall below 10 years (Hatch and Tie, 1979).

The main reason for shifting cultivators to fallow the land and plant elsewhere is the decline in yield. This rapid decline in yield has been attributed by various authors (e.g. Nye and Greenland, 1960) to declining soil fertility, increased weed competition, increased pest and disease problems, soil degradation due to accelerated surface erosion, or a combination of these factors. Andriesse (1987), however, found no evidence for declining nutrient levels as being reponsible for abandoning the farms after one year of cropping in Sarawak. Dunsmore (1968) reported that pest damage and disease are normally not serious in hill padi cultivation in Sarawak but hill padi farms have been observed to be abandoned because of weed encroachment.

TABLE 2. Mean soil loss from trial plots at Semongok and Kampung Benuk, Sarawak (1978-1985).

Land Use[a]	Mean Soil Loss (t/ha/yr
Primary Jungle	0.25
Traditional Hill Padi/ Secondary Regrowth	0.10
Hill Padi on Terrace	0.37
Terraced Pepper	1.99
Clean-weeded un-terraced Pepper	91.24

a On a 25-degree slope; clayey, mixed, isohyperthemic, typic dystropept.
b Cleared and burned for one crop of hill padi in 1980-1981.

The results from soil erosion trials (Table 2) also show that the amount of soil losses occurring during the hill padi cropping cycle is very low and comparable to that under primary jungle (Federick Haili Teck, Department of Agriculture, personal communication). However, where the land has been over-farmed, declining fertility, increased erosion and aggravated pest problems have been observed. In some extreme cases, the soil can only support the growth of lallang (Imperata cylindrica) thereafter.

Research attempts to improve the traditional system

While it is the long-term aim of the Government to assist all shifting cultivators to change over to a more certain and rewarding form of agriculture, it has been accepted that the system will inevitably continue untill suitable alternatives are adopted. Within this context, attempts have been made to improve or complement the system by ways of increasing yields, reducing labour requirement, increasing cultivation factor, or a combination of these. Some examples such as the use of fertilizers, the selection of high-yielding varieties, and continual cropping on reverse-sloped dry bench terraces will be reported in the sub-sections below.

Use of fertilizers.

The main objective of this research programme is to find an economical and practical way of fertilizing hill padi which would be generally applicable irrespective of the previous cropping history, the effectiveness of the burn, the soil type or the slope. The programme dates back to 1958 but there has been no concerted nor continuous efforts. However, all field experiments carried out on farmers' land and closely following the traditional practice can be broadly divided into seed dressing, NPK basal dressing and N topdressing trials.

As hill padi is planted on steep slopes, the reasons for placing fertilizer together with the seeds in the planting holes at the time of sowing are obvious. Seed dressing experiments were therefore the earliest to be set up. Up to 1985, 53 field trials using Ammophos (initially mono-ammonium phosphate, changed as from 1970 to di-ammonium phosphate) as seed dressing were conducted all over Sarawak (Dunsmore, 1970; Chai, 1983). All these trials showed positive responses, but only 18 of them showed siginificant ($P < 0.05$) yield increases. The most effective rate of application was found to be 0.36 kg of Ammophos per kg of seeds; higher rates would reduce germination and cause injury to the seedlings, particularly if dry weather prevails after sowing. The average increase in grain yield was 252 kg/ha or 28% over the control. Taking the State's average hill padi yield of 735 kg/ha, Ammophos seed dressing would increase the yield by about 206 kg/ha (at M$ 0.60 per kg). At the current recommendation, the Ammophos requirement is 11 kg/ha or M$ 2.20 at the current (subsidised) price. The cost: benefit ratio works out to be about 1:56, making the practice highly favourable economically.

28 Seed dressing trials incorporating mainly K (apart from N and P) in different mixtures generally showed that responses to K were generally not significant.

Experiments were also conducted to determine the response of hill padi to basal dressing of NPK fertilizers broadcast immediately before sowing. The results of the earlier trials capable of statistical analysis showed that responses were very site specific (Table 3). The data demonstrated that a blanket recommendation for the whole State of Sarawak is not possible; other factors like the cropping history, the effectiveness of the burn and the soil type have to be taken into account.

TABLE 3. Grain yield (kg/ha)[1] of hill padi in NPK basal dressing trials.

Treatment[1] N-P-K (kg/ha)	1959-1960			1962-1963		
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Control	699a	861a	453a	1054a	862a	1566a
22.4-0-0	699a	1023b	606b	1201a	1111ab	1901b
0-13.4-0	805b	1179c	982c	-	-	-
0-26.9-0	866c	1544e	1203d	1156a	1247bc	2036bc
22.4-26.9-0	882c	1417c	1157d	1223a	1326bc	1901b
44.8-26.9-0	1027d	1269d	1244d	1347a	1494cd	2213cd
44.8-40.3-0	-	-	-	1325a	1818de	2165cd
22.4-26.9-33.6	1138e	1444e	1207d	-	-	-
44.8-40.3-11.2	-	-	-	1378a	1856e	2360d
SE (Mean)	17	36	43	108	117	88

1 Figures followed by the same alphabet are not significantly different (DMRT at 1% for 1959-60 and 5% for 1962-63).
2 Urea for N, CIRP for P and MOP for K.

In general, however, most of the experiments showed positive and significant responses to N, P and their interaction (Chai, 1986). Split application and the use of more soluble fertilizers (e.g. triple superphosphate instead of Christmas Island rock phosphate) have been observed to boost the yield increase from 42-77% to 167% over the control. The most beneficial rate of application seems to be 45-50 kg N/ha and 22-27 kg P/ha, split into one at sowing and another at maximum tillering. Responses to K were usually not significant.

As part of some of the seed dressing trials, the effect of N topdressing had been examined. The summarised results of 52 experiments presented in Table 4 again showed considerable variability and inconsistency. In general, it appeared that seed dressing with Ammophos (plus the nutrients released from the burn) would be sufficient to give good yields without N topdressing, provided the weeds, pests and diseases are well controlled (Department of Agriculture, 1970; Chai, 1986).

In going through the massive amount of data on hill padi fertilizer experiments (1958-1985), it is quite clear that consistency in repsonses was difficult to obtain. However, this inconsistency is to be expected because, apart from the high coefficients of variation of the data, other important variables have not been taken into account.

The age of the fallow vegetation, the effectiveness of the burn, the soil type and the slope position, which would strongly affect the nutrient supply, had been poorly controlled and these data were usually inadequately recorded. Specific guideline on fertilizer requirement, given as broadcast, is therefore not possible, and blanket recommendation derived from pooled data is at best an educated guess. However, seed dressing at the recommended rate is practical because it is cheap and involves little extra effort to apply.

TABLE 4. Responses of hill padi yields to N-topdressing.

Seasons	No. of experiments			N topdressing (kg/ha)[b]
	Significant[a]	Non-Significant	Total	
1965-68	16(+) 2(-)	13	31	11.2 on top of Ammophos seed dressing (SD) at 21 days after sowing (DAS).
1969-71	0	11	11	11.2 or 22.5 on top of Ammophos SD at 20 and/or 80 DAS.
1971-72	0	5	5	11.2 with or without Ammophos SD.
1972	1(+)	1	2	22.5 on top of ammophos SD at 80 DAS.
1976	1(+)	0	1	0, 20.5 or 41.0 on top of Ammophos SD.
1984	0	2	2	0, 50, 100 or 150 without SD at 40 and 60 DAS; P and K applied as blanket dressing.

a significant at 5% level; (+) = positive, (-) = negative.
b urea used up to 1976; ammonium sulphate in 1984.

Varietal Selection.

All the local varieties selected through generations of planting seem to be well adapted to the conditions under which they are cultivated. In comparison to wet padi varieties, the plants are taller with thick stems, extensive root system and broad and droopy leaves. Hill padi is rather prone to lodging when the yield is high, but this is generally not a problem under the traditional circumstances. Most local varieties are susceptible to blast (Piricularia oryzae).

Hill padi also has a poor tillering ability. This is borne out by the fact that 8-10 seeds are traditionally dibbled per planting hole. The traditional planting distance is 38-46 cm. There were indications that closer spacing of 30 cm square or 30 x 15 cm could increase yields per unit area (Dunsmore, 1970; Department of Agriculture, 1972). The yield potential of some of the better varieties is in the range of 1.9 - 2.3 t/ha.

It appears that the local hill padi varieties are rather unresponsive to fertilizer application. Cases of negative response due to higher rate of N topdressing have been reported. They are however very tolerant of the acid condition that prevails in the highly-leached Red-Yellow Podzolic soils. Dunsmore (1970) has observed no response in hill padi yield as a result of dolomite application.

The ability to produce full, fertile grains even under conditions of very low fertility and at times, severe moisture stress demonstrates the adaptability of the local hill padi varieties. This is a very important feature as it minimizes the chances of total crop failure and ensures the production of seeds for the following season.

Table 5 shows the mean concentrations of major nutrients in various parts of hill padi plants sampled from the NPK trials. Ishizuka (1965) reported 0.31% P and 0.32% K in the ears of adequately fertilized wet padi. Nutritional studies in wet padi showed that 0.15% Ca, 0.10% Mg and 1.0% K in mature straw are the critical values for deficiency (Shouichi et al., 1976). By these standards, it appears that hill padi plants from the trials had low levels of P, K and Mg.

TABLE 5. Mean nutrient concentrations in various parts of hill padi plants sampled from three NPK fertilizer trials.

Plant Part	Nutrient element (% D.M.)				
	N	P	K	Ca	Mg
Grain	1.31	0.19	0.27	0.10	0.09
Culms	0.58	0.05	1.11	0.18	0.06
Leaves	0.71	0.04	0.48	0.43	0.06
Roots	0.71	0.06	0.48	0.16	0.06

From the data, it can be calculated that at a grain yield of 1.0 t/ha (14% moisture), the quantities of major nutrients in the grain fraction are 11.2 kg N, 1.6 kg P, 2.3 kg K, 0.9 kg Ca and 0.8 kg Mg per ha. These figures (except P) are higher than 7.2 kg N, 2 kg P, 0.8 kg K and 0.3 kg Ca per ha recorded by Zinke et al. (1978) for hill padi in Thailand.

Although it is not possible to compute the total nutrient uptake of the whole plant because dry matter yields of various vegetative fractions were not recorded, it may be inferred from the nutrient distribution among the plant fractions that substantial amounts of K and Ca remain with the straw fraction which is not harvested.

Bench terraces

As an alternative to shifting cultivation of hill padi on slopes, dry reverse-sloped bench terraces were introduced in 1978 on an experimental basis. The rationale for testing this idea is that if terraces could be used for continuous cropping of hill padi and other food crops, a lot of land, time and labour could be saved for other appropriate uses. At the initial stage of terrace construction, the labour requirement is undoubtedly very high, but thereafter it should be less than that of the traditional practice.

Whilst the rate of soil erosion under the traditional practice of hill padi cultivation gives no cause for alarm (see above), there is ample evidence to show that the reverse is true when continuous cropping of the hill slopes is practised (e.g. traditional pepper). On the other hand, the reverse-sloped bench terraces have been proven to be an effective measure against surface erosion. The soil loss from such terraces continuously cropped with hill padi with or without an off-season crop has been monitored from 1978 to 1985, and the average soil loss is only 0.37 t/ha/yr (see Table 2).

The actual performance of hill padi on the bench terraces is presented in Figure 1. Whilst the first year yield at Semongok terraces was encouragingly high, it dropped off rather severely in the second year, less severely in the third and then levelled off in subsequent seasons.

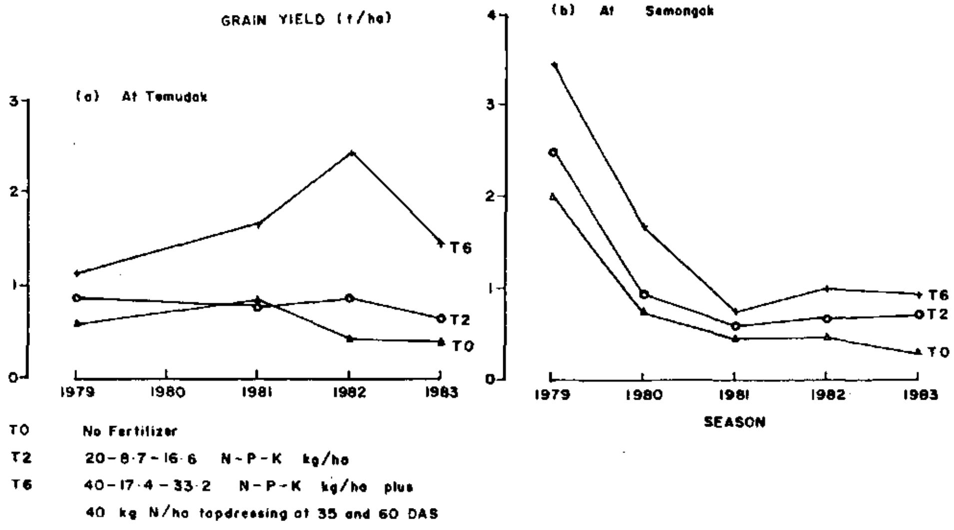

Figure 1. Yield trends of hill padi grown on bench terraces.

The trend was different at Temudok terraces: the first year yield was poor but it increased in the third and foruth year before declining to its original level in the fifth.

Attemps to utilize <u>Leucaena leucocephala</u> as a source of organic matter and nitrogen have failed due to the poor growth of the trees on the acid soils in Sarawak. Some studies have also been made to test the beneficial effects of growing leguminous crops such as mungbean, soya bean, groundnut and cowpea as off-season crops or in rotation with the hill padi. The results so far have not been encouraging.

For hill padi growing on terraces, seed dressing with Ammophos in the first season had been found to be ineffective (Chai, 1986). NPK fertilizer trials generally indicated strong responses to N and P basal dressing and their positive interaction. The effect of K was only examined in one trial on a newly built terrace; it was found to be not significant. Any response due to N topdressing was also specifically studied in another experiment; the results showed that at lower levels of inputs, N topdressing in addition to basal dressing did not improve the yields. However, at 40-17-33 kg N-P-K/ha basal dressing, topdressing with 40 kg N/ha each at maximum tillering and panicle initiation did increase yield significantly. Compared to the one growing on slopes, it appears that hill padi growing on terraces would respond better to higher level of N up to 120 kg/ha but similar level of P at 22 kg/ha would suffice. The reason behind this observation has not been ascertained, but it could be due to the fact that some organic matter is inevitably lost during the terrace construction although every effort has been exercised to conserve all the topsoils.

Summary and conclusions

Shifting cultivation in Sarawak as traditionally practised is a low-input, sophisticated system that is capable of producing a reasonable food crop on marginal soil resources on a sustainable basis. However, the system will break down when the bush-fallow period is shortened due to population and land pressure. The quantities of nutrients removed by the crop are not large.

Fertilizer experiments have shown that P is a more limiting element than N and K. This is supported by the fact that the soil P status is generally very low and the P-fixing capacity of the Red-Yellow Podzolic soils can be very high. Although significant N and P responses are not uncommon, the responses have not been consistent. This is attributed to variations in other yield-controlling factors such as length of fallow period (cropping history), soil type, effectiveness of the burn, time of planting and rainfall distribution during the season. A blanket recommendation for NP fertilizer requirement to be given as broadcast is therefore not possible. Potassium and other nutrients may become limiting but in general the inherent soil fertility plus the nutrient release from the burn appear to be adequate for the traditional practice. The most economical and practical way of complementing the traditional practice appears to be mixing 1 kg of seeds with 0.36 kg Ammophos at sowing.

During the cropping period, build-up of pests and diseases is generally not serious under the traditional practice. The encroachment of weeds is however an absolutely fundamental aspect of the whole system and its influence must not be underestimated. Imperata cylindrica is a particularly aggresive weed. Under the traditional practice, soil erosion does not appear to be a problem even under the prevailing conditions of intense rainfall and steep slopes.

The local varieties selected over generations of cultivation are well adapted to the conditions of low fertility. However, they are rather unresponsive to fertilizer application and the yield potential at 1.9-2.3 t/ha is very low compared to wet padi.

The use of bench terraces has been tested, but the results have not been very encouraging. Although the practice is sound in terms of soil conservation, the performance of hill padi on a continuous cropping basis is not satisfactory. The rapid decline in yield after the first few crops has not been adequately studied but rapid loss of soil organic matter and deterioration of the physical properties have been cited as likely causes under experimental conditions.

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NUTRIENT MANAGEMENT FOR UPLAND CROPS IN VIETNAM.

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Upland soils in Vietnam and their properties.

Upland soils in Vietnam are cultivated on various soil types, with a total area of 2.4 - 2.5 million hectares, which is 24 - 25 % of the total cultivated area of the country. However, the agricultural production is relatively low: the rice production in the uplands is only 15 - 17 % of the national rice output.

Based on their utilization, upland soils in Vietnam are divided into two groups:

Group 1: Soils under upland crops in rice-based cropping systems.

As a result of environmental conditions (monsoon climate with alternatiing wet and dry seasons, topography), and management practices, the following annual crop rotations are being practiced:

- 2 rice crops + 1 upland crop. In this case upland crops such as white potato, winter maize or sweet potato are mainly planted in winter.
- 1 rice crop + 2 upland crops. In general these upland crops are planted in winter and spring. Major spring crops are peanut, maize, sweet potato and soybean.
- 1 rice crop + 1 upland crop. The upland crop such as peanut, maize, sweet potato or soybean is usually planted in spring.

Areas with two rice crops annually are generally alluvial soils of river deltas, with pH 5.5-7.0, organic matter 1-2%, total nitrogen 0.1-0.15%, total phosphorus 0.07-0.15%, total potassium 1-2% and a CEC over 10 meq/100 g soil.

Yields of upland crops may range from 10-15 tons/ha for potato, 1.5-2 tons/ha for maize, 6-7 tons/ha for sweet potato, 1-1.5 tons/ha for peanut and 0.5-0.6 tons/ha for soybean.

Areas with only one rice crop every year are mostly located on light-textured soils, occurring on degraded profiles and coastal sands. The pH ranges between 4.5-5.0, organic matter is < 1%, total nitrogen 0.07-0.08%, total phosphorus 0.05-0.06%, total potassium 0.5-0.8%, CEC 4-6 meq/100 g soil.

Crop yields are relatively low, with production levels between 1-1.5 tons/ha for maize, 5-6 tons/ha for sweet potato, 7-8 tons/ha for white potato, and 0.4-0.5 tons/ha for soybean. Only the yields of peanuts may reach relatively high levels up to 1-1.5 tons/ha.

Group 2: Soils under upland crops without irrigated rice.

Mainly because of climatic and topographical conditions, only rainfed crops can be grown, such as cassava, maize, peanut, sweet potato, soybean, black gram and upland rice.

The soils in these areas are generally acid, with a pH between 4-4.5, organic matter 0.05-0.08%, total nitrogen 0.05-0.08%, total phosphorus

0.03-0.1% (except in soils developed on basaltic rock, which may have a phosphorus content of 0.2-0.5%), soluble phosphorus ranges from 1-3 mg/100 g soil, CEC 3-4 meq/100 g soil, and Ca and Mg levels are very low.

Crop yields are low as well, with yields between 0.7-1.5 tons/ha for upland rice, 0.5-1 ton/ha for peanut, 0.7-1 ton/ha for maize, 4-5 tons/ha for sweet potato, 8-10 tons/ha for cassava, 0.5-0.6 tons.ha for soybean and other legumes, and 8-9 tons/ha for pineapple.

Data on the nutrition of upland crops.

It is the general understanding in Vietnam that, in order to solve the food problem in the country, not all attention should be focussed on irrigated rice, but that also the production of upland crops should be increased in terms of acrage as well as yields/ha. Some research results on the improvement of upland crop production are presented here.

1. **The combination of organic and inorganic fertilizers.** By using inorganic fertilizers, farmers have observed that, particularly on light soils, crop yields were not increasing. Studies on the relation between organic and inorganic nutrient sources have demonstrated that the application of $N_{60}P_{60}K_{60}$ did not result in a yield of upland rice and maize, and resulted in a yield of 1.8 tons/ha of cassava. Application of 30 tons/ha of organic manure only yielded 0.2 tons/ha of maize, 0.35 tons/ha of upland rice and 4.1 tons/ha of cassava. However, the combined application of organic manure and fertilizer resulted in yields of 0.9 tons/ha of maize, 1.2 tons/ha of upland rice and 8 tons/ha of cassava. Similar results were obtained in the case of pineapple.

In order to produce substantial quantities of organic manure, the following methods are being practiced:

- The use of plant residues of peanut and other legumes for animal (mainly pig-) feed. Also, residues are being incorporated into the soil.
- Mixed cropping of legumes and food crops such as maize, cassava, sweet potato, etc.

Research results have shown that by incorporating peanut leaves into the soil, phosphorus fixation decreases, and levels of soluble phosphorus and soil moisture increase as compared to the control plots.

2. **The use of biomass of the previous crops as green manure.** As an example, research results have shown that the application of 50 tons/ha of pineapple leaves has the same effect as the application of 15 tons/ha of organic manure.

3. **Application of ammonium sulphate** has been shown to be better than urea, with yield increases as compared to applied urea of 20-30% in the case of peanuts and 40-50% in the case of maize. Ammonium sulphate increased protein content in maize grains by 20-30% as compared to the plots fertilized with urea.

4. **Alkaline phosphorus fertilizers are better than Superphosphate** on Ferralsols in hilly areas. Fused magnesium phosphate increased pineapple yields by 40-50% as compared to P-application as Superphosphate. The application of Phosphorit on pineapple on degraded soils has the same effect as Superphosphate, but is 2-3 times cheaper.

5. **The application of K is more beneficial on upland crops as compared to irrigated rice.** The efficiency of potassic fertilizers applied on irrigated rice has been observed to be very low. 1 Kg of K_2O can increase irrigated rice yields by 1-2 kg (on light soils this increase may be up to 4-5 kg of rice), but the same amount can increase yields of maize by 5-10 kg, soybean by 3-5 kg, and peanut by 5-6 kg.

6. **The efficiency of trace elements to upland crops is higher as compared to irrigated rice.** Trace elements have almost no impact on irrigated rice, but Mo, B, Cu and Zn may considerably increase the yields of upland crops. As an example, the combined application of Mo and B increased the yields of peanut and soybean by 15-30%, and a combination of B, Cu and Zn increased maize yields by 10-20% as compared to the control plots.

7. **The application of organic manure and phosphoric fertilizer** in pots in order to germinate maize seed is very economical. In recent years, winter maize is widely used after two rice crops. In order to save time, maize grains are sown in clay pots, filled with a mixture of soil, 20-30% organic manure and 0.15-0.16 g Simple Super Phosphate. After 5-10 days the maize plants are being transplanted to the field.

8. **The efficiency of inorganic fertilizers depends very much on soil moisture**, as it has been observed that the same applied amount of nitrogen fertilizer yielded 30-40% more maize on a soil with a moisture content of 70-80% fieldcapacity as compared to a soil at 40-60% fieldcapacity.

Research plans.

Fertilizer research in Vietnam in future will concentrate on the following items:

- The relation between the application of organic manure and inorganic fertilizers for upland crops.
- Determination of the optimum rate of NPK application on some specific soil types.
- Improved methods of fertilizer application, particularly in the case of nitrogen.
- Research on the effect of trace elements on upland crops.
- The relation between soil moisture levels and nutrition of upland crops such as maize, white potato, peanut and soybean.

THE DEVELOPMENT OF LEGUME - CEREAL CROPPING PATTERNS FOR FOOD CROP PRODUCTION IN ON - FARM RESEARCH IN NORTHERN GHANA.

Key words: Alley Cropping Groundnut Maize On-farm Research Pigeon Pea Relay Cropping Rotation Sorghum.

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Summary.

The development of a methodology for farm trials under farmers management with decentralized supervision is described.

After the experience of the high risk of increasing plant densities in traditional cropping patterns, emphasis shifted to testing of new crop varieties and cropping patterns. Legumes were included in alley and relay cropping with pigeon pea in rotation and paired row cropping with high density sole crop groundnut. These cropping patterns were tested as alternatives to farmers' maize-groundnut-sorghum intercrop on upland farms in the Savanna area of Northern Ghana.

Pigeon pea alley cropping proved to be more remunerative than farmers practice in a village in the south with higher rainfall, mainly because of a good return of pigeon pea seed yield.

Cropping patterns with sole crop groundnuts plus maize/sorghum intercrop gave better maize and groundnut yields, but so far sorghum establishment has been a problem. Farmers considered these cropping patterns easier to weed.

The great discrepancy in yields between the research station and farmers fields needs further study. A possible cause is the very low phosphate status of upland soils around the villages.

Introduction.

Northern Ghana with an area of 97.702 km2 covers about 40% of the Republic of Ghana. The total population is about 12 million, with 85% of people live in rural areas. In this savanna area, the bulk of upland food crops such as maize, sorghum, millet, yams (Dioscorea spp.), cassava, cowpeas and groundnuts is produced by subsistence farmers in extensive cropping systems, that rely mainly on fallow rotation for a modest nutrient input. In the denser populated areas of Northern Ghana fallow and farming lands are now becoming scarce. Yields per hectare are low (table 1) and will further decline in the foreseeable future without interventions.

The use of chemical fertilizer for food crop production is limited because of unfavourable cost-benefit ratios and infrastructural problems. Fertilizer is mainly used on crops such as cotton and rice, that is gaining increasing importance in the seasonally flooded valleys.

The Nyankpala Agricultural Experiment Station runs a joint project of the German Agency for Technical Cooperation (GTZ) and the Crops Research Institute of Ghana, and has the responsibility for the development of low external input cropping systems for a sustained and reasonable yield. At the station, various techniques are being developed using moderate chemical fertilizer inputs, and incorporation of legumes in the cropping systems. The station also has a strong plantbreeding unit.

The on-farm agronomy work aims at adapting the station research findings for their implementation by subsistence farmers, and to obtain feed-back on farmers' constraints to the station researchers. This paper presents results of farmer-managed trials in Northern Ghana from 1984 to 1986. Trials tested yearly crop rotation of groundnut and maize/sorghum, alley cropping of pigeon pea with maize-groundnut-sorghum, and relay cropping of maize and pigeon pea.

TABLE 1. Major crop yields in villages of Northern Ghana, ton/ha (Source: Diehl, 1985, 1986).

Crop	Village and year						
	Binduri	Nakpanduri		Wantugu		Nakpa	
	1985	1984	1985	1984	1985	1984	1985
maize	-	1.18	1.63	1.08	0.56	0.53	0.43
early millet	1.08	-	-	-	-	-	-
sorghum	0.79	0.86	0.98	0.45	0.31	0.39	0.57
cowpea	0.09	0.29	0.24	0.23	0.19	0.24	0.11
groundnut	n d	0.54	0.43	0.63	0.29	0.45	0.51

Description of study area and target group.

Rainfall in Northern Ghana is characterized by a bimodal pattern with a dry season of about five months from November through March. By the end of the dry season most of the area will have been swept by bushfires. Average annual rainfall ranges from 900 mm in the north to 1200 mm in the south where the rainy season shows two peaks around June and September-/October.

Geomorphologically the Volta basin comprises roughly half of the area. It has a rolling landform at a height of 140-170 m above see level with slopes of 0-2% and scattered peneplains. The Volta river and its tributaries that drain Northern Ghana, Burkina Faso and Northern Togo are meandering in seasonally flooded valleys to end in the Volta Lake.

Soils in the Volta basin are derived from sandstone and shale and can roughly be devided in upland soils developed in situ of low inherent fertility and alluvial soils in the valleys (table 2). Shallow poorly drained concretionary soils over laterite hardpans cover large areas.

Cattle is daily herded into the bush and kraaled at night around the houses. Systems of "compound farming" have evolved where the kraal manure is incorporated in fields directly around the house or compound.

TABLE 2. Some characteristics of representative upland and valley soils of the Volta Basin (Source: Nyamekye, 1986).

Depth cm	pH CaCl2	Org.C %	N %	P-Bray ppm	CEC me/100g	Clay %
Tingoli series (upland) Paleustalf						
0-10	5.5	0.92	0.044	3.49	5.0	9.5
10-48	5.2	0.46	0.034	2.74	4.8	18.2
48-78	4.9	0.33	0.028	2.99	4.6	20.7
Volta series (valley bottom) Tropaquept						
0-25	4.5	0.69	0.045	3.39	4.3	5.3
25-50	4.4	0.57	0.041	2.44	7.0	16.8
50-65	4.1	0.47	0.045	3.21	13.0	31.8
65-85	4.1	0.33	0.038	3.11	13.9	37.1

Maize or early millet are grown on compound fields, which is illustrated in the higher yields for these two cereals (table 1) in the villages Binduri, Nakpanduri and Wantugu. In Nakpa and during 1985 in Wantugu there were no compound farms. Complementary to the compound farms are the bush farms that receive little inputs but provide the bulk of the family's food.

Because labour is the main input that goes into food crop production in the upland bush farm, the subsistence farmers are geared towards maximum production per unit labour. At present because of low yield levels, it is necessary to plant large acreages to supply food for the family. This extensive land use has been made possible with the advent of bullock traction and tractors.

We have chosen as our target group the subsistence farmers and have set as research goal, to develop together with them cropping patterns for the upland bush farms than can give sustainable and higher yield in order to reduce the need for ever increasing farm sizes.

Design of experiments.

On-farm experiments started in 1983 with over 30 trials spread in small clusters of two to three over a very large area of the Northern Region. These trials were supervised centrally from Nyankpala. The main innovation tested was for increased plant densities. It turned out that 1983 was an abnormally dry year and increasing plant densities in the traditional cropping patterns proved to be extremely risky.

In 1984, we concentrated on testing of new varieties and cropping patterns for maintaining soil fertility, with decentralized supervision of the trials. Five villages in Northern Ghana were chosen to represent the great diversity with respect to rainfall, soils and traction systems used. In each village we appointed an enumerator responsible for economic surveys and on-farm trials. Five farmers in each village were randomly selected, who were willing to manage a small field of three plots each.

These fields were considered replicates for the trial carried out for that village. In 1984 the three plots were:

C: Farmers practice with farmers varieties
B: Farmers practice with new varieties
A: New cropping pattern with new varieties

The farmers practice consisted mainly of maize-groundnut-sorghum intercrop planted on ridges. The new maize and groundnut varieties used were found to be superior than the traditional varieties. The new sorghum variety was of similar duration and equal in yield as the farmers varieties.

We have been using new improved maize, groundnut and sorghum varieties since 1985 in order to concentrate on testing different cropping patterns. The number of farmers in each village was increased to ten. Enumerators were made fully responsible for trial execution. They were supported by detailed instructions with field books, and given one week training at Nyankpala Agricultural Research Station before the season. Since 1985, trial fields with each farmer consisted of three or four plots comparing farmers practice with two or three new cropping patterns. New cropping patterns tested were:

AC Alley cropping pigeon pea with maize-groundnut-sorghum.
R Rotation of sole crop groundnuts with maize/sorghum.
PR Paired rows of sole crop groundnuts with maize/sorghum.
RC Relay crop of pigeon pea in full stand early maize.

Agronomic practices used were the following (plant densities on total area basis):

Farmers' practice

Groundnut in the middle of each ridge at	30.000/ha
Maize to the side of each ridge at	14.000/ha
Sorghum on the other side of the ridge at	18.000/ha

Rotation

Initially half of the plot was sole cropped with groundnuts at high density and the remaining half with maize/sorghum intercrop at high density. The next year the maize/sorghum plot was rotated with groundnuts. Plant densities used were:

Groundnut at	60.000/ha
Maize at	14.000/ha
Sorghum at	18.000/ha

Paired row

Two ridges with sole crop groundnut alternating with two ridges of intercrop maize/sorghum. Maize/sorghum ridges to be planted on previous year's groundnut ridges and vice versa. Plant densities as in rotation.

Alley cropping

Farmers practice, but every 4th ridge was planted to late maturing pigeon pea. Spacing of other crops on remaining three ridges was adapted to give the following densities:

Pigeon pea at 10.000/ha
Groundnut at 30.000/ha
Maize at 14.000/ha
Sorghum at 18.000/ha
Pigeon pea was cut back in the second year before soil preparation, and then pruned twice during the rainy season to prevent shading of other the crops. Prunings were applied as green manure to maize.

Relay cropping of pigeon pea
Early maturing maize at 42.000/ha
Medium maturing pigeon pea at 42.000/ha
Pigeon pea planted 2 weeks after maize. Starter fertilizer applied as 20-20-0 compound to give 15 kg N/ha and 6,5 kg P/ha. Broadcast applied on all plots before ridging. Sorghum was planted 10 days after maize emergence. Topdressing of 1 g N/plant as urea was applied to maize only.

Results and discussion.

1. Crop yields in rotation and paired row cropping patterns.

One advantage of sole cropping groundnuts, is the possibility of planting at high density without much risk of crop failure because it is quite drought tolerant. When the crop residues are ploughed in at the end of the rainy season, it can lead to substantial yield effects on the subsequent maize crop (table 3).

TABLE 3. Maize yield (ton/ha) in continuous maize cropping (M) or in rotation with groundnut (G), with or without N (Schmidt and Frey, 1987).

Year	Without N		With N*		LSD; 5%
	M	G	M	G	
1982	1.04	2.83	2.80	4.12	0.64
1983	0.38	1.60	1.58	3.20	0.45
1984	1.79	3.02	4.72	6.36	0.72
1985	1.72	3.62	4.47	5.55	0.45
1986	2.35	3.35	3.74	4.06	0.27
Average	1.46	2.90	3.46	4.66	

* 30 kg N/ha to groundnut and 60 kg N/ha to maize

In on-farm trials, we tried to attain the above mentioned benefits of sole cropped groundnuts but, although groundnut was planted in densities well above farmers' practice, farmers refused to plant as close as was recommended. This may be due to the fact, that farmers are used to a spreading variety while the new variety is semi-erect.

For maize and sorghum we intended to keep plant densities constant on total area basis as compared to farmers' practice. With maize we usually succeeded, but with sorghum it failed especially in '85 and '86 when the rains started late. Farmers started planting late, planted their own farms first before the trials, and sorghum was usually planted too late. In addition, bird damage to emerging seedlings was a great problem. Some conclusions can however be drawn (table 4).

TABLE 4. Crop yields (kg/ha) in rotation (R) and paired row (PR) cropping patterns as compared to farmer's practice (FP) in four villages of Northern Ghana, 1984-1986.

Location	Year	Maize R	Maize PR	Maize FP	LSD; 5%	Groundnut R	Groundnut PR	Groundnut FP	LSD; 5%
Namburugu	1984	-	372	311	-	-	381	363	-
	1986	512	533	386	99	282	309	168	54
Cheshegu	1986	332	376	436	ns	250	260	123	46
Wantugu	1985	281	-	212	-	431	-	411	-
	1986	424	333	404	83	352	363	144	90
Nakpa	1985	529	-	575	-	n d	-	259	-
	1986	382	-	212	119	361	-	224	72
Average		410	404	362		325	328	242	

Maize yields in most locations, in both years were higher under rotation or paired row patterns than under farmers practice. This was due to higher per-plant yields (table 5).

TABLE 5. Per-plant maize yield (g) in different cropping patterns in villages in Northern Ghana.

Location	Namburugu		Cheshegu	Wantugu		Nakpa		Average
Year	1984	1986	1986	1985	1986	1985	1986	
Cropping pattern								
Rotation	-	42	41	27	39	59	18	38
Paired row	42	46	42	-	29	-	-	40
Farmers practice	34	24	29	15	25	44	9	26
LSD; 5%	n d	21	12	8	9	11	5	

Whether the higher per plant maize yield is attributable to the rotation effect with the previous groundnut crop cannot yet be concluded. Groundnut yields were usually significantly higher with rotation and paired row patterns mainly due to higher plant densities. The higher per-plant yields indicate a shading effect by the cereals in farmer's practice.

Despite the low yields and high variability, it appears that rotation or paired rows of sole crop groundnuts and maize/sorghum leads to higher yields for both maize and groundnut as compared to farmers practice. However, researcg is still going on to ensure a reasonable sorghum yield or switch to a maize-groundnut system only.

2. Crop yields in alley cropping or relay cropping with pigeon pea.

In pigeon pea alley cropping, the yield loss of other crops due to reduction of area and competition by pigeon pea has to be offset by the seed yield of pigeon pea and the possible increase of the cereal through application of prunings from the pigeon pea in its second year as green manure. The pigeon pea variety that is utilized should therefore give both a good seed yield and a high yield of prunings. Research at Nyankpala station has shown that late varieties are best suited for this purpose (table 6).

TABLE 6. Seed yield in first and second year (kg/ha) and total fresh weight of prunings (t/ha) of different pigeon pea varieties (Source: Sipkens and Marfo, 1987).

Variety	First year seed yield	Second year seed yield	Total fresh weight of prunings
Katinga (late)	361	1189	16.2
ICPL 265 (medium/late)	453	716	10.5
ICPL 304 (medium)	296	75	5.9
ICPL 1 (early)	624	44	1.2
LSD, 5%	125	212	1.4

Late maturing varieties matured on residual soil moisture and were harvested in January. In Wantugu, residual moisture was not enough for variety Katinga in '84 and variety ICPL 265 in '85 to produce seed, so we changed to a relay crop of maize and pigeon pea in '86. Because of late planting in '86, only a yield of maize was obtained (Table 7).

TABLE 7. Crop yields (kg/ha) in alley cropping (AC) or relay cropping (RC) patterns as compared to farmers practice (FP) in Northern Ghana.

Location	Year	Maize			Groundnut		Sorghum		Pigeon pea	
		AC	FP	RC	AC	FP	AC	FP	AC	RC
Nakpa	84	449	285	-	191	205	178	533	380	-
	85	649	575	-	276	259	133	182	360	-
	86	316	212	-	131	224*	0	0	662	-
Wantugu	84	222	305	-	297	223	116	218	0	-
	85	201	212	-	381	411	0	0	0	-
	86	-	404	765*	-	123	-	0	-	0
Cheshegu	86	-	436	826*	-	144	-	0	-	0

* significant difference at P = 0.05

In Nakpa, an area with higher rainfall and deeper soils, the late maturing pigeon pea variety gave a seed yield each year. In 1986 at Nakpa the effect was observed that the second year seed yield for late varieties was higher than first years.

Maize yields in Nakpa were higher (although not significantly) with alley cropping. Maize appeared to profit from application of pigeon pea prunings as green manure. Sorghum yields were reduced, because pigeon pea and sorghum are both late maturing and compete for residual moisture.

Groundnut yields were not much affected except for Nakpa in 1986. That year farmers decided not to prune the pigeon pea after the initial pruning before soil preparation, and obtained a high pigeon pea seed yield that more than offset the loss in groundnut yield due to shading by pigeon pea. Alley cropping at Nakpa in 1986 gave the highest return so far recorded (table 8).

TABLE 8. Marginal returns from different cropping patterns compared in on-farm trials in Northern Ghana in 1000 cedis/ha (Source: Sipkens and Diehl, 1985, 1986, 1987).

Cropping Pattern	Location	Year 1984	1985	1986
Rotation	Namburugu	-	-	15,167
	Cheshegu	-	-	9,605
	Wantugu	-	903	21,042
	Nakpa	-	n d	17,998
Paired row	Namburugu	13,420	-	18,078
	Cheshegu	-	-	11,845
	Wantugu	-	-	19,619
Alley cropping	Wantugu	3,664	-1,548	-
	Nakpa	17,534	9,531	30,777
Relay cropping	Cheshegu	-	-	5,681
	Wantugu	-	-	2,792

3. Economic analysis

Table 8 shows the difference in gross returns between new cropping patterns and farmers practice (marginal returns). Gross returns are calculated as crop yields multiplied by market prices at harvest. Costs for seed and fertilizer were substracted. Marginal returns therefore express the extra income a farmer obtained if he adopted the new cropping pattern.

From table 8 it can be concluded that alley cropping in Nakpa was remunerative over the years. Rotation and paired row cropping patterns were giving good returns in 1986 but we have to bear in mind the failure of sorghum, so that further observation is needed. Even though pigeon pea failed in the first year of relay cropping, the positive marginal returns (because of far higher maize yields) warrant inclusion of this cropping pattern in further trials.

Farmers' comments and conclusions.

From the beginning farmers have been interested in new varieties, as it meant very little additional cash input. We have been fortunate with the introduction of a high-yielding groundnut variety (FMix) that motivated farmers to continue even if part or the whole new cropping pattern failed.

It was difficult to motivate farmers to plant on-farm trials at the same time as they planted their own farms. Motivating factors have to be found, e.g. in some form of additional payment, to offset the risk a farmer takes by spending days on the trials that could be more profitably spent on his own farm.

Farmers in Nakpa have observed that alley cropping is best suited for maize and pigeon pea production and started their own on-farm trials. This is a valuable source of feed-back, and ongoing on-farm research activities should make full use of these activities.

Farmers agree that rotation or paired row cropping patterns lead to higher groundnut and maize yields but stress the need for increased sorghum yields as well. Paired row cropping may be the better pattern for sorghum ripening on residual moisture, so observations will be continued.

Many farmers observed that it is easier to weed cereals without intercropped groundnuts, and that sole cropped groundnuts at high densities can outgrow weeds after the initial weeding.

Valuable feed-back for researchers is the complaint of farmers that Striga, a weed that parasitizes cereals is increasingly becoming a problem. Its damage seems to be limited if cereals are rotated with groundnut, which is the only practical control method available at the moment. Fertilizer application at high rates enables cereals to tolerate striga infestation, but farmers usually cannot buy large large quantities of fertilizer. As rotation and paired row cropping seem to use fertilizer more efficiently, this in itself may help to reduce Striga damage.

Observations on changes in soil fertility by comparing soil samples before and after application of a new cropping pattern are difficult in on-farm research because of frequent changes in fields, farmers, and cropping practices. The observations on crop performance for the assessment of the suitability of a cropping pattern for maintaining yields appears to be adequate.

Differences in yields between farmers have been very great. In future, substantially more farmers (20-30) per village (or more replicates per trial) will be included in order to stratify fields in a high- and a low yield group and look more carefully at management and soil differences between these groups.

Although more productive and profitable cropping patterns were identified even at very low yield levels on farmers fields, more research will have to be done in order to explain the large differences between station yields (table 3) and yields in the villages (tables 1, 4, 8).

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INTEGRATION OF TREE LEGUMES IN CROPPING SYSTEMS IN THE INTERMEDIATE ZONE OF SRI LANKA.

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Abstract

A long term experiment was initiated in 1985 at the University Experimental Station, Dodangolla in the intermediate agro-ecological zone of Sri Lanka to study the effect of integration of tree legumes in cropping systems, their effect on crop yields and changes in soil fertility. The loppings of the alley crops and the residues were incorporated to the same plots at the end of each season.

Among sole crops yam (Dioscorea alata) recorded the highest yield (3.6 t/ha) followed by corn (3.5 t/ha). Corn + yam and winged bean + yam performed better than the corn + winged bean intercrop. The latter was incompatible due to heavy mutual shading by both crops.

The crop residues added by corn were the highest (6.6 t/ha) as compared to other crops, and ranged from 0.62 - 1.7 t/ha. The tree legumes added considerable amounts of biomass during and at the end of the growing season. The total biomass produced by both crops was approximately 3.5 t/ha. Gliricidia showed better growth than Leucaena particularly during prolonged periods of drought. Gliricidia also produced more fuel wood (4.7 t/ha) than Leucaena (2.7 t/ha) which could provide the subsistence farmers with energy for cooking, as 80% of their energy supply is fuel wood.

The soil fertility increased due to addition of crop residues and loppings of leguminous trees as indicated by changes in soil N and organic matter contents. The results shows the multiple advantages in the use of tree legumes and the potential of their extensive use in the intermediate zone of Sri Lanka.

Introduction

Nutrient losses due to leaching, crop removal, and organic matter oxidation resulting from continuous cultivation, are factors which limit sustained crop productivity in the dry and intermediate zones of Sri Lanka. The extent of available agricultural land is also shrinking and due to urbanization and land fragmentation as the growth of population increases. As a result, intensification of cropping has become inevitable to enhance food production which is the primary requirement for the well-being of the people.

As land has been cultivated for so long, the primary objective is to develop land management systems to increase the cropping intensity and improve production per unit area while maintaining the natural fertility of the soil. It is in this context that the simulation of conditions of natural forests by the integration of trees and food crops or a system of Agro-forestry has become important in arable farming. A system such as alley cropping provides a long term blend which is based on the principles of the bush fallow or shifting cultivation system, which has been regarded as a major advantage (Wijewardena and Waidyanatha, 1984; IITA, 1984). Increases in available plant nutrients, particularly nitrogen, improve soil conditions due to enhanced microbiological activity, and lead to a better soil physical condition, all of which are benefits of mulch farming systems (Weerakoon and Senevirathe, 1982; Weerakoon and Gunasekara, 1985). The in situ production of green manure also reduces the labour input and transport costs, while the forest cover controls weeds, making the system more economic.

A 70-80% reduction in weed population has been reported due to alley cropping in which the C4 types of weeds have been shifted by agronomic practices (Wijewardena, 1984). In tree based systems recycling of soil nutrients may occur with minimal dependence on expensive agro-chemicals and little damage to the natural resource base and the environment. In addition, it is also socially acceptable to the small farmers in most of the developing countries of the tropics.

The dry and intermediate zones of Sri Lanka are vulnerable to moisture stress due to the poor distribution of rainfall in the growing seasons, combined with excessive temperatures, which drastically reduce crop productivity.

The subsistence agriculture is practiced by peasants in plots less than one ha, without the possibility to use high technology. Therefore, the highest potential for integrated farming exists in those zones, where sustainable production systems can replace systems such as shifting cultivation. Thus, the objective of this investigation was to integrate tree legume species in various cropping systems commonly practiced in the intermediate zone, and to study their effect upon the changes in soil fertility due to the incorporation of crop residues and loppings of leguminous trees.

Materials and methods

A long term experiment was initiated in 1985 at the University Experimental Station, Dodangolla in the intermediate zone of Sri Lanka. The elevation of the experimental station was 367 m AMSL. The mean annual rainfall, relative humidity and temperature was 1563 mm, 79% and 31 ^{o}C respectively. The soil of the experimental site belongs to the Reddish Brown Latosols, having a pH of 6.5.

Single rows of Leucaena leucocephala and Gliricidia maculata spaced at 3.6 m formed alleys while corn (var. Thai composite), winged bean (cv SLS 40) and yam (Dioscorea alata, var. Rasawalli) either as sole crops or in combination as inter crops formed the cropping systems. The total of six treatments were replicated three times. The tree crops were propagated in 30 cm diameter polyethylene bags and transplanted in the field prior to sowing the crops.

The agronomic practices recommended by the Department of Agriculture were used in the growing of all crops. The crop residues were added to the same plots at the end of the growing season. The tree legumes were lopped at a height of 75 cm and the loppings were added to the plots.

Results and discussion

Economic yields of sole and intercrops:

The yields of sole and intercrops are given in Table 1

TABLE 1 Yield of sole and intercrops (t/ha)

Treatments	Component crop yields			
	corn	winged bean	Dioscorea yam	total yield
Corn	3.46	-	-	3.46
Winged bean	-	3.06	-	3.06
Dioscorea yam	-	-	3.55	3.55
corn + winged bean	1.97	1.00	-	2.97
corn + Dioscorea yam	2.31	-	1.93	4.24
Dioscorea+winged bean	-	0.98	3.15	4.13

The sole crops produced yields of over 3 t/ha. The highest yield was recorded for Dioscorea yam (3.55 t/ha) followed by corn (3.46 t/ha). The growth duration of corn and winged bean is four months while Dioscorea yam takes over 10 months to complete a season. Thus, when the productivity per day is considered corn (29 kg/day) was more sufficient than Dioscorea yam (12 kg/day).

The intercrop yields varied depending on the crops combination. THe highest yields were recorded for corn (4.13 t/ha). Corn + winged bean intercrop yielded only 2.97 t/ha as the component crops gave lower yields than the respectively sole crop yields. Therefore, corn, yam and winged bean appear to be compatible for intercropping in the intermediate zone. Corn + winged bean intercrop was subject to heavy competition leading to poor performance of both crops, particularly the winged bean. In this intercrop, corn grows faster, but as growth proceeds winged bean trials on corn stalks and gets heavily shaded. At the population used in this study, intercropping corn and winged bean is not feasible, unless time of planting or plant spacings are suitably adjusted. In general, erect growing plant species due to their vertical growth habit appears to be more compatible for intercropping.

Yield of crop residues:

The crop residues added by corn was the highest (6.6 t/ha) when compared to other crops. Intercropped corn also produced more residues (4.6 t/ha) irrespective of the associated component crop but less than that of the sole crop due to competitive effects (Table 2).

Table 2 Yield of Crop residues (t/ha)

Treatments	Residues of component crops			
	corn	winged bean	Dioscorea yam	total yield
corn	6.55	-	-	6.55
winged bean	-	1.72	-	1.72
Dioscorea yam	-	-	1.28	1.28
corn + Dioscorea yam	4.57	-	0.81	5.38
Dioscorea + winged bean	-	1.42	0.64	2.06

Biomass Productivity of Tree Legumes

In situ production of green manures has the advantage that no extra effort or transport costs are involved (Wijewardena, 1984; N.A.S.,1977), besides its effect in nutrient recycling (Weerakoon and Seneviratne, 1984). The total biomass production at the end of the 1st season amounted to 790 kg/ha for Leucaena and 550 kg/ha for Gliricidia, which added per hectare approximately 37 kg/N, 21 kg P and 12 kg K for Leuceana, and 21 kg N, 1 kg P and 11 kg K for Gliricidia. With the onset of drought in 2nd season the growth of Gliricidia was faster while pest damage was also observed in Leucaena plants. Due to its deep root system Gliricidia seems to tide over dry periods better than Leucaena. This was also shown in the biomass values at the 2nd lopping which amounted to 3040 kg/ha for Gliricidia and 2890 kg/ha for Leucaena. Based on biomass production, nutrients added per hectare would be about 135 kg N, 92 kg P and 32 kg K for Gliricidia and 117 kg N, 6 kg P and 60 kg K for Leucaena.

Table 3. Production of Fuel Wood (t/ha)

	Gliricidia	Leucaena
1st Lopping	1.06	0.53
2nd Lopping	3.66	2.12
Total	4.72	2.65

Gliricidia produced more fuel wood (stems) than Leucaena at both loppings (Table 3). At the 1st lopping the difference was 50% while at the 2nd it was 42%. Weerakoon and Seneviratne (1984) have reported similar results for the above tree legumes from their experiments on conservation farming. As 80% of the energy for cooking in the villages is provided by fuel wood, their inclusion in farming systems will be an important advantage.

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RICE-FISH CULTURE IN NORTHEAST THAILAND.
A pilot activity for introduction of integrated farming to rainfed areas.

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ABSTRACT

The rice farmers in the rainfed area of the northeastern area of Thailand are the poorest farmers in the country. As serious problems concerning land and water supply occur, crop yields per hectare are very low. Moreover, natural resources have deteriorated, so that the availability of forestproducts has seriously diminished. As a result, the population suffers from malnutrition and debts, and migrates in large numbers to other areas.

One solution to these problems is to develop a method of agriculture that enables farmers to use the local natural resources (land, water and labour) with greater efficiency by changing the farming technology, e.g. by changing from monoculture to diversified or integrated farming, where also activities such as fishculture are involved. In such a way, land, water and labour can be more efficiently utilized.

Table 1. GEOGRAPHICAL INFORMATION NORTH EASTERN THAILAND

Population (1984)	18.3 mill.	Forest area	2,533,561 Ha.
Agricultural area	8,523,213 Ha.	Irrigated land	2,958,689 Ha.
Rice field	4,605,280 Ha.	Cassava planting area	885,120 Ha.
Corn planting area	461,920 Ha.	Jute planting area	160,641 Ha.
Sugar cane planting area	78,880 Ha.	Mung bean planting area	44,954 Ha.
Income/person/year	442 US Dollar/person/year		

INTRODUCTION

The northeast of Thailand is densely populated (Table 1). The farming area is 50.48% of the total area, but only 5.5% of the area is under irrigation, so that the majority of the agricultural land is rainfed. The average annual rainfall in the northeast is approx. 1,370 mm. with an average number of rainy days of only 117 days per year. The distribution of the rainfall is irregular: there are periods of no rainfall of 20-60 days. The soils in the northeast are mostly infertile, with a low organic matter and clay content, and a high acidity (Tables 2 and 3).

Most of the farmers in the northeast practice rice farming in the rainfed area. The yields of the rice are low (av. 1,568 kg/ha.) as a result of the soil condition and shortage of water supply.

A simple method of improving the land and rice yield is to trap water so that the soil surface is always flooded. This will reduce the acidity of the soil and enable a better nutrition for the rice plant. In such a way, the yield may be increased from the original yield by 900-1800 kg/ha, without having to rely on other methods.

Table 2. Percentage organic Matter in The North East Soils

Location	Depth (cm.)	% Organic Matter
Flood plain soils	10-30	2.22
	50-100	0.68
Low terrace soils	10-30	1.03
	50-100	0.37
Middle-high terrace soils	10-30	0.94
	50-100	0.27
Residual and colluvial soils	10-30	1.90
	50-100	0.56

Table 3. Average pH, of soils in the North-East

Location	Depth (cm.)	pH.
Flood plain soils	10-30	5.4
	50-100	5.8
Low terrace soils	10-30	5.3
	50-100	5.6
Middle-high terrace soils	10-30	5.8
	50-100	5.6
Residual and colluvial soils	10-30	5.2
	50-100	5.2

Another method of improving the soil, in the same manner as flooding the soil surface, is to increase soil organic matter. Both methods can be integrated by raising fish in the paddy field. Farmers trap as much water as possible for the fish culture, and the fish will produce organic matter in the form of excrements. The fish will also get rid of the insects, weeds and other rice pests such as namatodes. This allows farmers to reduce input costs on chemical fertilizer, insecticide and herbicide.

Fish culture is therefore an appropriate agricultural technology for the farmers in the rainfed area of the northeast, and can be used to solve the problem of low productivity. By changing from monoculture to an integrated farming system with rice and fish, local natural resources are more efficiently used, leading to a more sophisticated agricultural system where farmers themselves will benefit from the economic, social and ecologic effects.

VILLAGE FRESHWATER FISHERY PROJECT (VFFP)

The staple food of the people in the northeast is rice and vegetables supplemented by fish. Rice gives carbohydrates, fish proteins and vegetables the minerals and vitamins. Farmers traditionally grow rice and vegetables for their own consumption, and would catch the fish in their natural habitat. But since 1980 the natural supply of fish began to dwindle due to increased fishing and a fish disease during the cold season (December-February).

Due to the resulting shortage of fish, the farmers in the northeast lost their most importance source of protein, and malnutrition occurred in the area. The group most seriously affected by this shortage of protein were children in the age group of under 5 years old.

There have been attempts to solve the problem of fish shortage by promoting the consumption of protein from other sources, such as eggs, beans and so on, but these attempts were never very successful, as possible alternatives were not easy to get, expensive and not suitable to the local consumption habit.

The best way therefore to solve the problem is to promote the farmers to cultivate fish themselves. However, many potential problems occur in fish culture: water supply, land and capital (preparation of the pond and feeding the fish), especially in the rainfed areas.

In 1984 Appropriate Technology Association (ATA), which is a Non Governmental Organization cooperating with CUSO (a volunteer organization of Canada), had begun their project using the agricultural technology trying to tackle problems in the rainfed area of the northeast. The project was a pilot action-research project which lasted from 1984-1987.

The objective of the project was to develop and propagate a suitable form of farming technology among the rice farmers in the rainfed area in order to solve the problem of malnutrition, unemployment in the dry season and deterioration of the ecology. Important aspects of the project were the utilization of the local natural resources, reducing costs and dependency upon outside resources, and conservation of the ecology. The activity to be implemented should be as much as possible acceptable to the local population, and local-based.

Therefore, the integration of rice and fish cultivation was chosen as the pilot project for the following reasons:

1. It is a technology which some local farmers are already practising, although it is not widespread.
2. It is a method of improving the soil, which can be easily applied, without too much dependance on outside resources, such as lime and inorganic fertilizer.
3. Soil moisture conditions for other crops after the harvest of the rice are improved.

MANAGEMENT

VFFP operates with the cooperation of Governmental and non-Governmental organisations, especially in the field of social functions while the VFFP is involved in the farming technology.

The project started in 2 provinces in the northeast (Khon Kaen and Surin) covering 7 villages, and later on expanded to 9 villages in 4 provinces (also in Roi-Et and Mahasarakham). The nature of the work was basically the promotion and propagation of fish culture in farmers fields by taking key-farmers from the target villages to integrated rice-fish cultivation in the neighbouring areas. When the farmers in the target villages had implemented the rice-fish farming on their own fields, VFFP acted as consultant, and tried to improve the technology.

As a result of the above-mentioned method, the rice-fish culture has established itself firmly during the later stage of the project: the project started with 78 families participating in the project with VFFP in 1984, and in the last year of the project enjoyed the participation of over 1,000 families engaging in rice-fish farming as a direct result from the project. This number is still rapidly increasing because of the transfer of knowledge between the farmers.

The results of fish culture in the fields of the farmers in the rainfed area of the northeast, according to the assessment of VFFP, are:

1. Productivity in rice has increased by the average of 330 kg/ha.
2. Average fish yield is 125 kg./ha.
3. Reduction of diseases and weeds in the rice fields.

PROMOTIING FISH CULTURE IN THE RICE FIELDS

The fish culture in the rice fields is only the pilot activity in order to make farmers adopt a more suitable technology for the rainfed area of the northeast. Therefore, when there is the fish culture for a certain period it was found that other activities could be introduced, such as:

1. Use of underground water in the dry season. Even though fish culture could store more water for a longer period of time, soil moisture may not be sufficient during the dry season. The shortage of water for farming purpose is the major reason that the farmers have to migrate to work outside the village as their land cannot be tilled.

VFFP has developed the method of drilling for underground water for agricultural use in the dry season. This method could be conveniently applied and at reasonable cost. The expenses for the drilling of underground water do not exceed US$ 40 per well, and water could be utilised for cultivation of vegetables during the dry season in an area of 1/3 ha.

2. Promotion of planting perennial trees in the farm fields. The perennial trees have a very important role in the area, because of nutrient recycling and environmental conservation. In the farmland of the farmers in the northeast few perennial trees grow naturally, as most have been cut for firewood. In order to promote tree plantation, farmers need to see the benefit and use, for example of fruit trees of good quality for their own consumption. The problem however is the shortage of water in the dry season, as a good fruit trees need good soil and water supply.

VFFP solves this problem by providing water in the dry season from underground water. Local tree varieties are being planted as root stock for budding or grafting, so that the fruits trees become strong and of good quality. The technology of budding and grafting is transferred to the farmers. The result is that the farmers have grown more fruit trees in their farmland, in the same manner as the fish culture and vegetable growing in the dry season with the use of underground water.

CONCLUSION

This activity is only a start, a change from the monoculture farming to that of integrated farming in a simple form. The technology applied already exists. The change will not stop now, but will be the basis for further development of agriculture, which is more adequate and beneficial to the farmers in the future in a social, economical and ecological sense.

AZOLLA AS A GREEN MANURE FOR CROPS

Key words: Azolla Biofertilizer Green manure Organic-N mineralization Upland and Wetland rice Soybean

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SUMMARY

The effect of Azolla biomass application on growth was studied in two tropical soils, i.e. a N-poor sandy loam from Tanzania and a N-rich clay soil from Surinam. A yield response was only observed in the Tanzania soil. A simultaneously performed experiment with ^{15}N-labelled Azolla indicated, however, that additions of 660 mg N and 1320 mg N as Azolla-N per pot of 6 kg of soil resulted in 14.0% and 25.0% Azolla-N recovery in the plants on the Tanzania soil and in 8.6% and 10.4% Azolla-N recovery in the plants on the Surinam soil, respectively. The frequently used "Yield Difference" method as a measure of agronomic effectiveness of a fertilizer apparently cannot be applied in the case of the Surinam soil.

Upland conditions (soil at 60% of water-holding capacity) seem to stimulate the desintegration and mineralization of organic Azolla-N since in 25 days about 15-26% of the original Azolla-N was found to be released as NH_4^+-N. Azolla biomass contained 4.2% N and 44.1% C, giving a C/N ratio of 10.5. The slow desintegration rate of Azolla biomass is hard to understand in the light of the fact that vegetative tissues and sloughed-off root materials which are readily decomposed, usually have a C/N ratio of around 9.

The slow N-release from Azolla biomass is especially important for upland soils and for soils alternatively used for rice and upland crops, which are usually very low in organic matter. The presence of Azolla biomass improves soil structure, water retention and microbial activities. It retards soil desiccation and leaching of nutrients. Although in the present short-term experiment the use of Azolla did not lead to increases (except for an increase in N-content of the plant tissue), it can be envisioned that the slow mineralization rate of the organic matter and the slow release of N will have lasting beneficial effects on the physical condition of a soil and on the long-term supply of nitrogen and other nutrients to crops grown on the soil.

INTRODUCTION

Azolla is a small aquatic fern, which is widely distributed in tropical, semi-tropical and temperate water environments. It is well-known for its capacity to fix atmospheric nitrogen by means of a cyanobacterial symbiosis in which Anabaena azollae Strasburger is involved.

Azolla is of economic importance for tropical agronomy, especially in wetland rice cultivation. Because of its nitrogen-fixing capacity it can be used as biofertilizer and in this way can obviate to some extent the production and application of expensive inorganic N-fertilizers. Moreover, Azolla application as green manure has already been known and practiced for centuries in Vietnam and China, in particular in relation to flooded rice cultivation (Moore, 1969; Dao and Tran, 1979; Liu, 1979; Lumpkin and Plucknett, 1982). Presently, Azolla is becoming a potential nitrogen source for rice production in many other regions (Silver and Schrøder, 1984).

Recently some ^{15}N-tracer studies have been made in which the incorporation of Azolla-N into the rice crop was investigated. In a study with a Bangladesh sandy loam paddy soil in which the availabilities of ^{15}N-Azolla-N and $(NH_4)_2SO_4$-N were compared, it was found that 34% of the applied ^{15}N of Azolla and 61% of the $(NH_4)_2SO_4$-N were taken up by the rice plants in 60 days. About 45% of the Azolla-N was released in 60 days. About 45% of the Azolla-N was released in 60 days, 55% remained in the soils as undecomposed material and 11% was lost in gaseous form (Mian and Stewart, 1985).

In another experiment (Kumarasinghe et al., 1986) in which the ^{15}N-isotope dilution technique was used, the recovery by rice of Azolla-N incorporated at a rate of 144 kg N. ha^{-1} was found to be 32% versus 26% for ^{15}N-labelled urea supplied at a rate of 100 kg N. ha^{-1}. These values were, however, found to be not significantly different. In another experiment 100 kg N.ha^{-1} of ^{15}N-urea was applied separately or in combination with either 250 or 330 kg N.ha^{-1} of unlabelled Azolla. At both rates of Azolla incorporation, dry matter yield and N yield were significantly increased as compared with those obtained when urea alone was applied.

The objective of the present study was to obtain more information on the availability of Azolla-N for rice relative to that applied as urea. Further, the effect of Azolla incorporation was investigated with the same rice variety under wetland and upland conditions, since it was assumed that the breakdown and mineralization of organic Azolla-N is affected by variations in soil physical conditions. In the latter experiment the effect of Azolla-N as green manure for a leguminous crop (soybean) was examined as well.

MATERIALS AND METHODS

The experiments were conducted in two separate experimental series. In experiment I, the effect of fresh Azolla incorporation and urea application on the growth of rice on two tropical soils was examined. In experiment II, a temperature-climate soil was used under wetland and upland conditions with the same rice variety, after Azolla or urea-N had been applied. In this experiment, a leguminous crop grown under upland conditions was included.

The two tropical soils used were a sandy loam from Tanzania and a clay soil from Surinam. The sandy loam from Tanzania was obtained by mixing a loam with sand of the same origin. Relevant soil characteristics are the following:

<u>Tanzania soil</u> (Typic Acrorthox): pH (H_2O) 6.3, total N 0.16%, P extractable in ammonium lactate-acetic acid (PAL) 37 mg/100 g.
<u>Surinam soil</u> (Histic Tropaquept): pH (H_2O) 4.6, total N 0.42%, P extractable in ammonium lactate-acetic acid (PAL) 1 mg/100 g.

A temperate-climate silt loam (loess) soil (Typic Hapludalf) from Eijsden (Prov. Limburg, The Netherlands) was used. The characteristics of this soil are: pH (H_2O) 6.4, total N 0.13%, P extractable in ammonium lactate-acetic acid (PAL) 5.3 mg.100 g^{-1} soil.

For all experiments, enamel Mitscherlich pots were used containing 6 kg of air-dry soil. All treatments and pots received basal dressings of potassium magnesium sulphate (25% K, 6% Mg) in variable amounts (500-750 mg K and 120-180 mg Mg) depending on the nutrient status of the soils. Phosphate was added as triple superphosphate (TSP) in variable amounts depending on the original P-level of the soil. The P-rich Tanzania soil received 220 mg P per pot, while the P-poor Surinam and Eijsden soil received 440 mg and 560 mg P per pot, respectively. Other nutrients such as iron were added as Fe-EDTA solution and a mixture of other trace elements was supplied including 0.08 ppm Co as $CoCl_2$ in the case of the soybean crop.

The ^{15}N-labelled Azolla was obtained by growing <u>Azolla pinnata</u> R.Br. plants in a glasshouse in tanks on a nutrient solution containing 40.9% or 54.5% ^{15}N-labelled NH_4Cl. In about 19 days, after which the nutrient solution was nearly depleted of nitrogen, these Azolla fern plants produced a biomass with 8.9% or 13.9% ^{15}N enrichment levels, respectively.

Under both upland and wetland conditions, use was made of the rice (<u>Oryza sativa</u> L.) variety IR-36, being a day-length insensitive cultivar with a relatively short growing cycle (apporximately 3.5 months). Soybean (<u>Glycine max</u> L.Merr) cultivar Gieso was the leguminous plant tested under upland conditions. The rice plants germinated on sand, kept with a Mariotte's bottle continuously under irrigated conditions, and were transplanted at an age of 12-19 days to the Mitscherlich pots. Two rice plants per pot were used. The soybean seedlings germinated in wet sand and were transferred to the pots at an age of 3 days. The pots containing soybean were inoculated with the appropriate <u>Bradyrhizobium japonicum</u> strain KA 107 obtained from the Laboratory of Microbiology, Agricultural University, Wageningen.

In the experiment with the Tanzania and Surinam soils, the rice plants were harvested at an age of 103 days. The experiment with the Eijsden soil lasted longer (120 days), because the plants grew under less favourable winter conditions (November till February). In the greenhouse the day temperature was kept at about 24°C and the relative humidity between 70-75%. All treatments were present in triplicate in a design in which each crop species occupied a greenhouse table on which the pots were originally placed in a randomized fashion and changed positions daily.

After harvesting, drying, weighing, and grinding, composite plant samples consisting of representative portions of generative and vegetative plant parts were digested with conc. sulphuric acid, hydrogen peroxide and salicyclic acid (Van Schouwenburg and Walinga, 1983). Total N, NO_3, and P were determined colorimetrically following the usual procedures. Additional nutrients were determined as well, but these data are reported in the Graduate Research reports of Braam and Velthof (1987) and the M.Sc. thesis of Sarwani (1987).

The $^{15}N/^{14}N$ isotope ratios present in the N fractions of the Azolla and rice crops were determined with a Finnigan (formerly Varian) MAT-250 (GmbH. Bremen, BRD) mass spectrometer.

The relative agronomic effectiveness of Azolla green manure in incorporation was calculated with the equation (a), also known as the yield-difference method:

$$RAE = \frac{\text{N-yield in fertilized plants - N-yield in unfertil. plants}}{\text{N-quantity in Azolla fertilizer}} \times 100\%$$

The percentages ^{15}N-recovery in the rice plants in the ^{15}N-isotope experiment were calculated with the equation (b):

$$^{15}\text{N recovery fraction} = y_{xp}/y_{xgm} \times N_{ab}/N_{ap} \times 100\%,$$ in which:

y_{xp} = atom percent excess ^{15}N in crop,
y_{xgm} = atom percent excess ^{15}N in green manure,
N_{ab} = amount of N absorbed by rice,
N_{ap} = amount of N applied in green manure.

In the incubation experiment with soil amended with organic Azolla-N the percentages of NH_4-N release were calculated with the equation (c):

$$NH_4\text{-N released} = \frac{NH_4\text{-N (Azolla)} - NH_4\text{-N (control)}}{\text{Azolla-N applied}} \times 100\%$$

The statistical significances of the data obtained were tested with Duncan's Multiple Range test (<= 0.05) or the Least Significant Difference (LSD) test using ANOVA.

RESULTS AND DISCUSSION

Experiment I:

In Fig. 1 and 2 the dry matter production of the above-ground parts of the rice plants grown under inundated condition on the Tanzania and Surinam soils are presented. As evident from the results, dry matter production on the Tanzania soil was lower than on the Surinam soil. This effect can also be observed in the numbers of panicles formed per pot of the plants on the Tanzania and Surinam soil (Table 1). These results may be caused by the differences in level of soil N in the two soils (0.16% and 0.42% N for Tanzania and Surinam soils, respectively). As evident from the figures, this difference in N-availability could not be eliminated in the Tanzania soil by urea-N addition.

In both tropical soils the treatments with Azolla-N green manure (660 and 1320 mg Azolla-N per pot) showed an inferior rice production as compared to the same quantity of N applied as urea. Dry matter production with Azolla-N applied to the Tanzania soil was significantly higher than on the control pots (no N added), but due to larger variability, such a response could not be observed with rice on the Surinam soil.

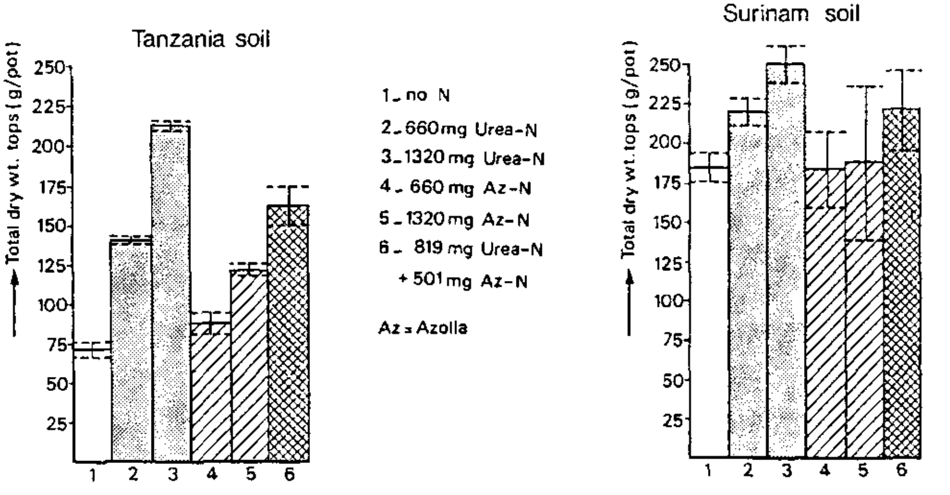

Fig. 1.: Dry matter production of the above-ground parts of rice plants (var. IR-36) grown under inundated condition on Tanzanian and Surinam soil supplied with urea-N, Azolla-N or urea-N+Azolla-N.

Table 1. Number of panicles produced by rice plants grown on two tropical soils in response to Azolla-N and urea-N dressing.

Treatment (addition)	Number of panicles (2 plants per pot)	
	Tanzania soil	Surinam soil
0 mg N	0	53 ± 2
660 mg Azolla-N	0	61 ± 7
1320 mg Azollla-N	14 ± 3	63 ± 14
660 mg urea-N	13 ± 1	69 ± 3
1320 mg urea-N	50 ± 3	72 ± 11
819 mg urea N+ 501 mg Azolla-N	21 ± 10	62 + 19

The N-quantities found in the rice plants grown on the two soils are presented in Table 2. No differences were observed in yields of N between the control and the two levels of Azolla application in the case of the Surinam soil, but for the Tanzania soils such differences were significant. With these data at hand, the N-uptake efficiency or the relative agronomic effectiveness values for the various N-supplements can be calculated with the aid of equation (a) mentioned earlier.

This equation is based on the supposition that the uptake of soil N is not affected by the various N treatments. As can be seen in Table 3, the efficiency values of N absorbed from the Azolla sources were 16% and 24%, with the Tanzania soil and -1% with the Surinam soil. Table 3 shows further that the efficiency of urea-N uptake for both soils was rather high, ranging from 65% to 90%.

Table 2. N-quantities in rice plants grown in two tropical soils after treatment with Azolla-N and urea-N. (N in two rice plants per pot, mg.)

Treatment	Tanzania soil	Surinam soil
0 mg N	692 ± 20	1328 ± 92
660 mg <u>Azolla</u>-N	800 ± 60	1324 ± 316
1320 mg <u>Azolla</u>-N	1004 ± 47	1312 ± 476
660 mg urea-N	1222 ± 43	1922 ± 88
1320 mg urea-N	1670 ± 37	2190 ± 280
819 mg urea N+ 501 mg <u>Azolla</u>-N	1425 ± 81	1792 ± 517

Table 3. Relative agronomic effectiveness of Azolla- and urea-N for the two rice soils, as estimated with the use of the "yield-difference" method.

	Apparent recovery of nitrogen, % of N applied	
Treatment	Tanzania soil	Surinam soil
660 mg <u>Azolla</u>-N	16	-1
1320 mg <u>Azolla</u>-N	24	-1
660 mg urea-N	80	90
1320 mg urea-N	74	65
819 mg urea-N+ 501 mg <u>Azolla</u>-N	56	35

In a simultaneously conducted ^{15}N-tracer study with ^{15}N-labelled Azolla applied to the two soils at the same N levels as in the experiment discussed above, N-recovery values could be calculated more precisely.

In Table 4 the N-percentages in the rice crop derived from Azolla-N are presented and the N-recovery percentages calculated. As shown by the figures, in the Tanzania soil with applications of 660 mg and 1320 mg Azolla-N, the recovery in rice was 14% and 25%, respectively. The latter figures are in good agreement with the estimates obtained with the method of yield increase as affected by N-fertilizer addition, i.e. equation (a) in Materials and Methods. However, in contrast with the results of the yield-increase method, the tracer study showed an Azolla-N recovery in the Surinam soil as well. In the Surinam soil with 660 mg and 1320 mg Azolla-N applied, the Azolla-N recovery was 8.64% and 10.4% respectively.

This discrepancy in outcome may be caused by the higher soil N-levels in the Surinam soil about twice as high as in the Tanzania soil, and the impossibility to discriminate the N-uptake from the various N-sources in the case of the yield-increase method.

Table 4. Relative agronomic effectiveness of Azolla-N for the two rice soils, as determined with the use of ^{15}N-labelled Azolla.

Treatment	% N of total N in plants derived from Azolla	Fraction of Azolla-N in plans, % of total N appl.
Tanzania soil		
660 mg *Azolla*-N	11.5 ± 1.0	14.0 ± 2.2
1320 mg *Azolla*-N	32.8 ± 0.7	25.0 ± 1.5
819 mg urea-N + 501 mg *Azolla*-N	7.6 ± 0.2	21.7 ± 1.0
Surinam soil		
660 mg *Azolla*-N	4.4 ± 0.7	8.6 ± 1.1
1320 mg *Azolla*-N	10.9 ± 2.5	10.4 ± 2.5
819 mg urea-N + 501 mg *Azolla*-N	4.2 ± 0.3	14.8 ± 3.2

In this context it is important to know the sizes of the N fractions in the soils before and after the various treatments. In Fig. 2 the various quantities of N before and after N additions, and in relation to the N-uptake by the rice plant are presented. As evident from these figures, the amounts of N added were small compared with those already present in the soil and even more so in the relatively N-rich Surinam soil than in the Tanzania soil. Apparently, a large portion of the N initially present in the soil is unavailable to the rice plants, as can be judged from the N-uptake values.

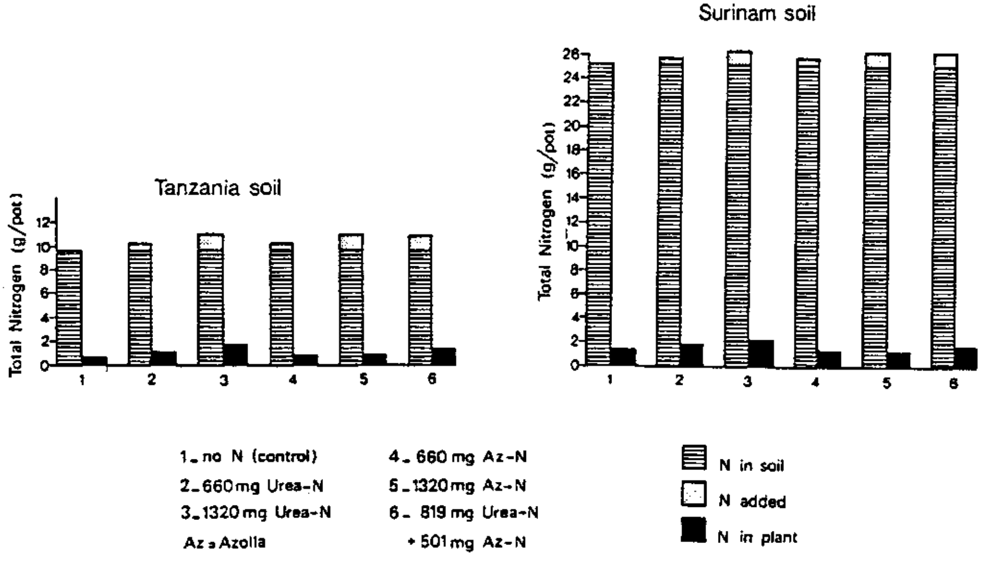

Fig. 2. Quantities of N in soil, plant and fertilizer for the Tanzanian and Surinam soil before and after the additions of urea-N, Azolla-N and urea-N + Azolla-N.

Before and after N application and rice growth, no NO_3 could be detected in the flooded soils. The degree of availability of Azolla-N may be related to aerobic processes stimulating the breakdown and mineralization of organic nitrogen compounds. Certainly, the nitrification process is an aerobic process, because oxygen is required for NO_3^- formation.

In view of these considerations it is worthwhile also to test the availability of Azolla-N under upland conditions and to compare the responses of rice to Azolla-N under upland and wetland conditions. In addition, it was of interest to know the effect of Azolla green manure on a legume (soybean) grown under upland conditions.

Experiment II:

In this experiment the responses of rice under wetland and upland condition to Azolla green manure and urea as nitrogen sources are studied. A loess soil (pH 6.4) and the rice cultivar IR-36 were used in this experiment. The individual pots received 500 or 1000 mg N in the form of Azolla-N or urea, or as a mixture of both (500 mg Azolla-N + 500 mg urea-N). For the flooded pots, a water level of 5 cm was maintained, whereas for upland conditions the moisture content of the soil was restored to 60% of the water-holding capacity each day.

Under wetland conditions, the initial growth of rice supplied with Azolla was better than on the control pots, but the difference gradually disappeared and N-deficiency symptoms also developed in the Azolla-treated plants. At harvest time (120 days), there was no difference in dry matter production between control and Azolla-treated plants (Fig. 3). In contrast to this, the rice plants responded favourable to urea, and also to the 1/2 urea-N + 1/2 Azolla-N treatment (Fig. 3). The N-contents of Azolla- and urea-treated plants were similar, and both were higher than the content of the control plants (Table 5).

Table 5. Percentage N and total N in the shoots of wetland rice for the various N treatments.

Treatment	% N in shoots	Total N in shoots (mg/pot)
Control	1.04	306
Azolla-N	1.20	358
Urea-N	1.21	932
\ urea + \ Azolla	1.14	583

Table 6. Percentage of N and total N in the shoots of upland rice for the various N treatments.

Treatment	% N in shoots	Total N in shoots (mg/pot)
Control	0.99	697
Azolla-N	1.33	909
Urea-N	1.72	1541
\ urea + \ Azolla	1.27	1061

Under upland conditions over a considerable length of time the control plants grew as well as the N-treated plants, indicating that soil N was becoming available. Initially, the rice plants in the control pots grew even better than in the pots with Azolla, but after 8 weeks N-deficiency symptoms began to appear in the control plants. Eventually, the Azolla-treated plants and the control plants appeared to have produced similar quantities of dry matter, with significantly higher yields obtained with the plants that had received urea with and without Azolla (Fig. 3). Again, the N-contents for the Azolla-treated plants were found to be significantly higher than for the control plants (table 6).

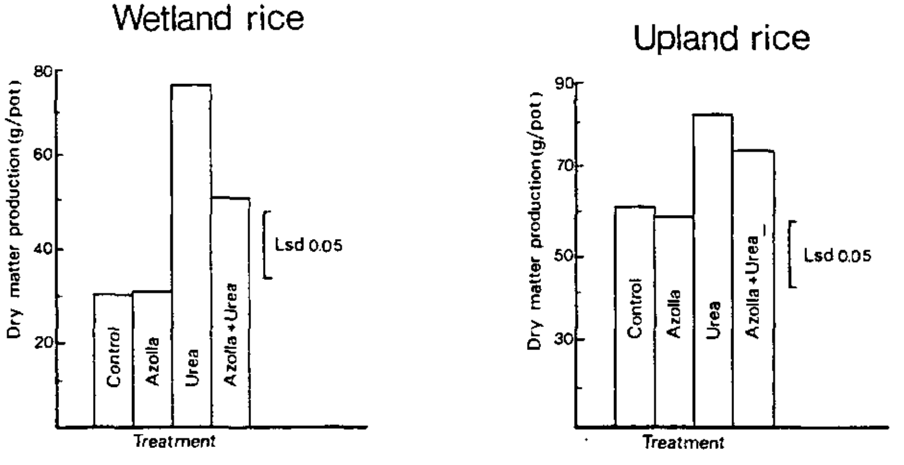

Fig. 3. Dry matter production of the above-ground parts of rice plants (var. IR-36) grown under wetland and upland conditions in a Dutch loess soil after addition of urea-N, Azolla-N or urea-N+Azolla-N.

When the dry-matter yields of rice plants growing under wetland and upland conditions are compared, it is clear that under upland condition the control and Azolla-treated plants had yielded 70% higher than plants in the same treatments under wetland conditions. Apparently, upland conditions favoured N-release. In order to obtain more insight in this N-release process, the yield-of-N values obtained under both water regimes are graphically presented (Fig. 4).

It can be seen that the soil contained a considerable amount of N, which is apparently difficultly available to the plants. Upland conditions seem to stimulate the N-release in this soil as indicated by the higher N-yields in plants grown under this regime. The figures indicate in addition that N-release from Azolla green manure is about three times higher under upland than under wetland conditions (Fig. 4)

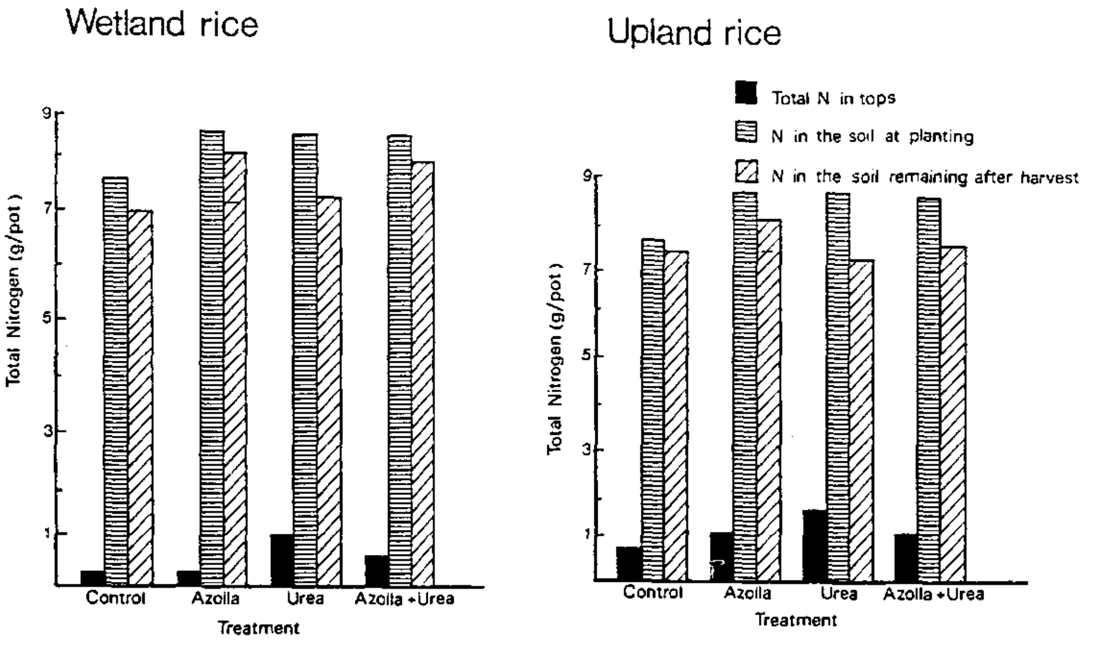

Fig. 4.: Total N in the soil before and after harvest and in the ricetops (var IR-36) after treatment with urea-N, Azolla-N or urea-N+Azolla-N in the Dutch loess soil under wetland and upland conditions.

Table 7. Effect of various N-sources on shoot, straw, and seed dry matter production of soybean.

Treatment	Yields of dry matter, g per pot		
	Shoot*	Straw*	Seed
Control	35.8	19.4	10.2
<u>B. japonicum</u>	65.3	27.1	27.5
<u>Azolla</u>-N + <u>B. japonicum</u>	56.9	22.8	23.4
Urea-N (as basal dressing) + <u>B. japonicum</u>	51.8	19.2	24.0

Table 8. Effect of various N-sources on N-content and total N in shoots of soybean.

Treatment	N content in shoots, %	Total N in shoots, mg/pot
Control	2.12	758
<u>B. japonicum</u>	3.74	2453
<u>Azolla</u>-N + <u>B. japonicum</u>	3.54	2023
Urea-N (as basal dressing) + <u>B. japonicum</u>	3.27	1659

Growth and yield of soybean plants under upland conditions were found to be significantly improved by Rhizobium inoculation and addition of the N-sources. However, Azolla green-manure dressing produced more N-yield and gave also a higher N-content in the soybean tissue than urea-treatment alone (Table 8). This would indicate that the slow release of inorganic N from Azolla biomass is more favourable for nitrogen fixation and root nodule formation of soybean than is the rapid release of NH_4 from urea, which is known to hamper the nitrogen-fixation process and to reduce root nodule formation.

In a separate experiment, the ammonium release in Azolla-treated soil was studied. The conditions were completely comparable to those in pots of the previous experiment in which 1000 mg Azolla-N had been added to 6 kg loess soil. The soil was kept under upland condition as its moisture content was daily restored to 60% of moisture-holding capacity. As shown in Table 9 the Azolla green-manure biomass releases NH_4 under the prevailing aerobic conditions and greenhouse temperature, the NH_4-N release ranging within 25 days from 15 to 26% of total N added.

Table 9. Release of NH_4-N from Azolla under aerobic conditions (mg/kg of soil).

	Time (days)					
Treatment	0	5	10	15	20	25
Control	12.47	32.07	13.10	25.11	23.10	23.38
<u>Azolla</u>-N	12.47	76.39	51.46	51.60	61.80	60.60
Net release	0.00	44.32	38.36	25.79	38.70	37.22
% of total N added	(0)	(26.6)	(23.0)	(15.5)	(23.2)	(22.3)

CONCLUSIONS

The results of the rice experiment with two tropical soils amended with ^{15}N-labelled Azolla green manure indicate that in the Tanzania soil 14.0% and 25.0% and in the Surinam soil 8.6% and 10.4% of the Azolla-N is recovered in the rice plants after application of 660 mg N and 1320 mg N in Azolla biomass per 6 kg of soil, respectively. Recovery of Azolla-N by the crop is more pronounced in the N-poor Tanzania soil than in the N-rich Surinam soil. Estimates of the efficiency of Azolla-N use obtained with the yield-difference method as measure of agronomic effectiveness (see equation (a) in Materials and Methods) yielded for the Tanzania soil efficiency values of 16% and 24% for the Azolla-N quantities applied, but no indication of Azolla-N use by rice in the Surinam soil. The discrepancy between data obtained with the difference method and the isotope method indicate that after addition of Azolla-N to a N-rich soil, such as the one from Surinam, the rice plants make preferential use of NH_4 recently released from Azolla at the expense of residual soil N. The relatively high apparent recovery values of urea-N (90% and 65%, see Table 3) lead to a similar assumption.

Our estimates of utilization of Azolla-N are lower than those presented by Mian and Stewart (1985), who observed in a ^{15}N-labelled Azolla experiment that 34% of the N applied was taken up by rice in 60 days, and those from a field experiment, also with ^{15}N-labelled Azolla, conducted by Kumarasinghe et al. (1986) in which a N-recovery of 32% was found. Our results are, however, consistent with those of Watanabe (1982), who demonstrated a 26% recovery by rice plants of N applied in ^{15}N-labelled Azolla. All above-mentioned experiments were performed with rice growing under wetland condition, on more or less permanently flooded soils. With 3 times more N incorporated in rice under upland than under lowland conditions (see Figs. 7 and 8), it seems justified to conclude that the desintegration of Azolla biomass and the subsequent release of inorganic N proceed more rapidly under upland than under lowland conditions. With soybean plants, Azolla green-manure dressing increased yields. The slow rate of mineralization of Azolla biomass apparently does not hamper nitrogen fixation and root nodulation, and Azolla is therefore a better N-source for these plants than is urea. In general combined nitrogen tends to inhibit both processes, as was also demonstrated in the present experiment.

The results of experiments on the mineralization of Azolla-N under upland conditions showed that in about 25 days 15-27% of the Azolla-N was released as NH_4^+-N (Table 9). The slow mineralization rate of Azolla biomass under upland conditions (15-27% of Azolla-N in 25 days) is rather remarkable. The Azolla used contained 4.2% N and 44.1% organic C, with a C/N ratio of 10.5. According to Crul and Truelove (1986) organic material sloughed-off from roots such as tissue fragments, individual cells or root caps, which are subject to ready microbiological decomposition, usually have a C/N ratio of 9. Hence, it is difficult to understand why inorganic nitrogen is so slowly released from Azolla biomass. More experiments on this subject are urgently needed.

On the other hand, the slow mineralization rate of Azolla, with a release of approx. 25% of organic N within the growth period of one rice crop, cannot merely be viewed as a disadvantage. In wetland rice culture, Azolla green manure would act as a N-reservoir for subsequent crops and particularly in upland soils it is a very good N-source acting as a slow-release N-fertilizer. Many tropical soils are very low in organic matter, which lack has serious repercussions for such characteristics as soil structure water retension, microbial activities, etc. The organic material would be very useful in improving the physical characteristics of soils alternately used for the growth of wetland rice and upland crops. The usually poor physical conditions of such soils shortly after removal of the floodwater, would be improved when a substantial portion of earlier applied Azolla green manure is still present in the soil. Likewise, the physical condition of soils permanently used for upland-crop culture, would be strenghtened by regular incorporation of Azolla green manure.

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EFFECTS OF LIME FERTILIZERS AND CROP RESIDUES ON YIELD AND NUTRIENT UPTAKE OF UPLAND RICE, SOYBEAN AND MAIZE IN INTERCROPPING SYSTEM

Key words: Acid and Low Fertility Liming Over Liming Fertilizer Recommendation Intercropping

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SUMMARY

Field experiments were carried out to determine the best rate of lime application and the rate of fertilizer recommendation, and the effects of the application of crop residues on yield and nutrient uptake of upland rice, soybean, and maize in intercropping systems.

Yields and nutrient uptake of upland rice, soybean, and maize in intercropping systems on Red-Yellow Podzolic soils (Ultisols) are significantly increased by liming. The best lime application rate is 2 t $CaCO_3$/ha for each meq Al/100 g soil and overliming rate is around 4 t $CaCO_3$/ha for each meq Al/100 g soil. The best fertilizer doses per hectare are 150 kg Urea, 75 kg TSP, 75 kg KCl and 75 kg Kieserite for 50% of maize plant density; 180 kg Urea, 60 kg TSP, 60 kg KCl, and 60 kg Kieserite, for 80% of upland rice plant density, and 60 kg Urea, 120 kg TSP, 60 kg KCl, and 60 kg Kieserite for 80% of soybean plant density.

The effects of crop residues that were mulched, burnt, or removed were irregular in terms of crop responses and should be studied further.

INTRODUCTION

Acid upland soils account for about half the land area of the tropics, and for a very high proportion of the land potentially available for arable cropping. Most of the acid upland soils of the humid tropics are classified as Oxisols (Ferralsols) and Ultisols (Acrisols) (Uexkull, 1986, Dudal 1986). In Indonesia acid upland soils occupy more than 50 percent of the 191 million hectares of Indonesia (Satari and Orvedal 1968). Among these acid soils, the Podzolic soils (Ultisol) are predominant, representing 38.4 million hectares (Muljadi, 1977). These soils are highly productive under virgin forest, but clearing the forest leads to serious problems due to the low soil pH, Al and Mn toxicity, low base status, and very low levels of plant nutrients such as N, P, K, Mg, Zn and B (Hakim 1982, Uexkull 1986, Dudal 1986).

The problems of Podzolic soils are more seriously felt in Indonesia as, in the framework of the transmigration program, people are being resettled from the island of Java to other islands, where Podzolic soils frequently occur. Without liming and/or application of fertilizer, the food crops perform very poorly on these soils (Hakim, 1983; Syarifuddin 1984). However, lime and especially fertilizers are costly inputs.

Kamprath (1972) suggested that lime recommendations should be based on the amount of exchangeable aluminum in the topsoil. For every milli-equivalent (meq) of exchangeable aluminum per 100 g soil, 1.5 meq of calcium or the equivalent of 1.65 t/ha of $CaCO_3$ should be applied. Since 1983, liming has been recommended to increase crop yield in Indonesia (Ditjentan Tanaman Pangan 1982). The recommendation is 2 t $CaCO_3$/ha for every meq of exchangeable aluminum/100 g soils.

In fact, all food crops respond very positively to lime application (Team Studi Kapur IPB, 1983). However, over estimation of lime requirement will give some negative effects, and should be looked into.

Recommendations of the fertilizer use in Indonesia are generalized for N, P, and K. The general recommendations per hectare suggested for upland rice are 150 kg Urea, 50 kg TSP, and 50 kg KCl; for maize 200 kg Urea, 100 TSP and 100 kg KCl, and for soybean 50 kg Urea, 100 kg TSP, and 50 kg KCl (Badan Pengendalian BIMAS, 1977). However, these rates appear to be insufficient to get higher yields on Podzolic soils. Therefore, increased rates of fertilizers were studied.

Intercropping systems and crop rotation are the technologies to get maximum productivity of land. Many food crops such as upland rice, soybean and maize can be used in intercropping systems. However, the intercropping system will be successful only if the higher fertilizer inputs have been applied. Organic manure, such as crop residues, could reduce Al saturation and supply nutrients.

Fertility experiments were therefore conducted in an intercropping system. The objectives of the study were to indentify the best rates of lime application, to improve fertilizer recommendations and to test the effect of crop residues on production and nutrient uptake of upland rice, soybean and maize in intercropping systems.

METHODS

From 1985 to 1988 the Andalas University and the Food and Agricultural Organization of the UN (FAO) carried out integrated plant nutrient research experiments on an acid Podzolic soil (Ultisol) in West Sumatera, Indonesia. The first year programme is presented in this paper.

For the first season crop planting the design was a 4x4 factorial in split - plot, and a 4x4x3 factorial in split - split plot for the second season crop planting, all in 3 replicates. Main plots were four rates or lime: 0, 6, 12, and 18 t/ha (equal to 0, 2, 4, and 6x me/100 g exchangeable Al). Sub plots received rates of N, P, K, Mg fertilizers, 0.5, 1.0, 1.5, and 2.0 times the conventional recommendations in Indonesia (Table 1). Sub-sub plot were three treatments of crop residues, mulched, burnt, and removed.

The land had been cleared in 1981 with heavy machinery, but never cultivated. In October 1985 tree trunks were cleared and the land was cultivated manually. After cultivating twice, lime was applied by top dressing and incorporated in the soils at about 15 cm depth in November, 1985. The first planning season was in December, 1985, or 30 days after liming, with the following crop pattern: upland rice (80% of the normal crop density) + maize (50% crop density). The second planting season was in April 1986, with the crop pattern soybean (80% crop density) + maize (50% crops density). Varieties of upland rice were Sentani, Arjuna for maize and Wilis for soybean. Fertilizers were placed about 10 cm beside the crop at 10 cm depth. Plants were protected by spraying pesticides.

TABLE 1. Fertilizer rates in intercropping systems.

Crops	Fertilizers material	Conventional recommendation equivalent			
		0.5	1.0	1.5	2.0
		(kg/ha)			
Upland rice	Urea	60	120	180	240
(80% density)	TSP	20	40	60	80
	KCl	20	40	60	80
	Kieserite	20	40	60	80
Maize	Urea	50	100	150	200
(50% density)	TSP	25	50	75	100
	KCl	25	50	75	100
	Kieserite	25	50	75	100
Soybean	Urea	20	40	60	80
(80% density)	TSP	40	80	120	160
	KCl	20	40	60	80
	Kieserite	20	40	60	80

Soil samples were collected from all plots at 0-20 cm depth before treatment, 30 days after liming, and one year after liming. The selected soil chemical properties such as pH, N-total, P Bray-2, and exchangeable Al, Ca, Mg, and K were measured.

RESULTS

The effect of treatments on aluminum

Liming the soil at 6 t/ha decreased Al content from 3 me/100 g soil to trace levels, and Al saturation decreased from 78% to trace level (table 2). These conditions are beneficial for all food crops. Liming at a rate over twice the amount of exchangeable Al, such as 12 and 18 t/ha in this research, is not needed. Kamprath (1970) recommends liming to neutralize exchangeable aluminum only. Hakim (1982) found 1.5 ton $CaCO_3$ per hectare to suffice for each meq exchangeable Al/100 g. soils. One year after liming, exchangeable Al has not yet reappeared.

Decreases of Al content and saturation and pH increase occurred simultaneously. Freitas and Van Raij (1975) reported that exchangeable Al can not be measured when soil pH is more than 6.

The effects of fertilizer and crop residue treatments on Al content and saturation were not consistent if the soil was not limed.

Table 2. Soil acidity as affected by lime and fertilizer application at Setiung, West Sumatera, Indonesia.

Lime $CaCO_3$ t/ha	Fertilizer (Conventional recommendation Equivalent)	pH (H_2O)	Acidity Exch. Al meq/100 g	Al-sat. %
		Before lime application		
		4.20	3	78
		30 Days after liming		
0		4.17	3.3	79
6		6.80	tr	tr
12		6.93	tr	tr
18		7.18	tr	tr
		One year after liming		
0	0.5	4.32	2.65	60
	1.0	4.37	2.40	68
	1.5	4.08	3.13	70
	2.0	4.30	2.67	61
6	0.5	7.10	tr	tr
	1.0	6.64	tr	tr
	1.5	6.85	tr	tr
	2.0	6.23	tr	tr
12	0.5	7.19	tr	tr
	1.0	7.13	tr	tr
	1.5	7.34	tr	tr
	2.0	7.19	tr	tr
18	0.5	7.41	tr	tr
	1.0	7.27	tr	tr
	1.5	7.55	tr	tr
	2.0	7.32	tr	tr

The effect of treatment on soil nutrients

Liming increased Ca-levels significantly , whereas other nutrients did not clearly so (Table 3). Phosphorus levels tended to increase with lime addition up to 6 t/ha, but decreased by liming up to 12 and 18 t/ha. There is a general consensus from the vast literature on P availability that it is depending upon the soil pH. Lutz et al (1972), Farina et al (1980) and Hakim (1982) reported the availability of P to decrease with pH over 6.

In general, the increase of fertilizer level from 0.5 to 2.0 times the conventional recommendation, tended to increase contents of N, P, K and Mg in the soil. Nutrient concentrations under crop residues mulched, were slightly higher than where residues were removed and burnt. The sharp increase in organic matter (%) in table 3 can be attributed to the decomposition of plant residues during the incubation period.

TABLE 3. Soil organic matter and major nutrients as affected by lime and fertilizer treatments in Sitiung, West Sumatera Indonesia.

Lime $CaCO_3$	Fertilizer	Organic matter and major nutrients					
		O.M.	N	P	K	Ca	Mg
t/ha	(conventional recommendation equivalent)	- - (%) - -		ppm	- - - - me/100 g - - - -		
				Before liming			
		0.22	0.11	5.5	0.22	0.4	0.08
				30 days after liming			
0		0.85	0.11	6.4	0.02	0.4	0.12
6		2.85	0.10	6.1	0.04	4.3	0.28
12		2.49	0.14	3.2	0.03	5.6	0.34
18		3.50	0.12	6.8	0.03	4.7	0.38
				one year after liming			
0	0.5	2.83	0.08	7	0.04	0.73	0.25
	1.0	1.32	0.07	10	0.10	0.76	0.17
	1.5	2.04	0.08	13	0.08	0.45	0.19
	2.0	2.79	0.17	17	0.03	0.64	0.29
6	0.5	2.29	0.15	14	0.07	3.90	0.45
	1.0	2.01	0.26	17	0.05	3.77	0.36
	1.5	2.72	0.24	38	0.06	4.30	0.46
	2.0	2.88	0.22	46	0.05	3.23	0.58
12	0.5	2.21	0.15	11	0.03	4.87	0.26
	1.0	1.50	0.16	11	0.03	4.77	0.24
	1.5	2.40	0.15	20	0.05	4.97	0.38
	2.0	1.75	0.15	37	0.05	4.70	0.51
18	0.5	0.53	0.15	8	0.03	5.27	0.19
	1.0	1.58	0.16	11	0.03	5.43	0.41
	1.5	1.97	0.17	29	0.04	5.77	0.38
	2.0	2.45	0.17	42	0.03	5.13	0.40

Crops yields at the first crop planting

At the first crop planting, liming effects were significant for upland rice and maize. The failure of maize to grow on Podzolic soils without liming is very interesting. Maize roots could not grow with Al saturations over 70% and pH 4.17. Setijono (1985) obtained Al toxicity symptoms on unlimed soil having aluminum saturation >30%. Upland rice was capable to grow, but it performed poorly. Apparently, upland rice is more tolerant to high acidity and high Al-saturation than maize.

The effects of liming on upland rice and maize grain yield are presented in Fig. 1. The limed soils give significantly higher yields, but maize response is higher than that of upland rice. The equations in Fig. 1 show that the maximum yield is obtained at a liming rate in tons equal to 4.5 times the exchangeable Al (in me/100 g) for upland rice and 4.05 times the exchangeable Al for maize. Therefore, overliming will be found if lime application exceeds 4.5 t/ha for every meq exchangeable Al. The highest yield increase was found at 6t $CaCO_3$/ha for soils with 3 me/100 g exchangeable Al. Lime applications of 12 t $CaCO_3$/ha were not economical. It means, the best rate of lime application in this experiment was 2 tons $CaCO_3$/ha for every me of exchangeable Al.

The same result was found at Carimagua (Colombia)on acid upland soils. There was no production without lime, while the normal growth was found soils limed at 6 t $CaCO_3$/ha. Some varieties of upland rice responded to the low rate of lime, but there was no positive response to higher lime application (Spain et al 1975). In greenhouse experiments Devnita (1987) obtained an overliming effect for mungbean on soils given more lime (in ton/ha) than 3.8 times the amount of exchangeable-Al in me/100 g soil, and for the soybean Kenedi (1987) found a critical value for lime applications (in tons) more than 3.85 times the amount of exchangeable-Al (in me/100 g soil). At high lime rates, grain yield decrease may be due to nutrient imbalance.

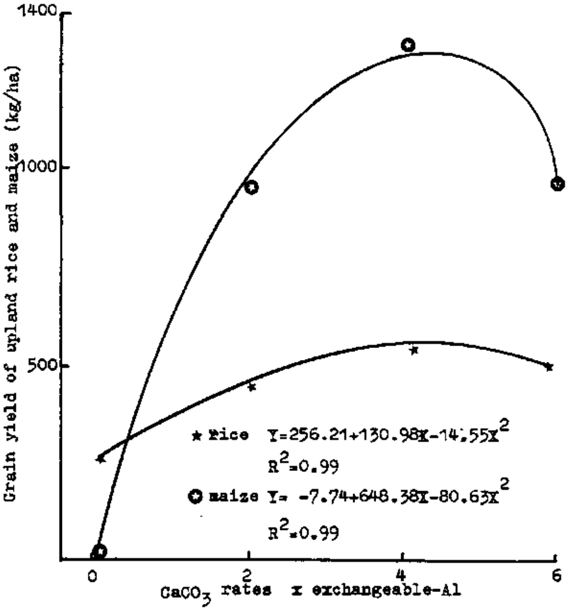

Fig. 1. The effect of liming on grain yield of intercropped upland rice and maize.

In general, the increasing fertilizers rates, from 0.5 to 1.5 times the conventional recommendations, significantly increased upland rice and maize yields (Table 4). However, on unlimed soils increasing fertilizer rates decreased upland rice yields, whereas positive responses were obtained on limed soils. Both upland rice and maize showed a good response to increasing fertilizer rates on limed soils up to 6 t $CaCO_3$/ha (Fig. 2). The best rate of fertilizers applied on limid Podzolic soils was 1.5 times the conventional recommendation. These rates were 180 kg Urea, 60 kg TSP, 60 kg KCl, and 60 kg Kieserite per hectare for upland rice, and 150 kg Urea, 75 kg TSP, 75 kg KCl, and 75 kg Kieserite per hectare for maize in intercropping systems. The conventional recommendations of fertilizers apparently were insufficient to get good yields of food crops on Podzolic soils.

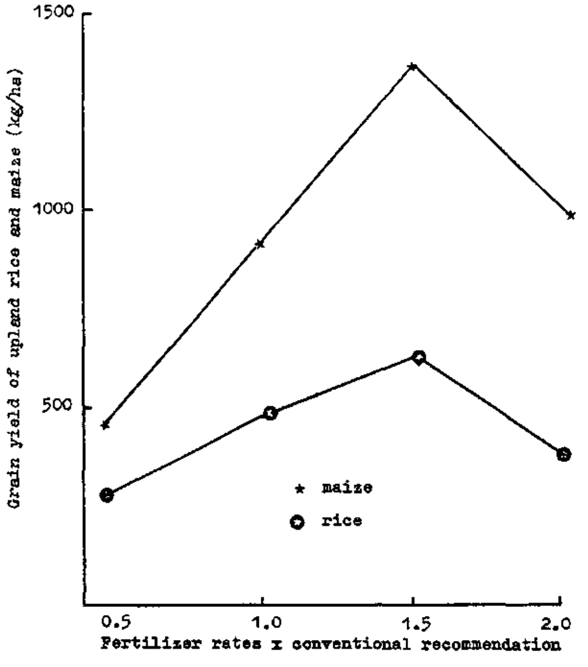

Figure 2. The effect of fertilizer on grain yield of upland rice and maize with lime 6 t/ha.

TABLE 4. Rice and maize grain yield (for 1st crop after liming) as affected by rates of lime and fertilizer on Podzolic soils, in Sitiung, West Sumatera Indonesia.

Lime (t/ha)	Fertilizer (cre)+	Upland rice (kg/ha)	Maize (kg/ha)
	- - - - - - - - - - - -	(kg/ha)	- - - - - - - - - - - -
0	0.5	358.1	0
	1.0	337.1	0
	1.5	221.1	0
	2.0	115.9	0
6	0.5	284.4	473.2
	1.0	495.1	918.5
	1.5	642.5	1392.0
	2.0	395.1	1002.0
12	0.5	574.1	1141.2
	1.0	468.7	1224.7
	1.5	663.6	1336.0
	2.0	505.6	1614.3
18	0.5	379.2	640.2
	1.0	848.8	974.2
	1.5	410.8	1530.8
	2.0	426.6	835.0
	LSD 0.05	272.2	687.4

+ cre = concentional recommendation equivalent

Nutrient uptake at the first crop planting

The uptake of major nutrients (N, P, K, Ca and Mg) from the soil increased with liming (Table 5). At the same fertilizer doses applied, nutrient uptake by upland rice was 2 to 3 times greater than on unlimed soils. On the other hand, fertilizer applications for maize could not be effective when acid soils were not limed.

TABLE 5. Major nutrient uptake by upland rice and maize (grain and straw) at the first crop planting after liming, as affected by lime and fertilizer rates on Podzolic soil in Sitiung, West Sumatera, Indonesia.

Lime (t/ha)	Fertilizers (cre)[a)]	Nutrient uptake (kg/ha)				
		N	P	K	Ca	Mg
		Upland rice				
0	0.5	14.56	1.21	16.15	3.41	1.37
	1.0	21.02	2.27	20.65	4.47	1.75
	1.5	19.50	1.58	24.35	4.99	1.88
	2.0	12.94	1.33	14.54	3.28	1.04
6	0.5	18.52	1.41	16.04	3.28	1.04
	1.0	35.00	3.43	32.03	7.20	2.76
	1.5	43.63	4.35	48.85	9.80	3.16
	2.0	44.47	3.41	46.21	9.19	4.13
12	0.5	35.82	2.55	41.94	5.62	1.93
	1.0	45.58	3.41	44.65	6.40	2.18
	1.5	53.11	4.58	55.70	7.32	3.86
	2.0	38.17	1.62	41.64	5.55	1.60
18	0.5	24.70	2.55	25.36	3.72	1.03
	1.0	25.83	3.00	30.37	4.55	1.54
	1.5	33.39	3.57	41.99	5.16	1.18
	2.0	28.72	2.86	43.94	2.85	1.95
		Maize[b)]				
6	0.5	31.12	4.26	37.80	6.07	1.45
	1.0	25.72	6.72	26.55	4.77	1.49
	1.5	49.34	10.72	21.83	7.96	2.19
	2.0	42.53	9.08	43.27	6.08	2.33
12	0.5	33.99	6.78	32.52	4.88	1.57
	1.0	35.36	7.81	31.43	4.29	2.02
	1.5	45.18	9.20	15.01	6.09	1.59
	2.0	60.77	13.05	31.55	10.23	1.15
18	0.5	29.87	6.08	19.93	4.94	1.53
	1.0	42.13	7.72	50.06	6.42	2.13
	1.5	43.81	10.58	18.02	6.80	2.83
	2.0	38.92	8.45	39.92	5.72	1.22

a) cre = conventional recommendation equivalent

b) maize died before flowering

In general, nutrient contents increased with increasing fertilizer doses, but not proportional to yield increases. Nutrient uptake and grain yields of upland rice and maize increased by increasing fertilizer rates from 0.5 to 1.5 times the conventional recommendations.

Crop yield at the second crop planting

At the second crop planting after lime application maize grew better as compared to the first season. Actually, maize and soybean growth were very good at the beginning, but water deficiency at blossom time prevented seedformation of soybean. Maize still could produce cobs, because of the earlier seeding time.

Table 6 shows for the second planting season yields of maize, both on unlimed and limed soils. Yields were low in the absence of lime.

TABLE 6. Main effect of liming, fertilizers and crop residues on maize grain yield and soybean straw yield on Podzolic soils in Sitiung West Sumatera Indonesia.

Lime treatment	(t/ha)	Fertilizers treatment [a)]		Crop residues treatment	
	Maize grain yield at 50% crop density (kg/ha)				
0	143.1	0.5	452.8	mulched	592.7
6	887.5	1.0	588.9	burnt	656.2
12	783.3	1.5	779.2	removed	697.9
18	781.9	2.0	775.0		
LSD.05	496.9		214.4		93.9
	Soybean straw yield at 80% crop density (t/ha)				
0	0.283	0.5	1.019	mulched	1.317
6	1.700	1.0	1.317	burnt	1.254
12	1.852	1.5	1.467	removed	1.397
18	1.447	2.0	1.481		
LSD.05	0.758		0.422		0.194

a) conventional recommendation equivalent

There is no significant interaction between lime, fertilizer, and applied crop residues on maize grain yield and soybean straw yield. Therefore, the main effects only will be discussed here (Table 6).

Maize grain and soybean straw yield with residual lime applied at (6 t/ha) were 7 times higher as compared unlimed crops. The residual effects of lime applied at 12 and 18 t/ha tended to decline yields. The relationship between lime rates (x) and maize grain yield (y) equals:

$$y = 190.67 + 370.28\,x - 46.61\,x^2,$$

and soybean straw yield:

$$y = 0.437 + 0.826\,x - 0.114\,x^2.$$

The maximum yield of maize was found at a lime rate (ton/ha) equal to 3.97 times the exchangeable-Al expressed as me/100 g, and equal to 3.63 times the exchangeable-Al for soybean. It means, that overliming effects will be found if lime rates approach 4 t $CaCO_3$/ha for each me of exchangeable-Al per 100 g soils.

As discussed before, the highest yield increase by residual lime (applied at 6 t/ha), caused Al-saturation to decrease. There was no exchangeable-Al at pH 7 (Table 2), and growth was optimal for maize and soybean. Decreasing yields with high lime rates may be due to deficiency of micro nutrients (Lindsay, 1972). Sanchez (1976) reported, that P and Zn availability will decrease drastically by overliming.

Fertilizer doses from 0.5 to 1.5 times the conventional recommendations increased maize and soybean yields significantly. The effects of fertilizer rates were not different from those of the first crop planting as discussed before, where the best fertilizer rate was 1.5 times the conventional recommendation of 60 kg Urea, 120 kg TSP, 60 kg KCl amd 60 kg Kieserite per hectare at 80% crop density of soybean. The main effects of crop residue treatments were not significant. Nevertheless, yields appeared to be higher when removing the crop residues, and lower in the mulching treatment.

At the second crop planting, nutrient contents in the plant tissue were also measured. Ca concentrations in maize and soybean straw were very high with liming. N and P, in both maize and soybean also tend to increase by liming, while K and Mg content do not seem to be influenced by lime.

CONCLUSIONS

The production and nutrient uptake of upland rice, soybean, and maize in intercropping systems on Podzolic soils (Ultisols) is significantly increased by liming. The best rate of lime application appears to be 2 t $CaCO_3$/ha for each meq Al/100 g soils. In this experiment it was 6 t $CaCO_3$/ha. The over liming rate is > 4 t $CaCO_3$/ha for each meq Al/100 g soils. Rates above 12 t $CaCO_3$/ha in this experiment tend to decline yields of upland rice, maize and soybean.

Fertilizer rates of 1.5 times the general recommendation are advised: 150 kg Urea, 75 kg TSP, 75 kg KCl and 75 kg Kieserite for 50% maize plant density, and 180 kg Urea, 60 kg TSP, 60 kg KCl, 60 kg Kieserite for 80% upland rice plant density, and 60 kg Urea, 120 kg TSP, 60 kg KCl, and 60 kg Kieserite for 80% of soybean plant density.

The effects of crop residues should be studied further.

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OBSERVATIONS ON DECOMPOSITION RATES OF LEAVES OF SEVERAL SHRUB AND TREE SPECIES APPLIED AS MULCH UNDER HUMID TROPICAL CONDITIONS.

Key words: *Acioa barterii* *Cassia siamea* *Flemingia congesta* *Gmelina arborea* leaf decomposion

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ABSTRACT

Decomposition rates of leaves of *Acioa barterii*, *Cassia siamea*, *Flemingia congesta* and *Gmelina arborea* applied as mulch were studied under humid tropical conditions. The rate of breakdown of leaves depended on the species, time of pruning and age of the leaves. Except during the dry season, initial decomposition of leaves of the four species was faster followed by later slower rates. Decomposition rate of the four species during the main season were as follows: *Cassia* > *Gmelina* > *Flemingia* > *Acioa*. At the onset of the rain, decomposition rate of *Flemingia* was faster than *Cassia*. *Gmelina* leaves showed faster initial decomposition rate during the rainy season than during the dry season.

INTRODUCTION

For maintenance and restoration of soil fertility in traditional upland crop-production system in large parts of the humid tropics, including West Africa, farmers still rely on a short cropping period followed by a long bush-fallow period. However, increasing population pressure has resulted in the shortening of the fallow cycle or the practice of continuous cultivation on low fertility soils, prevalent in many parts of the humid tropics. On these soils, severe problems occur in sustaining adequate food production without external chemical inputs.

Alley cropping, which is potential alternative to shifting cultivation, is essentially a production system in which food crops are grown in alleys formed by hedgerows of trees or shrubs (Kang et al., 1981, 1984). One of the basic principles of this production system is the periodical pruning of the hedgerows to reduce shading and competition with the foodcrops (Kang et al., 1985). The prunings left as mulch on the surface between the hedgerows are meant to improve the physical, chemical and biological properties of the soil (Kang et al., 1984). The contribution of the plant residues to the fertility of the soil will largely depend on the amount of biomass applied and on the rate of release of nutrients from the biomass. The decomposition of plant residue is known to be primarily affected by the nitrogen content of the biomass (Campbell, 1983) and the organic components, such as lignin (Alexander, 1977), polyphenols (Vallis and Jones, 1973) and soluble carbohydrates, and by environmental and management factors (Wilson et al., 1986). For optimum utilization of nutrients released during the decomposition of prunings, the time of pruning need te be adjusted to the nutrient demand of the associated food crop to be grown (Swift, 1986).

In order to obtain more information on the decomposition rate of prunings of selected tree and shrub species under humid tropical conditions, during the year field studies were carried out and its effect on crop growth was evaluated in a pot experiment using undisturbed soil cores.

MATERIALS AND METHODS.

Soils.

The experiments were conducted at the Onne High Rainfall Substation of the International Institute of Tropical Agriculture, located near Port Harcourt in South-Eastern Nigeria, with an average annual rainfall of 2420 mm. The rainy season extends from March till November.

Classified as Typic Paleudults (loamy, siliceous, isohypertermic family), an derived from Plio-Pleistocene coastal plain sediments, the soils at the experimental site are deep and well-drained, but highly leached and strongly acidic (Arora and Juo, 1982) and chemically very poor. Its clay content (predominantly kaolinite) is 18% in the surface layer and increases with depth to 35% in the B_2 horizon. Exchangeable Al is the dominant cation on the exchange complex.

Litterbag Experiment

The decomposition rates of leaves of the following hedgerow species, *Acioa barterii*, *Cassia siamea*, *Flemingia congesta* and *Gmelina arborea* were studied under field conditions in an alley cropping system.

The alley cropping experiment was established in 1983. The hedgerows were pruned at 3 periods depending on the species, namely (1) in December 1986 at the end of the rainy season for the *Gmelina* hedgerow only, (2) in April 1987 at the onset of the main rainy season for the 4 species and (3) in May 1987 during the main growing season for the *Cassia*, *Flemingia* and *Gmelina* hedgerows.

Fresh leaves were placed into woven polythylene bags, 80 cm long and 50 cm wide. The bags had meshes of 13 x 3 mm. The fresh leaves were evenly distributed within the bags. For the December and April prunings, the quantities of fresh leaves placed in the bags corresponded with the amounts present for the same surface area (of the bags) in the alleys. For the May prunings, the weight of fresh leaves inside the bags were double the actual amounts spread in the alleys.

For each species, 12 litterbags were installed. Subsamples were collected and dried (65 ^{o}C) for dry weight measurements. The bags were placed randomly in the appropriate alleys on the soil surface. Fresh prunings were removed from the chosen locations, but all other debris remained in place.

The litterbags were weighed weekly, except for the *Acioa* treatment, which was weighed fortnightly. Following the weighings, the content of one bag of each of the series was dried at 65 ^{o}C, to estimate the litter dry weights. Weighing was done carefully in order to prevent loss of material. Any soil present in the sample was removed. Litter dry matter was expressed as moving averages, i.e. the average of 2 consecutive weekly determinations.

Throughout the experiment, the alleys were either in fallow or cropped with maize (April-July, 1987). No fertilizer was applied to the plots.

Pot Experiment

Undisturbed soil columns (0-25 cm depth) were cut in an 8-year old grass fallow at the Onne station, using the technique described by Belford (1979). The polythene cylinders (30 cm long and 20 cm in diameter) were filled with the soil within an area of 25 m^2. The soil was kept near field capacity; moisture loss by evaporation was prevented by covering the soil with polythene sheet.

At the start of the pot experiment, the monoliths were cut level with the bottom rim and sealed watertight with an external plastic stop-end. The moisture content of the soil was adjusted to 90% of field capacity, and daily restored to that level by using water condensed on a dehumidfier.

The treatment consisted of the application of prunings of *Acioa*, *Cassia*, *Flemingia* and *Gmelina*. Leaves were gathered at random from the hedgerows. Fresh leaves were cut into pieces of about 1 cm^2, simulating physical breakdown. Enqual weights of leaves (on a dry matter basis) were distributed evenly over the soil surface, at a rate of 42 tons/ha. *Flemingia* leaves were applied at a (about 20%) higher rate. Control pots (no mulch applied) were included.

A completely randomized design, with 3 replications was used. Pots were placed in an open roofhouse covered with transparent polythene, transmitting about 75% of the sunlight.

Each pot contained 12.9 kg soil at 90% of field capacity, at a bulk density of 1.46 gram cm^{-3}. At planting, the following fertilizer basal dressing was applied: 22.5 mg kg^{-1} N (NH_4NO_3), 20 mg kg^{-1} P (CaHPO4), 35 mg kg^{-1} K (KCL), 7.5 mg kg^{-1} Mg ($MgSO_4.7H_2O$) and 2.5 mg kg^{-1} Zn ($ZnSO_4.7H_2O$).

Maize was used as a test crop. Three days after emergence of maize, plants were thinned to 3 plants per pot. At 4, 6 and 8 weeks after sowing (WAS), one maize plant per pot was harvested; plants were dried at 65 °C and weighed. The dry weight per plant is multiplied by 3 and 2 in order to arrive at the dry matter production per pot at 4 and 6 WAS, respectively. The total amount of stover harvested per pot (Table 1) is the sum of the actual dry weight of the plants harvested at 4, 6 and 8 WAS.

RESULTS AND DISCUSSION.

The leaf decomposition rates of the 4 species studied vary substantially. Pruned at the onset of the rainy season, *Gmelina*-, *Cassia*- and *Flemingia*-leaves decomposed at comparable rates during the first 6 weeks, losing about 30% of the dry matter (Figure 1). Later on, the decomposition of *Cassia* leaves slowed down considerably.

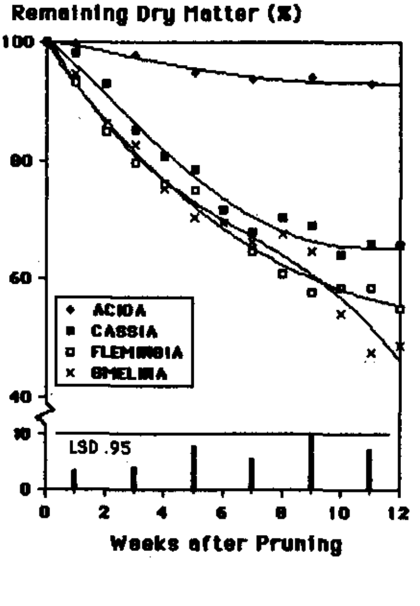

Fig. 1. Decomposition of surface-applied *Acioa barterii*, *Cassia siameia*, *Gmelina arborea* and *Flemingia congesta* fresh leaves, pruned at the beginning of the rainy season.

The decomposition of Flemingia leaves continued at about the same rate up to 8 weeks and also declined afterwards. This observation followed the same trend of rapid initial loss of about 25% of the original organic material, followed by a period of slower decomposition, as reported by Parker (1962) and Swift (1986). A decline in breakdown rate for *Gmelina* leaves was observed after four weeks. Afterwards, the original rate was restored, resulting in a higher disappearance of *Gmelina* leaves at 10 weeks after application. *Acioa* leaves decomposed very slowly. After 3 months (Figure 1) only about 10% of the dry matter was decomposed. After 6 months (data not shown), only 15% of the applied leaves had disappeared.

The decomposition pattern of leaves of *Cassia*, *Flemingia* and *Gmelina* pruned during the main rainy season (May pruning) is shown in Figure 2.

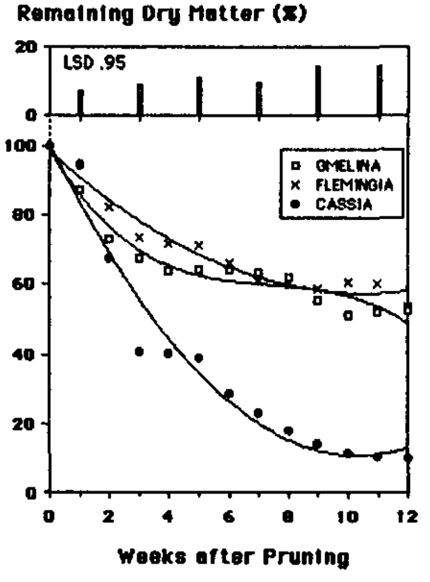

Fig. 2. Decomposition of fresh leaves of *Cassia siamea*, *Gmelina arborea*, and *Flemingia congesta* applied as mulch during the main growing season.

For *Gmelina* and *Flemingia* leaves, they were similar to those observed at the onset of the rainy season (Figure 1). The decomposition of *Cassia* leaves in the rainy season was faster (Figure 2) than that observed at the onset of the rainy season (Figure 1). At 9 weeks after application, only 15% of the dry matter remained in the field (Figure 2). The slow decomposition rate at the beginning of the rainy season may be due to alternating wetting and drying effect, which may retard the breakdown of *Cassia* leaves. In addition, it appears that due to differences in maturity and composition, the *Cassia* leaves pruned during the rainy season decomposed faster. It has been reported that the nitrogen content of green leaves decreases with age (Cisternas and Yates, 1982), and that immature green tissue may decompose more rapidly than matured plant tissues (Faulkner, 1934).

Decomposition of *Gmelina* leaves pruned at the start of the dry season was much slower during the first 6 weeks (Figure 3) compared to those pruned at the beginning of the rainy season (Figure 1) or during the rainy season (Figure 2). Similar results of retarded decomposition rates under droughty conditions were also reported by Shield and Paul (1973). After about 6 weeks, the decomposition rate appeared not be affected by weather conditions. Apparently, moisture supplied by dew was sufficient to initiate and maintain a high decomposition rate (Figure 3). Leaf composition and other than environmental factors may be responsible for the much faster decomposition rate of *Gmelina* leaves during the dry season.

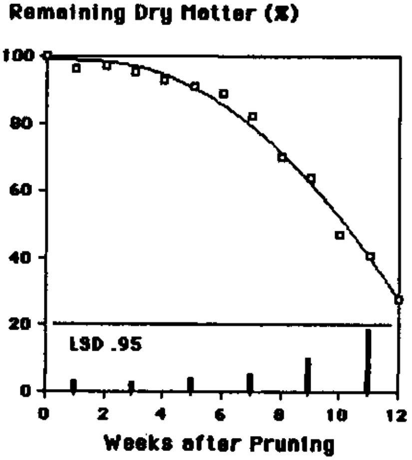

Fig. 3. Decomposition of *Gmelina arborea* leaves pruned at the start of the dry season.

Results of the pot trial (Table 1) did not show any distinct effect of differences in decomposition rates of the mulch materials on the dry matter weight of maize. *Gmelina* mulch, which had a faster decomposition rate than *Acioa* mulch, had no significant effect on maize growth over the control. *Acioa* which had a slower decomposition rate appears to have more effect.

TABLE 1. Effect of addition of fresh leaves of various woody species as mulch on dry matter weight of maize grown in pot test on Typic Paleudult.

Woody Species Mulch	Dry Matter, g pot^{-1}			
	Weeks after sowing			
	4	6	8	Total harvest
Acioa barterii	6.26 ab[1)]	12.46 a	14.79 bc	23.11 b
Cassia siamea	8.05 a	17.52 a	21.57 a	33.01 a
Flemingia congesta	6.32 ab	12.54 a	15.14 b	23.52 b
Gemelina arborea	7.55 ab	12.52 a	11.15 c	19.93 b
Control	4.28 b	11.39 a	12.79 bc	19.91 b

1) Figures within columns followed by the same letter(s) are not significantly different according te Duncan's Multiple Range Test at 5% level.

Mulch from *Flemingia* and especially *Cassia*, both leguminous species, improved maize dry matter production significantly. Rapid decomposition and high nitrogen content could benefit the maize crop already in an early growth stage: with *Cassia* the effect of mulch addition was already noticeable at 4 weeks after sowing.

The results show, that the decomposition rate of leaves applied as mulch are affected by (1) nature of mulch material; species such as *Acioa* even under humid conditions showed a slow decomposition rate, and (2) timing of pruning, which reflects age of the material and also that of the effect of environmental factors. To obtain optimum nutrient benefit from the added mulch material, further studies are forthcoming in order to obtain a better understanding of decomposition rates and nutrient releases of various woody species with potential for alley cropping, so that prunings of the hedgerows can be adjusted to improve the benefit for the associated crops.

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INFLUENCE OF TILLAGE AND NITROGEN FERTILIZATION ON SOIL NITROGEN, DECOMPOSITION OF ALANG-ALANG (*Imperata cylindrica*) AND CORN PRODUCTION OF ALANG-ALANG LAND

Key words: Alang-alang Conventional Immobilization Ladang Mineralization No-tillage

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SUMMARY

Research was conducted in Lampung to determine the effect of different tillages and N fertilizer rate on potential N mineralization-immobilization by alang-alang (*Imperata cylindrica*) residues and corn yield.

The experiment was a factorial, randomized complete block design. Tillages were conventional, no-tillage with slashing and burning, and no-tillage; N fertilizer rates were 0, 100, and 200 kg/ha N.

There was a higher potential for N immobilization by alang-alang residues with no-tillage than conventional tillage as shown by higher N concentration in residue after corn harvest. Nitrate concentration under no-tillage alang-alang land tended to be lower than conventional tillage, but ammonium was higher under no-tillage. Corn grain yield in no-tillage alang-alang combined with 200 kg/ha N was consistently higher than those of conventional, and no-tillage with slashing and burning. However, with no N fertilization corn grain yield in no-tillage was consistently lower than other tillage systems.

INTRODUCTION

In Indonesia, the area of land covered with alang-alang (*Imperata cylindrica*) land is estimated to be 16-20 million hectares, mostly in Sumatra and Borneo (The Reesrach Group of Agro-Ecosystem, 1984). In Lampung province (Southern Sumatra), there are about 286.258 ha of alang-alang land which is 8.1% of total Lampung area (Hasan, 1987).

At the present time, there are very few tillage systems which can be effectively used for this type of land, but little research has been done on this subject. Although alang-alang land is potentially suitable for agriculture, this land remains abandoned, unused and thus nonproductive.

The increasing population in Indonesia requires an adequate agricultural production. As a result, agriculture will be forced onto presently nonproductive areas such as alang-alang land.

Several efforts have been made on alang-alang land to increase productivity. However, the utilization of this land for upland agriculture requires much energy and money, and proper tillage. Ardjasa, et al (1981) showed that conventional tillage on alang-alang land increased soil erosion, hastened soil degradation, failed to eradicate alang-alang growth, and decreased soil productivity. By using Dowpon M herbicide with minimum tillage, alang-alang was effectively suppressed, but the following crop yield was still slightly lower than with conventional tillage.

Similar studies by Bangun, et al (1984) with mungbean, and Dasril (1986) with soybean pointed in the same direction. The lower yields from minimum tillage than from conventional tillage were attributed to high N immobilization by alang-alang residues and lack of effective herbicides in killing down alang-alang. Arif (1984) and Dasril (1986) reported that roundup (Glyphosate) herbicide was effective for eradicating alang-alang.

The objective of this experiment was to study the effect of different tillage systems and N fertilizer rates on potential N mineralization and immobilization of alang-alang residues, and the resulting corn production on alang-alang land following these treatments.

MATERIALS AND METHODS

The experiment was conducted in January to May, 1987 at the Agricultural Experiment Station Farm, University of Lampung. Tanjungan, Lampung. This study followed intensive upland rice cultivation for several years as a ladang (land rotation with periods of fallow) which was abandoned, allowing alang-alang to take over the area. It was 4-years of age, with total dry matter of 15,000 kg/ha. The soil is a Typic Eutropept with slope ranging from 6 to 9 percent.

The experiment was a factorial, randomized complete block design, with 4 replications. Tillage treatments were conventional in which alang-alang was incorporated into soil (T1); no-tillage with slashing and burning plus roundup of 2.4 L per ha for killing the regrowth alang-alang (T2); and no-tillage with Roundup of 4.8 L a.i. per ha for killing alang-alang (T3). Each tillage was combined with N fertilizer rates of N0 (0), N1 (100 kg N/ha), and N2 (200 kgN/ha) as urea (45% N). One half of the N rate applied on February 26, and the remainder was applied on March 12, 1987. On February 12, 1987, hybrid maize was planted at a spacing of 75 x 25 cm, 3 weeks after herbicide application for no-tillage, or 3 weeks after plowing for conventional tillage. Before planting, treated alang-alang of the no-tillage treatment was laid down, then corn was planted directly into the alang-alang land.

To study decomposition, 15 g (dry basis) of alang-alang residues, in nylon bags (5 x 5 cm) were placed on the surface in the no-tillage, and at 5 cm depth in the conventional tillage treatment. Determination of residue dry weight and N-level of residues (micro Kjeldahl method), were sampled at biweekly intervals. Soil samples for NO_3^- and NH_4^+ determination were taken at monthly intervals throughout the growing season at depth of 0-20 cm. The samples were either analyzed directly (colorimetre procedure) or stored in a freezer at about -10 degree oC until analysis. Total soil N was determined by a modification of the macro Kjeldahl method of Bremner and Mulvaney (1982), after harvest at a depth of 0-20 cm. Maize grain was harvested on May 24, 1987 from 6.0 m of the two center rows of each plot. Yield values were computed on the basis of 15.5% moisture in the grains.

A similar experiment was conducted on a Typic Fragiudult soil in February to June 1987. Data reported from this experiment included only N uptake and corn grain yield.

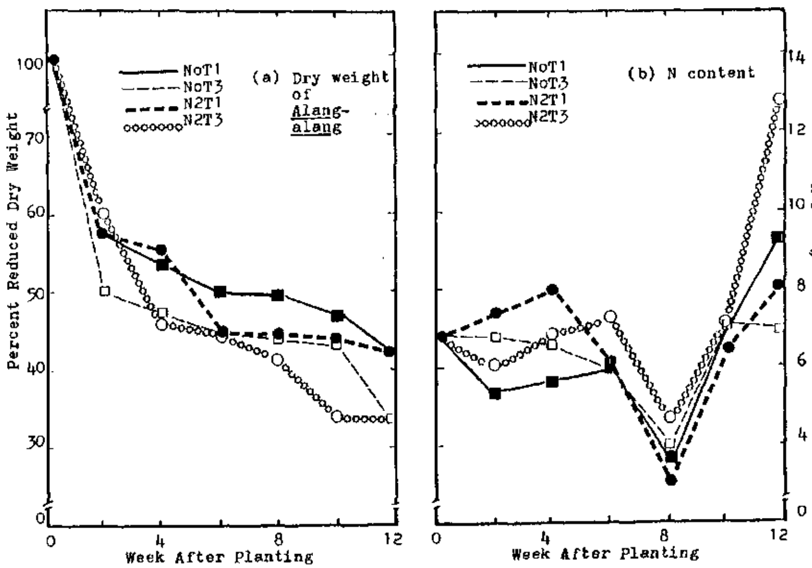

Fig. 1. Changes in dry weight (a) and nitrogen concentration (b) of alang-alang (above-ground parts) as affected by tillage and nitrogen fertilizer application (N_0= 0 kg N/ha, N_2= 200 kg N/ha, T1= conventional tillage, T3= No tillage).

RESULTS AND DISCUSSION

Decomposition of alang-alang residue:

Decomposition of residue and N concentration of alang-alang from the above-ground portion was determined on conventional and no-tillage with 0 and 200 kg/ha N (Figure 1).

The decomposition of residues throughout the growing season of maize was not significantly affected by either tillage or N rate (LSD 0.05). However, decomposition decrease in dry weight tended to be greater under no-tillage than conventional tillage, and also greater under a N rate of 200 kg/ha. The lack of treatment effects on decomposition of alang-alang residues was probably due to high rainfall, rainfall distribution, and/or insufficient N. Total rainfall throughout the season was high (1227 mm) and evenly distributed during the season, so that soil water content between tillage treatments was not different. Also the rate of 200 kg/ha N was probably insufficient for biological decomposition of residues with a high C/N ratio. Regardless of N fertilization, the alang-alang samples at 14 weeks after planting from no-tillage (T3) reduced residue as much as 65%, while residue at 5 cm depth of conventional tillage decreased 55%. This suggests that less mulch will remain after no-tillage than conventional tillage for the following crop.

Nitrogen concentration of the residue during the first 10 weeks of the corn growing season was not influenced by any treatment combination. At 14 weeks after planting N concentration of alang-alang residue under no-tillage and 200 kg/ha was significantly higher than all other treatments. This fact suggests a high potential for N immobilization in no-tillage with N application which should be taken into account when using no-tillage on alang-alang land.

Figure 1 indicates that potential immobilization began four weeks after planting on conventional tillage with 200 kg/ha N. It seems that if alang-alang residue was mixed with the soil such as in conventional tillage, it could immobilize N.

Eight weeks after planting, a different pattern occurred; N content of the residue dropped sharply from 6.8 g/kg N to 4.0 g/kg N. The rapid N decrease during this period suggested that a large amount of N was being released from alang-alang residue which was either native alang-alang N or immobilized fertilizer N. However, immediately after this time, some N remained immobilized until corn harvesting.

Soil nitrogen; total N and available N:

Total soil N was determined after corn harvest, which indicated the amount of total soil N that was present for the following crop. Total soil N was not significantly affected by tillage or the interaction of tillage and N fertilization rate (Table 1). But increasing N fertilizer rate did increase total soil N.

TABLE 1. Total soil nitrogen at 0 to 20 cm depth as affected by tillage and N fertilizer (Typic Fragiudult).

Tillage system	N application rate (kg/ha)		
	0	100	200
	- - - - - - - - N soil g/kg - - - - - - - -		
Conventional	1.28	1.35	1.66
No-tillage	1.03	1.53	1.69

Note: not significantly different, LSD 0.05 for tillage and interaction.

The lack of interaction of tillage and N fertilizer rate on total soil N was thought to be due to alang-alang having a very low N concentration (6.8 g/kg) which drastically reduced N release into the soil during the growing season.

At planting time, soil NO_3^- was significantly influenced by the tillage treatments which were carried out three weeks after plowing. Soil nitrate following conventional tillage was significantly higher than no-tillage (Figure 2a). This was attributed to the effect of soil-residue mixing which enhanced aeration resulting in more N mineralization. Regardless of the tillage treatment, soil N was already high under alang-alang vegetation which the residue retained from previous seasons. Four weeks after planting, N fertilization only affected NO_3^- and not the NH_4^+-levels. Nitrate-levels increased sharply from 4 to 8 weeks after planting in all treatments except no-tillage without fertilizer, while NH_4^+ changed very little (Figure 2a and 2b). Eight weeks after planting, the NO_3^--level reached a peak, but after that it dropped again. Fourteen weeks after planting, nitrate levels in plots treated with N fertilizer were still higher. Ammonium levels under no-tillage plots were somewhat higher than conventional tillage (Figure 2b).

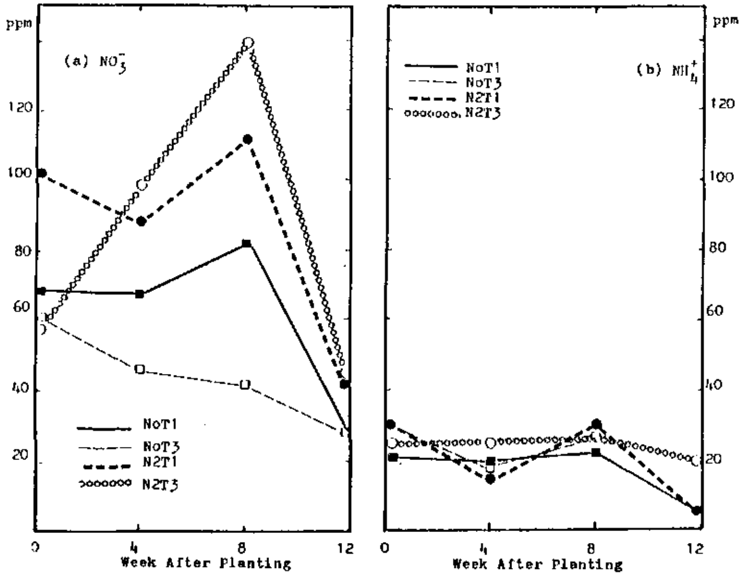

Figure 2. Soil nitrate (a) and ammonium (b) as affected by tillage and nitrogen fertilization in typic eutropept soil. NO-0 kg/ha N, N2-200 kg/ha N, T1-conventional, T3-No-tillage. rate.

The changes in NO_3^- and NH_4^+ concentration during the corn growing season shows the different behaviour between NO_3^- and NH_4^+ under different tillage systems. Under no-tillage, soil and residue conditions favored immobilization, and potential denitrification, but less N mineralization. The net result is that soil NO_3^- changes were opposite of changes in residue N concentration which indicated that N immobilization was important in total N availability to the maize.

TABLE 2. Nitrogen uptake of whole corn plant, eight weeks after planting.

		Soil	
		Typic Europept	Typic Fragiudult
N rate kg/ha	Tillage	N uptake g N/2 plants	
0	Conventional	1.56	1.19
	No-tillage	1.53	1.34
200	Conventional	2.77	2.69
	No-tillage	4.81	4.56

Note: not significantly different, LSD 0.05 for tillage and interaction.

Nitrogen uptake:

Nitrogen uptake of corn (8 weeks) was not significantly influenced by the interaction of tillage and N fertilization (Table 2) but increased with increasing N rate.

Although not significant, N uptake of both experiments was consistently higher in no-tillage than conventional tillage. The higher N uptake from no-tillage was probably due to a relatively higher soil water content in no-tillage soil which enhanced N uptake and resulted in increased N efficiency. This allows a higher potential corn yield in no-tillage at higher levels of fertilizer N (Wells, 1984).

Corn grain yield

Corn grain yield responses to all tillage and N rates treatments were somewhat similar in both soil subgroups (Table 3), and significantly affected by N rate for all tillage systems. Although the grain yield under no-tillage was higher than conventional tillage when no N was applied, yield under no-tillage was greater than conventional tillage at 200 kg/ha. This follows a similar report by Utomo, et al. (1985) for no-tillage in the U.S. even though climatic conditions between Indonesia and the U.S. are very different. At the highest N rate, corn grain yields following no-tillage + slashing and burning were close to no-tillage because of similar tillage treatments.

TABLE 3. Corn grain yield (15.5% moisture) as affected by tillage systems and N fertilization.

N Rate kg/ha	Tillage	Typic Eutropept	Typic Fragiudult
		- - - - - - - - kg/ha	- - - - - - - -
0	Conventional	1730	2335
	No-tillage, slash, burn, roundup	1321	1713
	No-tillage, roundup	1319	1749
100	Conventional	3789	3759
	No-tillage, slash, burn, roundup	3881	2765
	No-tillage, roundup	4577	3425
200	Conventional	4479	3097
	No-tillage, slash, burn, roundup	5138	3651
	No-tillage, roundup	5740	4018

Note: not significantly different LSD 0.05 for tillage and interaction

Higher corn grain yield in no-tillage compared to conventional tillage at 200 kg/ha was due to higher N efficiency in no-tillage than conventional tillage (Table 2). On the other hand lower corn grain yields under no-tillage with the lower N rates were probably due either to less N mineralization or high N immobilization by alang-alang residues of no-tillage (Figures 1 and 2). The higher corn yield in the slashing and burning treatments was thought to be due to more basic nutrients being released from the ash following the alang-alang burning.

CONCLUSIONS

There was a higher potential N immobilization by residue of alang-alang under no-tillage than conventional tillage, which should be considered for N management on alang-alang land agriculture.

Corn grain yields both in this Typic Eutropept and Typic Fragiudult soils with no-tillage combined with 200 kg/ha N were consistently higher than those from no-tillage with slashing and burning, and conventional tillage treatments. However, with no fertilizer N, corn grain yield in no-tillage was consistently lower than other tillage treatments.

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WELLS, K.L. 1985. Nitrogen management in no-till system. In R.D. Hauck (ed.) nitrogen in crop production. ASA, Madison, WI. considered for N management on alang-alang land agriculture.

AGRICULTURE UNDER SIMULATED FOREST - AN ALTERNATIVE TO SHIFTING CULTIVATION

Key words: Alley cropping, maize, weeding, nitrogen fertilizer.

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SUMMARY.

Due to decreasing land/man ration consequent to population expansion and multiplication of nonagricultural land uses, shifting cultivators can no longer readily abandon their fields to forest fallow, and clear forests for new farms. This calls for an alternative which permits continuous farming.

Such an alternative is attempted, using the same ecological principles that have sustained shifting cultivation. Instead of fallowing the used-up crop land, a simulated forest is maintained in the crop field.

A long-term field experiment showed that cropping under stimulated forest is promising.

INTRODUCTION

Until recent times, the intricacies of shifting cultivation were not known and the practice was discouraged as destructive to ecology and environment. There was little or no effort to understand it either.

Thanks to the critical assessment of different aspects of shifting cultivation made by some workers (Barholomew et. al.,1953; Abeyratne, 1956; Greenland and Nye, 1959; Greenland, 1975; Thrupp, 1981; Grandstaff, 1981 and Plumwood and Routley, 1982) it is now convincingly clear that shifting cultivation is about the most adapted system of annual farming to the forested tropical ecosystems, particularly those where irrigated farming is not feasible.

However, in today's context of population densities and the annually increasing demand for land for nonagricultural activities and for nonfood agriculture, shifting cultivation in its traditional form is no longer feasible. This calls for alternatives which can best be developed by improving traditional systems by way of correcting its weaknesses and refining its many virtues which have been discussed earlier (Handawela, 1983). This study is an attempt in this direction.

The first step was to understand the physical environmental reasons that compel the shifting cultivators to shift. The methodology followed was to make field observations over many years.

Three reasons emerged as critical:

(1) deteriorating surface soil tilth resulting in declining capacity of the soil to take in rainwater, store it in the soil and furnish it to growing crops,
(2) increasing weed hazards and
(3) decimation of nutrient reserves released by burning of felled forest biomass.

In the wet zone of Sri Lanka where the rainfall is well distributed and the soil is acidic to neutral, nutrient depletion of the soil may be more critical than the capacity of the soil to provide moisture. In the dry zone which is drought prone and has soils tending to be neutral to basic, moisture is certainly more critical than nutrients.

In the major part of the dry zone the rainfall is bimodal. The main season is from late September to December with a rainfall of about 750 mm in about 12 weeks. The smaller season is around April with about 350 mm rain in 4-6 weeks. Annual rainfall averages around 1400 mm, which is furthermore characterized by short duration, irregular distribution even within the season and high intensity, resulting in a low proportion of effective rainfall. Therefore it is imperative that the crop matures within the rainy season and that the soil is in a condition that does not make it vulnerable to heavy erosion and surface sealing, and allows to take in adequate amounts of water from rain, retain it in the profile and release it in adequate amounts to the crop in order to ensure that the crop can survive to three weeks without rain.

As land preparation has to be done well in advance of the rains or it has to be quickly finished with the early rains, a heavy demand for farm labour has to be reckoned with at this period.

A rapid land preparation is difficult because of the physical properties of the soils in Sri Lanka where shifting cultivation is common, as it can only be tilled when the soil moisture is near field capacity. Therefore the answer is to keep the surface soil tilth at a level close to that of a forest-covered soil. For this to be possible it is necessary to insulate the soil from hot sun and heavy rain, and to furnish the required amount of substrate for soil faunal activity. Weeds also determine the ease of land and seedbed preparation, and have to be managed.

With regard to the question of nutrient depletion, fertilizer application is not the complete solution. Recycling of nutrients and improving nutrient use efficiency should take priority and fertilizer application has to be resorted to when it is unavoidable, as in the case of P.

The alternative system that is proposed aims at replacing the forest fallow of shifting cultivation by a tree stand maintained in the cropland whose canopy is manipulated to permit cropping whenever necessary.

MATERIALS AND METHODS

The upper slope of a soil catena in the dry zone was selected. The soil was classified as a Rhodustalf, and was located at the Agricultural Research Station at Maha Iluppallama. The site was under *Brachiaria brizantha*, a forage grass which may have been planted after 1968. The grass growth was lush and showed no nutrient deficiency. It had not been used for grazing. Before 1968 had been sparsely used for various upland crops. The land had been cleared about 60 years ago.

In the experiment, alley cropping was compared to bare cropping with several treatments. For alley cropping *Gliricidia maculata* was selected, and planted in 1976 at a distance of 5 x 5 m. Grass was cleared around the planting holes. In 1980, when the first part of the experiment discussed here started, the tree density was increased to 1 x 5 m and the trial was carried out in 4 replications with the following treatments (N,P and K fertilizers in rates of 60 kg/ha each):

Year	Alley	Bare
1980/81	No fert, NPK, PK	No fert.
1981/82	No fert, NPK, NP, PK, N	No fert, NPK, N, NP.
1982/83	No fert, NPK, NK, NP, PK	No fert, NPK, NK, NP, PK.

The field was weeded from Brachiaria brizantha before the rains. The maize was planted after the first rains at a spacing of 62.5 x 30 cm, in rows parallel to the alleys.

About 10 days after germination of the maize, the trees were pruned at a height of 2 m, and the loppings were applied as mulch to the soil surface. The basal fertilizer application was added at the same time, and a topdressing was applied 45 days after planting. The trees were pruned regularly until the maize cobs had reached physiological maturity. Only the maize cobs were harvested, the crop residues were left in the field. Prior to the rainy season in april 1981, sesame was sown as a cover crop.

In 1983, the experimental design was changed, after it was realized that only nitrogen was the limiting nutrient. From 1983 onwards, the experiment no longer focussed on the different types of nutrient supply (NPK), but on different nitrogen levels of 0, 30, 60, 100 and 150 kg N/ha. The fertilizer was applied in two splits, 10 days and 45 days after seedling emergence.

In 1984 the effect of trees on weed density and flora was monitored in order to assess the effect of post planting weeding on crop yield at different levels of nitrogen fertilizer both with and without trees.

In 1985 the tree stand along the row was thinned to a spacing of 2 m in order to approach the plant densities in a forest-situation.

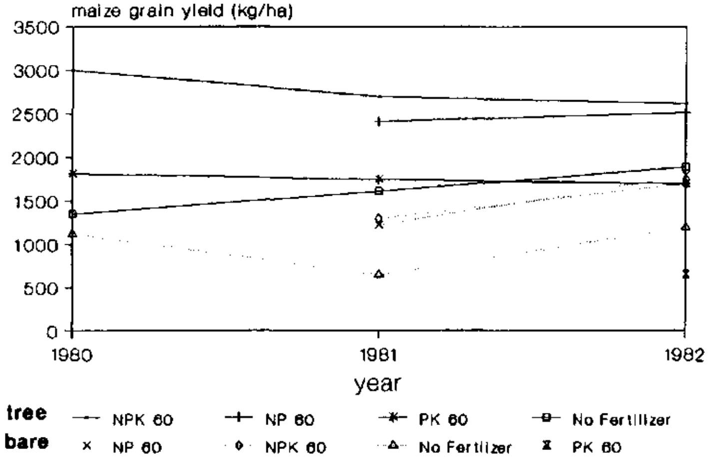

FIGURE 1. Response of maize to fertilizer with and without trees.

RESULTS AND DISCUSSION

In the first year of experimentation little effect of trees was observed due to the limited amount of loppings added (600 kg/ha). Response to N was high as compared to PK, demonstrating the inability of the grass fallow to supply adequate nitrogen, while P and K appeared to be sufficiently available either in the soil or in the grass residue (figure 1). In the year 2 all the tree treatments gave a higher response, possibly due to the higher amount of loppings added (2972 kg/ha).

The results of the third year confirm the observations made in year 2 for the bare plots, there being a response only to N. The tree plots too showed response only to N. It is assumed that by this time the trees had grown adequately with more ramified root systems to explore deeper subsoil for P and K. The composition of Gliricidia leaves, reported in a separate study, was found to be 4.15% N, 0.27% P and 1.30% K (Nagarajah and Amarasiri 1977).

Over the 3 years the yield gap between plots with and without trees at zero N widened demonstrating the beneficial effect of the trees. Yield decline in the bare plot at zero N in year 2 was attributed to a two-week drought experienced in November.

In the fourth experimental year, results (figure 2) showed that the yield difference between plots with and without N had widened, and that the tree plots yielded more than twice that of the bare plots. At higher levels of nitrogen, the effect of trees was insignificant. The rainfall during this season was well distributed, so that the moisture stabilizing role played by the simulated forest system was not put into effect.

In year 5, a year with heavy rains, the tree plots maintained as in the previous year, while the bare plots showed a drastic yield reduction. In year 6 however the bare plots at high N levels recovered as compared to year 5, although yields at zero N remained low. Rainfall was normal and the crop perhaps was able to benefit from added N, in comparison to year 5.

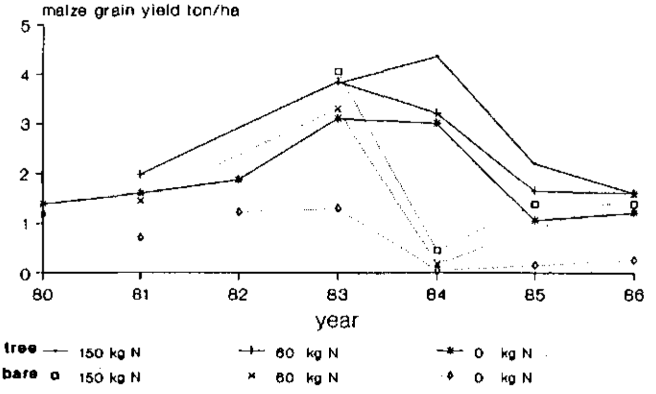

FIGURE 2. Response of maize to nitrogen with and without trees.

All the tree plots registered a decline after year 5. It is doubtful whether thinning of the tree population to 50% was responsible for this decline. Results of year 7 give the probable clue to the yield decline in the tree plots: it may be that the P reserve in the soil in the tree plots got depleted over the years, as analysis of grain and straw P show lower percentages of P in grain in tree plots in comparison to bare plots because of the higher grain yield in tree plots obtained over four years without application of P fertilizer. Unlike K, P is largely removed via grain. In fact grain P levels of 0.19% and 0.23% for tree plots at 60 and 150 kg/ha applied N respectively are indicative of P deficient Alfisols (Morris, 1987). Even in the bare plots a drop in grain P levels at high levels of N also indicates low soil P levels (table 1).

Despite the depletion of soil P reserves at zero N it is remarkable that the tree plots continued to yield more than 1000 kg/ha of grain, far above the corresponding bare plot yields.

TABLE 1. Phosphorus uptake and phosphorus percentage in whole maize plant and grain at three N levels on weeded plots in 1986/87.

Treatment		P uptake kg/ha	Percent P in whole plant	Percent P in grain
Without trees	0 N	2.5	0.25	0.38
	60 N	5.0	0.17	0.27
	150 N	3.9	0.14	0.26
With trees	0 N	4.4	0.12	0.27
	60 N	4.1	0.10	0.19
	150 N	4.5	0.10	0.23

Yield data of tree plots and bare plots at different levels of N with and without weeding, presented in figure 3A+B, show that weeding after planting is more important in the bare plots than in tree plots. The proportion of grassy weeds to dicotylidenous weeds is shown in table 2 where it is clear that the simulated forest system has a profound effect on weed composition and density.

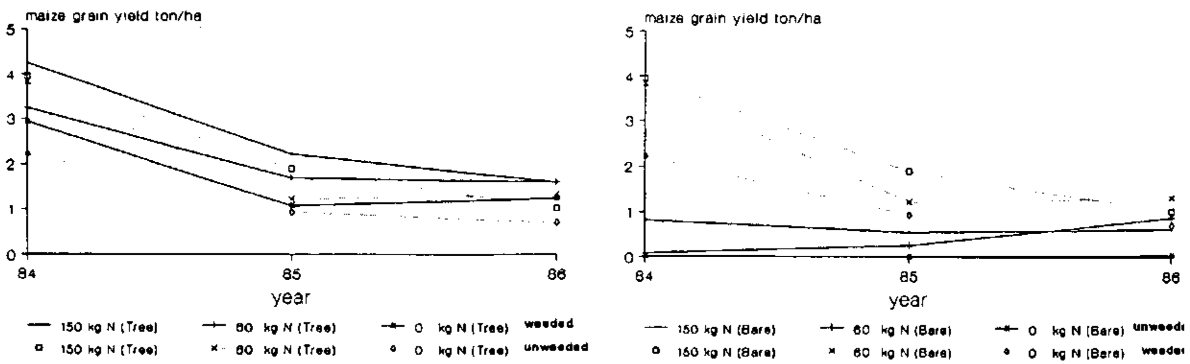

FIGURE 3 A+B. Effect of post plant weeding on maize at three levels of nitrogen with and without trees.

TABLE 2. Effect of trees and weeding on weed flora and density.

Weeding treatment and year	Weed dry matter kg/ha			Dominant species
	Dicotyl.	Monocotyl.	Total	
	Tree plots			
Before planting				
1985/86	894	166	1060	Euphorbia heterophylla
1986/87	1199	489	1688	Euphorbia hirta, Ageratam conizoides.
Before and after pl.				
1985/86	117	111	228	Celosia argonton
1986/87	292	197	439	Tridax procumbens Melochia corchorifolia
	Bare plots			
Before planting				
1985/86	251	1755	2006	Cynodon dactylon
1986/87	299	1578	1807	Cyperus rotundus
Before and after pl.				
1985/86	42	588	630	Cynodon dactylon
1986/87	14	860	874	Cyperus rotundus

CONCLUSION

Results of field experiments conducted over a period of seven years show that simulated forest conditions achieved by maintaining a tree stand of Gliricidia maculata in an upland field may improve upland rainfed agriculture in terms of :

(1) improvement of surface soil physical conditions through which the crop is protected from moisture deficiencies as well as from surplusses,
(2) enabling early land preparation by improving surface soil tilth, reducing perennial grassy weeds and providing shelter to labour,
(3) making manual weeding after planting possible and reducing the effect of weeds on crop yield and
(4) contributing to crop yield by supplying nitrogen and perhaps potassium to the accompanying crop if soil phosphorus is not limiting.

ACKNOWLEDGEMENTS

Mr. Ray Wijewardane is gratefully acknowledged for winning the support of the research administration of the Department of Agriculture for this experiment. Dr. R.A. Morris is thanked for his interest in this experiment and for interpretting the yield decline in the last two years. His contribution was most valuable as it came at a time when I was away from Maha Iluppallama. Dedication shown by Mr. P.T. Bandara to this investigation enabled the continuation of this work despite my absence from Maha Iluppallama for many years. Mr. L.A. Amorasingha obliged to conduct the weed studies. I owe much to them for their valuable contributions.

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SHIFTING CULTIVATION - SOME SOIL MANAGEMENT ASPECTS FOR ITS IMPROVEMENT

Key words: Shifting cultivation nutrient management low input technology

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SUMMARY

Shifting cultivation, a land management system of great importance for world agriculture, has attracted much attention in the past. An area of 400 million ha of tropical land is estimated to be occupied by shifting cultivation and related systems of agriculture. Highest percentages of forest fallow areas are found in West Africa and in continental Southeast Asia, where forests are decreasing by about 1.25% annually to live from shifting cultivation (HAUCK, 1974). Since then their number has certainly increased.

Shifting cultivation is based on long fallow periods after the site has been cropped three or more seasons. In a number of countries, this fallow period which should have restored soil fertility has decreased to lengths which no longer meet this objective. A decline in the sustainability of this farming system is obvious as nutrients become depleted, physical properties deteriorate and weeds and pests become persistent.

In order to develop strategies for improvement or replacement of shifting cultivation, research on two related issues of soil management namely, burning the slashed vegetation and the length as well as management of the fallows after cropping, are most important. Crop yields can be maintained at reasonable levels through judicious soil management practices.

Recent research results on the effects of burning and fallow periods on soil productivity maintenance are reviewed in this paper.

Influence of burning on soil properties

The effect of burning on nutrient release under shifting cultivation system has received much attention recently. Burning could be controlled and the quality of the burn influences the amount of nutrients released. Depending on the dryness of the biomass, the weather and the amount of biomass, burning could be described as complete or incomplete.

Temperatures are relatively low if the biomass burnt is small and not completely dried. Low to medium burn temperatures, with ranges from 150 to 300 OC at the soil surface result in incomplete burn with some of the woody parts of the slash still intact. Below the soil surface, temperatures decrease nearly exponentially with increasing depth (ANDRIESSE, 1987). Consequent leaching of small organic particles and ash into the soil may lead to increasing values of C, N, P, organic matter and of CEC (ANDRIESSE, 1987; LAL and CUMMINGS, 1979). These changes result in increased soil fertility and improved growth conditions for crops.

Oxidation of carbon begins at a temperature of 150 °C (ANDRIESSE and KOOPMANS, 1984), consequently soil organic matter (SOM) is affected by these incomplete burns. SOM content in the top few centimeters decreases but addition from leaching of burned organic material may mask this process. As a result of these processes the carbon content of the soil and the CEC may be even higher than before the burn. This has a particularly positive effect on tropical lowland acid soils with a low CEC.

The content of plant-available phosphorus increases slightly after burning as a result of the partial destruction of SOM (ANDRIESE, 1987; SERTSU and SANCHEZ, 1978). However, P contribution from an incomplete burn is expected to be small. The influence of burning of slashed vegetation on nitrogen content of the soil due to volatization have an important effect on soil nutrient supply. ANDRIESSE (1987) and other workers reported that with medium burn temperatures (300 to 400 ^oC), the total N content of the top 2 cm of the soil decreased by 20-25% but that the ammonium content increased with low temperaratures of 200 to 250 0C (KITUR and FRYE, 1983; SERTSU and SANCHEZ, 1978). If the mass of nitrifying bacteria in the soil is reduced after burn, the plant available NH_4 might be the main N source supporting young plants after germination. Most of the N from plant residues is volatilized, in addition to the relatively small loss from SOM. Critics of shifting cultivation argue that the loss of a high percentage of nitrogen from the slashed vegetation by volatization is not acceptable. However, if the same amount of biomass would be used to improve soil properties through green manuring or mulching, not all of the N present in the vegetation would be readily available for immediate plant growth either. Leucaena leaves used as mulch, for example, may have an N efficiency of about 33% (GUEVARA, 1975). Furthermore, the combination of nitrification and leaching may lead to low availability of nitrogen from biomass.

As a result of fixing by oxalates, exchangeable Ca and Mg contents decrease at temperatures between 150 and 250 ^oC (ANDRIESSE and KOOPMANS, 1984). This might result in a drop of the soil pH value. But ash addition counteracts this decrease and the net result usually is a pH increase of 0.5 to 1 unit (ANDRIESSE and KOOPMANS, 1984; KANG and SAJJAPONGSE, 1980; KITUR and FRYE, 1983; SERTSU and SANCHEZ, 1978). Such pH changes might be beneficial in acid tropical soils.

In contrast to the management of an incomplete burn, large amounts of dried biomass piled up would completely burn with high temperatures up to 700 ^oC at the soil surface (ANDRIESSE, 1987). These high temperatures may be detrimental to soil fertility. Temperatures between 400 to 600 ^oC already cause a nearly total depletion of organic carbon and topsoil organic matter. Consequently the cation exchange capacity (CEC) will be decreased in the top few centimeters of the soil surface and nutrients will be leached from the ash to deeper soil layers under heavy rainfall conditions.

Carbon and organic phosphorus contents in top soils will be lowered by high temperatures (ANDRIESSE, 1987). About 80% of the total N contained in the litter and upper 2 cm mineral soil are reported lost at these burn temperatures (DE BANO, EBERLEIN and DUNN, 1979). Ammonium contents decrease as oxide and carbonate formation is enhanced (SERTSU and SANCHEZ, 1978). Consequently, plants may be restricted in their N uptake.

On the other hand, heat of burning may also have a positive effect on the N cycle. Nitrifying bacteria responsible for NO_3 formation are partially inhibited in converting ammonium to nitrates (DUNN, DE BANO and EBERLEIN, 1979). The availability of phosphorus and potassium is correlated with increase of temperature and also with the destruction of soil organic matter (ANDRIESSE, 1987; SERTSU and SANCHEZ, 1978). The following crops therefore may benefit from increase in these nutrients as a result of heating.

Local ash accumulations under piled wood may increase pH values to above 10 and hinder or inhibit crop seed germination (ANDRIESSE, 1987). However, pH changes under shifting cultivation are not always caused by ash. KANG and SAJJAPONGSE (1980) obtained an increase in pH value by heating a sample of soil (Paleustalf) to 600 °C. SERTSU and SANCHEZ (1978) reported on the contrary a decrease in pH value of Paleudult heated to 600 °C under laboratory conditions compared to values at 400 °C. It is likely that by heating the Paleustalf, silt and clay fractions decreased with an increase in sand fraction causing release of cations. On the other hand with the Paleudult, exchangeable Al might have been released causing a decrease in pH.

In Ferrasols and Acrisols Fe-oxides and Al toxicity might restrict cropping. The heating effect leads to formation of organic Fe-complexes which permit the extraction of Fe-oxides and the precipitation of aluminium after fixation in insoluble organic forms (ANDRIESSE and KOOPMANS, 1984). Crops with low tolerance to Al toxicity can then be grown for a few seasons.

Research data so far obtained from experiments on incomplete and complete burning indicate that low to medium burn temperatures are more beneficial for nutrient recycling. Soil properties such as available nutrients, soil organic matter content and CEC are improved while there are negative effects at higher temperatures. In situations when the farmer has to get rid of large amounts of biomass after clearing, the drying period of the slashed vegetation should be kept short. The fire will then burn at a lower intensity and at lower temperatures.

The effects of fallow.

Lengths of fallow period varies widely depending on land availability and population pressure on land. The basic objectives of fallowing appear to be:

(1) nutrients accumulation in the standing vegetation. These are made available to crops after slashing and burning in the following cropping phase,
(2) smother weeds by natural succession,
(3) restoration of soil organic matter content to adequate levels before the next cropping cycle and,
(4) improvement in the physical soil properties.

The length of fallow period necessary to achieve any or all these objectives depends on the soil and the type of vegetation. Accumulation of adequate nutrients in the standing vegetation needed for the cropping period after land clearing generally takes 8 to 15 years, but may be shortened by planting selected species. Restoration of soil organic matter, improvement of physical soil properties through litterfall, decomposition, root development and soil fauna activities, respectively, may require an equally long period. AWETO (1981) working in Nigeria found that a fallow period of 10 years was needed to build up 78% of the soil organic matter level of the manured forest. The required length of fallow period depends on site characteristics; the degree of soil depletion of nutrients, initial level of soil organic matter in the preceding cropping period; types of weeds and on the species composition of the succeeding vegetation. AHN (1979) reported that until the later thicket stage of woody species is reached a successful smothering of weeds by natural succession cannot be achieved.

Traditional farmers have been selecting suitable land for clearing using indicator plants in the standing vegetation (MARTEN and PATMA VITYAKON, 1986). This technique has been supported by recent research work. Component analysis of vegetation carried out by HALL and OKALI (1979), showed that there were detectable gradients in both structure and floristic composition which could be related to soil, topography and previous land use. These gradients can be used for the assessment of site conditions.

A comprehensive picture of fallow vegetation development after the end of the cropping period is very useful for the improvement of fallow species composition and for development or weed measured. Recent research results show that the distribution of successional species after a cut and burn disturbance can be predicted from the microhabitat distribution within the site (UHL et al., 1981). Plant density is low in the first months after cutting and burning. The first successional colonizers come from seeds which have survived in the soil, while the first grass colonizers come from seeds dispersed onto the site after the fire (UHL et al., 1981). Observations from the Amazon Basin (UHL et al. 1981) showed that density increased sharply after the fourth month because many of the initial colonizers began to set seed. AWETO (1981) showed that major structural and floristic changes take place in the first 10 years of fallow after cropping. Grasses, sedges and microphanerophytes which predominate immediately after cropping are mainly replaced by mesophanerophytes after 7 years. By the end of the 10th year life form composition of fallow vegetation is similar to that of mature forest. The change from grasses and sedges to broad leafed species in the 8th year may signify a great qualitative change in the contribution of the succession vegetation to soil fertility. Rooting depth increases and consequently the positive impact on soil physical properties. If these species can be planted before the 8th year of fallow, the required fallow length may be shortened. The litterfall from the broad leaves will have greater influence on the organic matter fraction and consequently on the effective cation exchange capacity (ECEC) particularly as the lignin proportion of the plant material increases.

Soil organic matter plays an important role in cation exchange capacity of Ferralsols and Acrisols which occupy about 56% of the humid tropical lowlands. Organic residues with a high lignin-nitrogen ration (L/N ratio) with long turn over periods, are most suited to increase or maintain the ECEC. PARTON et al. in their work pointed out that litterfall with low L/N ratio (short turnover period) may act as a nutrient store for plant growth as well as assist in building soil aggregates. These processes are important in planning managed fallows. An appropriate ratio should be maintained between woody and herbaceous plant species so as to increase both soil organic matter and plant nutrient levels.

About 60 to 95% of the nutrients are stored in the above ground biomass (FÓLSTER, 1986). Below ground biomass also contributes significantly to soil fertility. The estimated turnover of roots less than 2 mm in diameter in the upper 10 cm of a Venezuelan Oxisol is 25% per month. The annual fine root production is about 15,4 t/ha for this size and depth alone (SANFORD, 1985). This important contribution of root biomass to SOM is often neglected in discussing nutrient cycling in forests. HERRERA et al. (1984) working in the Amazon Basin showed that a thick root mat layer recycles nutrients from litterfall thereby preventing nutrient leaching. However such a thick mat is not found in every tropical forest. Where possible, it is desirable to leave trees and their root zones intact to promote nutrient recycling and prevent excessive nutrient leaching.

Nutrient recycling starts with litterfall. Especially important is nutrient rich leaf litterfall. Leaf litter accounted for nearly 70% of the mean annual litterfall in a regenerating Nigerian bush fallow of which about 2/3 fell in the dry season. Woody material was recorded to fall predominantly in the rainy season (SWIFT, RUSSEL-SMITH and PERFECT, 1981). EWEL (1976) estimated the amount of litter produced in a successional vegetation, reporting maximum litterfall of 10 t dry weight/h/year from a 14 year old stand in Guatemala. The litter accumulated on the soil surface would decompose, thus recycling nutrients. In the first 5 weeks after litterfall, the dry weight of residues might decrease by 40 to 50% because of decomposition. Thereafter the decomposition rate is not greatly affected by the age of the vegetation (EWEL, 1976).

Season influences the decomposition of litter. Observations from Nigeria showed that 400 g litter/m2 decomposed during the rainy season while values for the dry season were over 10 times as high (SWIFT, RUSSEL-SMITH and PERFECT, 1981). The net relative mineralisation rate after forest clearing in Nigeria followed the trend organic S > organic N > organic P (MUELLER-HARVEY, JUO and WILD, 1985). Although soil animals and microorganisms play a major role in decomposing organic materials, leaching by heavy rainfall be important. A mobile pool of N, P, and Mg accounting for about 20 to 40% of the total was leached within the first 2 weeks after litterfall in a bush fallow (ADEDEJI, 1986; SWIFT, RUSSEL-SMITH and PERFECT, 1981). Similar leaching losses might occur if mulch material is exposed to rainstorms. This should be taken into consideration when deciding on the application rate.

Improving shifting cultivation.

It is now generally recognized that there is an urgent need to improve shifting cultivation systems with the ultimate objective of replacing it by other sustainable land use systems if the resources base in the humid tropics is to be conserved and maintained productive to support the increasing population. The choice for a specific technology should depend on socio-economic, cultural and ecological conditions.

The development of an appropriate low input but sustainable land use system in the humid tropics should take into consideration a number of factors and basic principles. Farming systems design should be made with a holistic view and should be site specific. Recycling of organic residues appears essential for a low input system. This could be achieved through leguminous cover crops and crop residue management. Maximum use should be made of N_2-fixing microorganisms and advantages taken of mixed cropping systems. ADELHEIM and KOTSCHI (1986) and EWEL (1986) among others emphazised the need to adopt crops to site conditions as far as possible through breeding.

Some soil management techniques have been developed which partially meet the above mentioned principles. One of these is the no-tillage system which aims at growing crops with a minimum disturbance of the topsoil combined with effective weed control. Crop residue cover is used to reduce soil erosion and soil degradation (AKOBUNDU, 1983; EZUMAH, 1983).

Prerequisites for such a system are an adequate amount of crop residue mulch, minimal soil disturbance, favourable soil structure before the initiating of the cultivation phase and timely and adequate weed control using mostly herbicides (IITA, 1984). Some of these inputs are costly and very often not available in remote areas where shifting cultivation is practised. Many of the chemicals are also toxic to mammals and endanger farmers who apply them. In addition, there are a few perennial weeds that cannot be controlled by herbicides presently on sale in the market (AKOBUNDU, 1983).

Residue mulching.

Mulching with crop residues is one of the practices that shifting cultivators can adopt to improve soil fertility. In many instances, residue management for soil productivity maintenance is in conflict with provision of animal feed. It has the advantage to moderate maximum soil temperatures (AINA, 1981; HARRISON-MURRAY and LAL, 1979; HULUGALLE, LAL and OPARA-NADI, 1987; IITA, 1984; LAL, 1978; LAWSON and LAL, 1979; MAURYA and LAL, 1981; WADE and SANCHEZ, 1983). It has a positive effect on soil moisture content (SIMPSON and GUMPS, 1986; OPARA-NADI and LAL, 1987) improves soil physical characteristics (ADEOYE, 1986; NGATUNGA, LAL and URIYA, 1984) and soil chemical properties (HULUGALLE, LAL and OPARA-NADI, 1987). Its major disadvantage however, is the large amount of residue needed to be effective. Although attempts have been made to economize on mulching material through determination of critical mulching requirement periods for maize (AINA, 1981), the amount of crop residues needed is immense. At least 4 to 6t of mulch is needed per ha. Depending on the decomposition rates as mulch as 39% of rice straw applied at 6 t/ha decayed in 60 days (LAL, DE VLEESCHAUWER and NGANJE, 1980) and additional mulching may be necessary. Crop residues produced per unit land area are often insufficient for an adequate cover. Consequently, material would need to be taken from surrounding areas. This would involve the use of scarce labour force if suitable material is found at all. An alternative approach is the concept of live mulch farming in which crops are sown directly into the living mulch cover or into the mulch material which is provided after killing the cover plants (AKOBUNDU, 1982 and 1984; BANDY and SANCHEZ, 1981; HULUGALLE et al., 1986; MULONGOY and AKOBUNDU, 1985, WILSON, LAL and OKIGBO, 1982). The hazard of snakes and rodents are some of the drawbacks of the system.

Green manuring.

The concept of green manuring was developed to enable farmers to shorten the fallow period through growing of selected plant species high in nitrogen content and incorporation of these into the soil. It has worked in tropical highlands, as for example in Rwanda (PRINZ, 1986; ZEUNER, 1981). In the humid tropical lowlands, however, decomposition rates of incorporated organic material are too high to build up soil organic matter. This is especially true for sandy soils. LAL and KANG (1982) pointed out that from research results so far obtained it is now well established that green manures have a negligible effect on soil organic matter levels if continous cropping is followed. However, their effect on physical structure of soils and their contributions to soil biological life cannot be ignored.

Compost.

The application of compost for stabilizing organic matter content in soils for continous cropping cannot be recommended for similar reasons as given for the application of green manure. Composting of organic residues is a concept developed in the temperate zone to accelerate residue decomposition. In humid tropical lowlands high temperatures and moisture levels prevail. Decomposotion rates are therefore high. Production of adequate amounts of compost under this climatic condition requires large quantities of organic materials and high labour input. Furthermore, transportation is a major problem which makes compost application uneconomic in farm operations. This technique might find an application where household waste is composted and used on vegetables. The concept is widely used in maintaining soil fertility in the "home gardens" in Asia and in the "compound farming" system of the savanna areas in West-Africa.

Alley cropping.

Alley cropping has been developed in the past decade and has a great potential as a stable alternative system to shifting cultivation. The system enables the farmer to extend his cropping period using the same field without a rapid decline in soil fertility as in the case of shifting cultivation. Alley cropping is a farming method in which food crops are planted in alleys between rows of fast growing leguminous trees or shrubs. They are pruned to avoid excessive shading and competition with food crops in the alleys. Prunings are applied as mulch and N source for crops. During the first 6 months of growth, the amount of biologically fixed nitrogen with Leucaena leucocephala varies between 75 to 120 kg N/ha. This N-fixation might be limited by too frequent pruning (MULONGOY, 1986). The decomposition of leguminous tree prunings is very fast. WILSON et al. (1986) found that within the first 25 days of decomposition, prunings lose 50% of their leaf N. Although the amount fixed by Leucaena may be high, recent investigations show that crop utilization of N derived from prunings is usually low and that supplementary mineral N fertilizer is necessary for optimum food crop production (KANG, GRIMME and LAWSON, 1985). Nitrogen contribution to crops from prunings of Leucaena leucocephala, Gliricidia sepium, Cassia siamea, and Flemingia congesta is in the range of 38 to 78 kg N/ha, representing not more than 30% of the total N in the prunings (MULONGOY, 1986).
Application of prunings has the advantage that residual fertilization effects are observed on the succeeding crop READ et al., 1985). A major obstacle to the introduction of alley cropping in shifting cultivation systems is the amount of labour and the time if pruning is done manually. Requirements are increased by 50% over normal labour needs (NGAMBEKI, 1985). Further, labour peaks at pruning and weeding occur at the same time. This could be overcome if mulching with prunings would decrease weeding needs (TORRES, 1983). But as far as Leucaena is concerned, the leaves are to small to effectively suppress weeds. Also their decomposition is too fast. More research is needed to identify species that can fulfill these requirements. One of the unsolved problems is the removal of Leucaena alleys if farmers have to get rid of them. Pulling out of the plants is very difficult and destroys the favorable soil structure that has been built up (pers. comm. D.C. COUPER, IITA, 1986).

As in many African countries, the planting of trees is a sign of ownership over the land. Planting alleys might be impossible for a great number of farmers who rented only the land they crop (FRANCIS, 1987).

The number of tree species suitable for alley cropping that have been under investigation is still limited. A more intensive research programme is necessary to screen more species to overcome some of the present constraints such as soil acidity in establishing species that have been extensively worked on for example, Leucaena leucocephala.

Although much research has been conducted on Leucaena its use is excluded from more than half of all land of the humid tropical lowlands, because of the soil acidity.

The low input approach at Yurimaguas in Peru.

A low input technology developed by the North Carolina State University working in the Amazon Basin on Oxisols and Ultisols is aimed at obtaining about 80% of the maximum yield of acid tolerant crops (SANCHEZ and SALINAS, 1981). The main components of this technology are:

- selection of most appropriate land where a low input technology has a comparative advantage over high input technology, and
- the use of plant species which are more tolerant to major acid soil constraints as well as being adopted to climatic, insects and disease stress.

Techniques to develop and maintain a plant canopy over the soil are used and a deep root development is promoted. Phosphorus fertilizers are applied, while biological N fixation is taken advantage of in providing the crop's N requirement. The technology does not eliminate the use of mineral fertilizers for soil fertility maintenance.

A major obstacle for the introduction of this approach is the high cost of P fertilizers, particularly to farmers in remote areas as a result of high transport costs. A prerequisite to this approach is therefore a transition from a subsistence to a market economy with at least a fairly developed infrastructure such as transportation system.

Mixed farming systems.

The main objective of mixed farming system (integration of crops and animal production) is to have an additional income from the sale of animal and to take advantage of the manure production of the animals. Livestock manure is used extensively in the sub-humid and semi-arid zones of Africa. A successful system of manure exchange between cattle owners and crop farmers in Central Nigeria has been reported (POWELL, 1985). As the prospects of integrating crop and livestock production are greatest in areas of high rainfall, long growing periods and low population, it is the subhumid and humid zones in Africa which would most favor an integration (FAO, 1983). The high risk of trypanosomiasis in these areas in Africa, however, makes cattle husbandry very difficult and in some parts even impossible.

In the humid tropics of South America shifting cultivators, like farmers in the humid tropical lowlands in Africa, keep small ruminants, pigs and poultry. Amounts of manure produced are small and often not available. In cases where animals are kept in pens or kraals, the manure produced could be applied to cropping areas surrounding the homestead. Such practices will have a major impact on soil fertility as observed in "compound-farms" in the savanna areas of West Africa. Livestock owners will have the advantage of secured fodder supply from mixed farm enterprises. About one quarter of the foliage yield from alley cropping could be fed to goats and other small ruminants integrated into mixed cropping systems using a cut and carry away system (SUMBERG et al., 1986).

Agroforestry systems.

Basically there are two approaches in agroforestry: incorporating trees on farmland according to different tree/crop proportions, and integrating crop/animal components with monocultural stands of trees as in forests or plantations (NAIR and FERNANDES, 1984). A subsystem of agroforestry, where trees are integrated into the field is the Taungya system (RAINTREE, 1986). An improved form is used in forest villages in Thailand. Shifting cultivators are encouraged to grow long term perennial cash crops by widening the between-row spacing of commercial forest species. Also plots for permanent agricultural use are allocated for them (BOONKIRD, FERNANDES and NAIR, 1984). A conventional type of taungya is practiced in Ghana. Agroforestry practices and the production of charcoal create further interests for the shifting cultivators. Results so far have been less than satisfactory and the taungya system was temporary abandonend (BROOKAM-AMISSAH, 1985).

A more promising approach for smallholder development has been introduced in Rwanda in an agropastoral project. Erosion control measures and tree combinations were introduced on agricultural land. The trees provide firewood as well as reduce erosion. Additionally shortterm fallows are used to restore soil fertility (NAIR, 1986; NEUMANN, 1983; ZEUNER, 1981). The project site is in the tropical highlands with different climatic condition from the humid lowland tropics. Results obtained therefore may not be easily transferable to other areas in the humid lowlands. A major obstacle to the introduction of this agro-ecosystemm to small farmers is the high risk involved in the first year of establishment when they may not obtain full yield of crops cultivated. The increased labour demand to install the system might also be difficult to overcome.

The International Council for Research in Agroforestry (ICRAF) is currently assisting scientists in many countries to inventorize and identify traditional agroforestry practices. The results of this undertaking enable scientists to select traditional techniques suitable for transfer to other places of similar ecology. A few agroforestry practices reported deal with the intensive use of the homestead area by multistorey cropping and by use of multipurpose trees. Introduction of cash crops into the cropping pattern will create more cash income for shifting cultivators. This approach requires product marketing opportunities and transport facilities. Unfortunately it is questionable whether shifting cultivators will invest their scarce labour in trees which take a long time before production starts, and which may lead to complications in land tenure.

Outlook on future work.

The review shows advances made in recent years to assess the contribution of the two most important phases of shifting cultivation, burning and fallowing, in fertility maintenance of the system. Results on the influence of temperature on soil organic matter and nutrients as well as succession dynamics may help to develop amelioration techniques to bridge the gaps until new sustainable land management systems are developed.

Emphasis in future soil fertility work should be directed to research on rock phosphates efficiency under smallholders' conditions and techniques for their efficient application as phosphorus appears to be the most limiting nutrient, together with or followed by nitrogen in this soil fertility maintenance system.

Soil protective and N supplying techniques are essential to maintain sustainable yields. Alley cropping techniques should be extended to farmers on a wider scale. Research on screening of leguminous tree species with acid tolerance, low decomposition rates of leaves and large leaf sizes should be intensified. Weed control could be achieved and labour saved through application of prunings. In areas where population pressure on land is low and where availability of herbicides is adequate, farmers may become interested in using a no-tillage system. The practice of live mulch could be encouraged but the problem of rodents and snakes still needs to be solved before farmers are convinced to adopt it. More intensive work from plant breeding programmes on adaptation of plants to soil constraints, rather than eliminating these constraints should be carried out. This involves screening and breeding of stress resistant crops and the development of labour-saving weeding techniques. Application of herbicides presently available does not seem to be an alternative to hand weeding because of the high cost. Herbicides would probably be used once they are available in remote areas at low prices. But attention should be given to their toxicity to man and animals and to the residue problem.

The improvement of shifting cultivation and the change from shifting cultivation to improved systems of land use comprises more issues than just technical problems. Labour requirements and efficiency in the change over need to be given more emphasis than hitherto has been the case. Improved techniques have to fit into the socio-economic conditions of the farming family. Otherwise these techniques will not be accepted. Consequently, a more comprehensive approach for technology development and transfer is needed. An adaptive farming systems research approach could help to increase the acceptance of newly developed techniques (MERRIL SANDS, 1986 a and b). The approach has to be site specific and target group oriented and should be carried out in an integrated rural development project.

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