NITROGEN MANAGEMENT IN FARMING SYSTEMS IN HUMID AND SUBHUMID TROPICS.

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EDITORS' NOTE:

The published proceedings of this symposium were printed by photolithography. This means that there are some differences in layout, particularly in tables, figures and in type face. We regret for these disadvantages but believe that they are outweighed by the advantage of rapid publication.

We have corrected only obvious errors and have made no attempt to edit for content or style except in cases where the authors' first language was not English.

B.T. Kang
and
J. van der Heide

SCIENTIFIC PROGRAMME

Tuesday, 23 October

OPENING SESSION

Chairman- A.S.R. Juo (I.I.T.A.)
Rapporteur- J. van der Heide (I.B.)

Opening address	Bede N. Okigbo (I.I.T.A.).
Welcome address	K.W. Smilde (I.B.).
Key-note Paper: "Contribution of biologically fixed-N and fertilizer-N to foodcrop production."	D.J. Greenland (I.R.R.I.)

SESSION I: Dynamics of Soil Nitrogen.

Chairman- J.N. Ladd (CSIRO)
Rapporteur- A.T. Halm (Soil Research Institute, Ghana)

"Biological factors affecting Nitrogen accumulation and turnover in soils."	H.G. van Faassen and K.W. Smilde (I.B.).
"Inorganic nitrogen losses through leaching and denitrification in soils of the humid tropics."	H. Grimme (Buntehof) and A.S.R. Juo (I.I.T.A.).
"Modelling of transport, transformation and uptake of nitrogen in an Ultisol for high rainfall conditions."	P. de Willigen (I.B.).

Wednesday, 24 October.

SESSION II: Nitrogen cycling in different ecologies.

Chairman- N. Ahmed (University of the West Indies).
Rapporteur- R. Sylvester-Bradley (C.I.A.T.)

"Nitrogen status in the early succession of two forest types in East Kalimantan."	H. Riswan (BIOTROP).
"Nitrogen cycling in legume-cereal rotations."	J.N. Ladd and M. Amato (C.S.I.R.O.)

SESSION III: Nitrogen sources and crop responses.

Chairman- K.W. Smilde (I.B.).
Rapporteur- H. Riswan (BIOTROP).

"Contribution of biologically fixed nitrogen to foodcrop production in the West Indies."	N. Ahmed (Univ. West Indies).
"Contribution of biologically fixed nitrogen to foodcrop production in Brasil."	Avilio A. Franco (EMBRAPA).
"Nitrification and responses to rhizobium inoculation in a tropical savanna."	R. Sylvester-Bradley (C.I.A.T.).

Field tour Oyo State.

Thursday, 25 October.

"Effect of soil amendments in acid soils for increased efficiency of N-use."	Slamet Setijono (UNIBRAW) and Goeswono Soepardi (I.P.B.).
"Analysis of maize response to nitrogen and moisture stress in the humid climate of Surinam."	O. Boxman, D. Goense, B.J. Janssen, J.J. Neeteson, J.F. Wienk (Agric. University Wageningen).
"Leaching losses of nitrogen in yam-based crop mixtures under field lysimeter at Umudike, Nigeria.	B.O. Njoku, M.C. Igbekwe, A.C. Ohiri (N.R.C.R.I.).
"Effect of nitrogen sources and soil properties on crop yield in the savanna."	L.A. Nnadi(I.A.R.) and Y. Arora (A.B.U.).
"N and P responses and yield trends for continuous maize grown under conservation tillage."	A.F.E. Palmer (C.I.M.M.Y.T.).

SESSION IV: Nitrogen management in different farming systems.

Chairman- L.A. Nnadi (A.B.U.)
Rapporteur- S.K. Mughogho (I.I.T.A.).

"Nitrogen balance in some tropical farming systems."	J. Gigou, F. Ganry and J. Pichot (I.R.A.T.).
"Nitrogen management in alley-cropping systems."	B.T. Kang and B. Duguma (I.I.T.A.).
"Nitrogen uptake in live mulch systems."	K. Mulongoy and I.O. Akobundu. (I.I.T.A.).
"Nitrogen management in multiple cropping systems."	J. van der Heide (I.B.), A.C.B.M. van der Kruijs (I.I.T.A. B.T. Kang (I.I.T.A.) and P.L.G. Vlek (I.F.D.C.).
"Nitrogen management in cropping systems with particular references to rainfed lands in some arid regions of India."	R.P. Singh and S.K. Das (I.C.A.R.).

Friday, 26 October.

"Nitrogen management in rice-based cropping systems."	Vo Tong Xuan (C.T.U.).
"Systems approach to nitrogen management: F.A.O.'s experience."	R.N. Roy and H. Braun (F.A.O.).

Field tour I.I.T.A. Research Station, Ibadan.

CLOSING SESSION.

Chairman- D.J. Greenland (I.R.R.I.).
Rapporteur- J.N. Ladd (C.S.I.R.O.).

Chairmen's reports and recommendations.

OPENING ADDRESS

Bede N. Okigbo

Deputy Director General, IITA, Ibadan, Nigeria.

Mr. Chairman, participants, ladies and gentlemen, I take this opportunity on behalf of our Director General, Dr. E.H. Hartmans who would have very much wished to be here, but for unavoidable circumstances, to welcome you to this international symposium on Nitrogen Management in Farming Systems in the Tropics. This symposium is important and timely to IITA because we, other IARCS and national agricultural research institutes are giving highest priority to development of technologies for increasing agricultural production and especially food production. The current food crisis in Africa is of worldwide concern and almost all developing countries in the tropics are experiencing problems in raising agricultural productivity.

Until about three decades ago in the developed countries and less than a decade in most developing countries of the world increased food production has been achieved by increasing the area of land under cultivation. Soil fertility and productivity under these conditions are maintained through nutrient cycling and accumulation in vegetation and top soil during long fallow periods or by use of organic manures. But expansion of area under cultivation is getting more and more expensive, difficult and detrimental to environment. The increasing population and other pressures on the land has resulted in intensification of cultivation and drastic shortening of fallow periods resulting in increased erosion, soil degradation and decline in productivity. Nitrogen deficiency which was absent or rare on newly cleared land in tropical Africa is now more often being observed during the first year of cropping. It is therefore not surprising that increasing dependence on inorganic fertilizer has occurred in all parts of the world.

Currently, between 1969 and 1985 it is estimated that the developed countries of the world account for the bulk of production and consumption of nitrogen fertilizers amounting to about 44 million mt (69%) and 38 million mt (59%) respectively with annual growth rates averaging about 2% for both production and consumption. Developing countries on the other hand produce about 20 million mt and consume about 23 million mt with annual growth rates of about 5% and 3% respectively for production and consumption.

The rapidly increasing fertilizer production and consumption in the developing countries is due to the realization that fertilizer use is imperative in ensuring high yields and increased productivity on a sustained basis. In the tropics, nitrogen is the most important of the major nutrients required and is often the most limiting under continuous cultivation. But of all the nutrients nitrogen is the most energy consuming and consequently the most expensive especially since the energy crisis of the 1970's. It is also well known that most improved and high yielding cultivars require greater use of inputs such as fertilizers. Since, in both crop improvement and farming systems programs priority is given to the problems of increased production on small farmers with limited income, development of technologies that minimize fertilizer use and cost of inputs is called for.

As intensification of cultivation and increased use of improved varieties all require greater fertilizer use, then we have no choice but also to find ways of increasing efficiency of its use. This can be achieved through better soil, crop and water management. There are opportunities for intervention in management of nitrogen use not only because nitrogen is easily lost in many ways but of all the major nutrients nitrogen is the one most available from several sources - soil, inorganic fertilizers, organic manures, atmosphere and biological nitrogen fixation. Only about one-third of the nitrogen used by crops comes from the soil and this element undergoes several transformations that may take place in wetlands, uplands and soils exposed to alternate drying and wetting in certain farming systems under different environmental situations. Through improved management it is possible to manipulate the relative levels of losses as compared to gains in different transformations so as to ensure greater availability throughout the year in different situations.

IITA has made significant progress in contributing to increased availability of nitrogen to the crop and directly or indirectly to animals. In our various research programs, we have not only produced high yielding crop varieties in general but also developed cowpeas and soybeans varieties that nodulate effectively with native rhizobia without innoculation. Our research in mechanised land development and subsequent soil management under more continuous cropping has resulted in improved ecologically sound methods of land development, reduced tillage techniques, plant residue management, mulching and alley cropping soil/crop management systems. These practices have been shown to enhance biological nitrogen fixation, reduced nitrogen losses, reduced fertilizer nitrogen use, and ultimately increased yield to the farmer at reduced cost.

This symposium is therefore of immense value to our scientists in giving them the opportunity to exchange information on results and experiences from research on nitrogen management in farming systems which have been performed in different parts of the tropics. There will be exchange of data on nitrogen use, losses, problems and potentials in different production systems. I sincerely hope, that the symposium will culminate in identification of gaps in knowledge, prospects and problems in management techniques for nitrogen, design of more effective management systems and experiments and above all, collaborative research to find solutions to problems of mutual interest. All these will lead to more rapid progress in increasing food and agricultural production by farmers in the tropics.

I take this opportunity to express IITA's appreciation for the cooperation of the Institute of Soil Fertility (IB) in Haren, The Netherlands, in research and organization of this symposium and to the Netherlands Ministry of Development Assistance (DGIS) for continuing support in this and related IITA activities.

In addition, I also express appreciation to other organizations and individuals not mentioned above who have cooperated and are participating in this symposium.

Finally, I declare the symposium open, wish you successful deliberations and hope that our visitors will in this process take full advantage of our staff and facilities.

NITROGEN AND FOOD PRODUCTION IN THE TROPICS: CONTRIBUTIONS FROM FERTILIZER NITROGEN AND BIOLOGICAL NITROGEN FIXATION

Key Words: Nitrogen management Semi-arid Humid zone Wetlands.

D.J. Greenland The International Rice Research Institute, Los Banos, Philippines

SUMMARY

In farming systems of the semi-arid tropics responses to nitrogen fertilizers are frequently limited by water deficiencies. Where rains are concentrated over a short period fertilizer may be successfully and economically used. Grain legumes may contribute their own nitrogen. Cereal crops may receive some nitrogen accumulated in a previous fallow phase. Legume based pastures may contribute larger amounts of nitrogen to a succeeding arable crop, but for most of the semi-arid tropics satisfactory pasture legumes have still to be identified.

In the humid tropics nitrogen fertilizers normally produce significant yield increases, but other nutrients may also be needed, and soil acidity may need to be controlled. Grain legumes and green manures can also be successfully grown and contribute fixed nitrogen to the system. Nitrogen is also accumulated by BNF under forest fallows, and released to crops grown when the forest is cleared. Alley farming systems may be more productive and combine the advantages of the forest fallow system with much greater rates of BNF, and more intensive land use. Live and other mulches can also lead to increased BNF. Grass pastures may lead to accumulation of nitrogen, but the rates of associated nitrogen fixation are significantly less than under legumes.

In the wetlands, rice cultivation is normally accompanied by substantial nitrogen fixation. Although use of nitrogen fertilizers normally leads to greater yields of rice, BNF is sufficient to maintain stable yields at a moderate level over many years. Nitrogen can also be supplied to the crop from BNF associated with Azolla, BGA inoculation, and green manures or grain legumes grow in succession to rice.

Methods of integrated nitrogen management need to be developed whereby nitrogen fertilizers can be used to supplement and not reduce BNF contributions to the crops grown. Proper nitrogen management allowing maximum advantage to be taken of BNF can reduce the need for mineral nitrogen fertilizers substantially.

INTRODUCTION

Nitrogen is the key to soil fertility, and to continuing and increasing food production. Although other elements are of course essential for plant nutrition, it is nitrogen which most frequently determines the level of crop yields. Also, because nitrogen is an essential component of soil organic matter, maintenance of an adequate soil nitrogen level is synonymous with maintenance of an adequate level of humus, which in turn determines many other factors related to soil fertility.

Soil nitrogen levels are maintained by the natural processes of biological nitrogen fixation, and by additions of mineral fertilizers and organic manures. In this paper contributions from fertilizers, manures, and biological nitrogen fixation will be discussed, in different major food crop production systems of the tropics. An assessment will be made of the extent to which these contributions are adequate to meet present and future crop requirements, and to maintain or enchance soil nitrogen levels.

Food crop production systems of the tropics

Rather than attempt a global assessment of the contributions of fertilizers and biological nitrogen fixation to food production, which involves many uncertainties (see, for example, Soderlund and Svensson, 1976) nitrogen inputs from fertilizer use and biological nitrogen fixation in major food crop production systems used in different parts of the tropics will be discussed. Upland or dryland production systems will be considered for the semi-arid, and the humid tropics, and then the wetland production system.

The upland food crop production systems range from shifting cultivation (natural fallow rotation systems) to continuous intensive systems with substantial inputs of fertilizers. Robertson and Rosswall (1984) have attempted a detailed model for the nitrogen cycle in West Africa south of the Sahara, and rightly argue that the different ecological regions of West Africa provide a suitable basis for wider considerations of the nitrogen cycle in the developing countries of the tropics. Their model provides a valuable background for the discussions in the present paper, with additional reference to semi-arid regions of south Asia, which are climatically similar but much more densely populated, the acid savannas of Latin America which do not have a parallel in West Africa, and most importantly the wetlands of south and southeast Asia. The vast areas of wetlands in tropical Africa were recently estimated to cover more than 200 million hectares (IRRI, 1985). This figure may be compared with the 140 million hectares of wetlands presently used worldwide for rice production (IRRI, 1982). Thus, although not all of the African wetlands are suitable for development, they do represent a major underexploited reserve for food production.

Much of the semi-arid region of West Africa is used for shifting cultivation with infrequent periods of crop production. The soils are mostly of low inherent fertility. In the drier parts bordering the southern Sahara low availability of nitrogen and phosphorus often limits productivity (Jones and Wild, 1975; Penning de Vries and Djiteye, 1982). If nutrients are supplied as fertilizers or manures, water becomes limiting. The complex interaction of water and nutrients in controlling crop production in semi-arid areas in Africa and elsewhere largely determines the success or failure of any agricultural system. Nitrogen and other nutrients accumulate slowly in the soil under the savanna vegetation as a result of biological nitrogen fixation, but may be of little benefit to crops produced when the vegetation is cleared if the cropping period coincides with a period of drought.

Fertilizer responses

Responses to fertilizers may be limited by periodic lack of water, especially in the more arid regions with shallow soils of poor water retention. The classical illustration of this is provided by work in the semi-arid regions of Australia (Fig. 1).

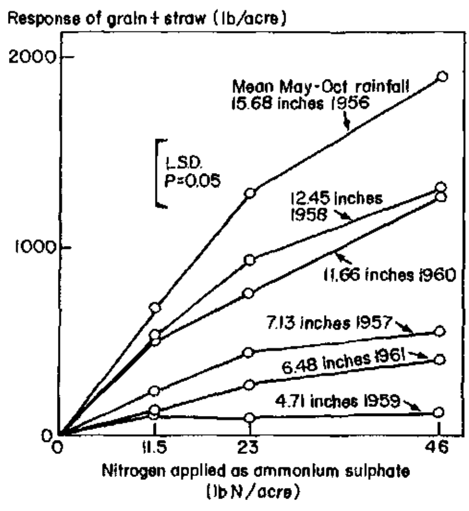

Fig. 1. Mean yearly response of grain + straw of wheat at four locations during the seasons 1956 - '61 (Russell, 1967).

Wheat shows progressively smaller responses to nitrogen as rainfall decreases. The frequency of drought has meant that nitrogen fertilizers are not generally used on wheat in Australia. In India similar areas have had to be cultivated more or less continuously, because of the high population densities. Mostly yields have been low or very low, lack of water limiting both yields and response to fertilizers. Traditionally, nitrogen fertilizers have been little used although the almost complete absence of use of nitrogen for cereals such as sorghum and millet may be a more conservative policy than is warranted (Kampen and Burford, 1980). Recent work has shown that careful soil management to conserve water, combined with appropriate fertilization and crop varieties, can give much better yields, at least on heavier soils (Table 1, from Chowdhury, 1979; Kanwar, 1982).

Table 1. Yields on farmers' fields under dry farming conditions in the Indian semi-arid tropics -- traditional v. improved technology with N fertilizers. (Choudhury, 1979).

	Traditional practice (Tons/ha)	Improved practice	Ratio
Barley	1.28	2.93	2.3
Maize	1.22	2.80	2.3
Sorghum	0.52	2.52	4.8
Wheat	0.84	2.41	2.8
Pulses	0.55	1.77	3.2

The great increase in the use of nitrogen fertilizers in India has been recorded in the irrigated areas, and predominantly for rice and wheat production.

In the semi-arid areas of south Asia and Africa much careful study will be needed of water availability to crops, as determined by climate and soil, to ascertain where nitrogen fertilizer use will give consistent responses.

Grain legumes

Grain legumes are often included within the cropping sequences used in semi- arid regions. They may fix their own nitrogen (50 to 100 kg N/ha). and if well supplied with nutrients and adequately supplied with water provide nitrogen equivalent to 20 to 50 kg of inorganic fertilizer nitrogen to a subsequent crop (App et al, 1980). At the present time most grain legumes grown in the tropics receive inadequate nutrients, particularly phosphorus, and are often prone to drought, so that the amounts of nitrogen fixed and contributed to a subsequent crop are significantly less than the potential. Work on cowpea and soybean improvement at IITA, groundnut improvement at ICRSAT, and on other legumes at other international centers and in national breeding programs has demonstrated that both varietal improvement and better management can do much to help realize the nitrogen fixation potential which exists. How much further improvement may come from inoculation with more effective rhizobia has still to be established.

Pasture legumes to supply N to food crops

The uncertain economics of nitrogen fertilizer use on wheat in Australia has led to the widespread system of pasture-wheat rotations. Nitrogen is accumulated under legume based pastures, and utilized for a cereal crop after two or four years (Greenland, 1971). The accumulation of nitrogen is directly dependent on phosphorus applied to the pasture (Donald and Williams, 1955) because the legumes will only grow well and fix nitrogen actively when adequate phospherus is present. About 10 kg of N may be fixed per kg of P applied. The system is economic because of the low cost of the nitrogen addition, particularly if the pastures are well managed and support livestock production effectively.

A legume-based pasture and livestock management system for African savanna regions, combined with periodic cereal production as has been advocated for many years (e.g. Nye and Greenland, 1960; Jones and Wild, 1975; Sprague, 1975; Boudet, 1975). Research directed to the development of such a stable, productive system for the semi-arid tropics of Africa should be given high priority. At the present time however there appear to be few forage legumes adapted to these areas of long dry season and high temperatures. The International Livestock Centre for Africa (ILCA) has recently formed a Forage Legume Agronomy Group, seeking to evaluate and promote the introduction of more productive legumes into African livestock production systems of all types (ILCA, 1983).

Under natural pastures nitrogen accumulation is very slow (Robertson and Rosswall, 1984, estimate 12 kg/ha/an.), and much is lost by burning. This may be compared with estimates of 45-60 kg/ha for legume based pastures in Australia (Greenland, 1971).

THE HUMID ZONE

The Guinea Savanna area of West Africa lies at the border with the semi-arid zone, and enjoys greater rainfall than the Sahelian or Sudan savanna. In the northern part of the zone the rainfall is often concentrated over a few months. When combined with deep soils which store substantial quantities of available water, much more vigorous natural grasslands are supported. Often they are associated with more fertile soils with higher nitrogen contents.

The Guinea Savanna merges into the derived savanna, which is followed by the drier forest, and moist, humid and perhumid forest zones, as the rainfall and number of wet months continue to increase. Once precipitation exceeds evapotranspiration significantly, at about 1500 mm. rainfall per annum, the soils start to become increasingly acid and depleted of nutrients. There is a transition in the dominant soils, from Alfisols to Ultisols (Greenland, 1981b). In the Amazon Basin the nutrient depletion is more extreme, and in spite of the high rainfall, savanna type vegetation appears to be the true climax, and covers large areas of Oxisols under rainfalls of 2,500 mm and more (Sanchez ans Salinas, 1981). These soil differences of course influence fertilizer efficiency and biological nitrogen fixation.

Fertilizer responses

In these more humid forest areas, responses are normally obtained from nitrogen fertilizers, as they are in the wet savannas of the Caribbean and Latin America (De Geus, 1977; Toledo and Sero, 1982). The economics of nitrogen use depends on the availability of inputs, and of markets for produce. It must also be recognized that, as Juo and Kang and their colleagues have shown in eastern Nigeria (IITA Ann. Reports, 1979-82) and as Sanchez and his colleagues have shown in the acid savannas of Brazil and Peru (Sanchez and Salinas, 1981; Nicholaides et al., 1983) properly balanced fertilization is necessary to maintain yields. Furthermore, use of nitrogen fertilizers on upland soils inevitably leads to acidification, due to the nitrification process, or the leaching of cations in association with nitrate (Jones and Wild, 1975). Correction of the acidity is then essential to maintain yields.

The rate at which acidification develops depends on the source of nitrogen. It is most rapid with ammonium salts, slower with urea, and very slow if nitrates are used. It is also slow when the nitrogen addition is due to biological nitrogen fixation, but it is important to recognize that it also inevitably occurs with nitrogen mineralization, whether the nitrogen comes as inorganic fertilizer, or as an organic form of nitrogen associated with biological processes. This has been well demonstrated by recent work in Australia where soil acidity in the pasture-wheat rotation areas has become a problem (Williams, 1980).

In spite of some uncertainties about the efficiency of nitrogen fertilizer recovery in the very acid soils of the superhumid areas, the work at IITA's Onne station by Juo, Kang and others, and in Latin America by Sanchez and others, has shown clearly that these uncertainties can be forgotten. Although recovery may be below 50 percent, that figure is quite typical of nitrogen recovery by arable crops, even in temperate areas. If acidity is not corrected, little response may be obtained. Liming to correct aluminium toxicity has been widely recommended and used (e.g. Juo and Uzu, 1977; Friessen et al., 1980). This requires annual applications of as little as 0.5 tons of lime per hectare. However, marganese toxicity may persist to rather higher pH levels, and if legumes are to be grown successfully it may be necessary to lime slightly more heavily (Van Raij, personal communication).

There is a very large volume of evidence now available to show that use of nitrogen fertilizers is the most effective way to produce high yields, and when complemented by appropriate weed control and other nutrients can be effective in maintaining yields (Figure 2). It is still not clearly established whether a suitable crop rotation, adequately fertilized, will maintain high yields indefinitely, whether under zero tillage or other cropping systems (Greenland and Okigbo, 1982). If erosion is controlled and sufficient organic matter returned in crop residues, and as mulch from associated tree crops as in alley farming systems, it is probable that it does. In these high rainfall areas continued cropping with nitrogen added as ammonium salts leads to very rapid acidification. With urea or legumes acidification will be slower, but again inevitably occurs, and will need to be corrected.

Nitrogen fixation in moister savanna grasslands

There has been much debate about the extent to which nitrogen is fixed under savanna grasslands. Greenland and Nye (1959) estimated that under Andropogoneae grasslands the annual fixation might be 40 kg/ha/an, of which 25 kg might be lost in the annual burn. Robertson and Rosswall (1984) suggest an average annual nitrogen fixation of 30 kg/ha/an. The source of this nitrogen fixation under grasslands has been the subject of much speculation and more recently of much study (Dommergues et al., 1973; Day, 1975; Neyra and Dobereiner, 1977). At present there appears to be little immediate prospect of enhancing the quantity of nitrogen accumulated under grasses. Legumes planted as pasture components such as Centrosema sp. and Stylosanthes may contribute substantially larger amounts of fixed nitrogen to the ecosystem (100 kg/ha. and more have been reported), particularly when they are adequately supplied with phosphorus (Sprague, 1975; Jones, 1967). If the pastures can be effectively managed for livestock production, which is difficult in areas where the tsetse fly is prevalent, considerably greater benefits could be obtained from biological nitrogen fixation. Grass pastures, which provide open grazing for cattle, are successfully utilized in Brazil. The pastures are not regularly cultivated, although they require renovation after several years, and this may be best achieved by taking an arable crop or crops, prior to reseeding. Direct translation of the Brazilian systems to West Africa is still made difficult because of the trypanosomiasis problem in West Africa. In the Cerrados of Brazil, and the acid soil regimes of Colombia, Brachiaria, Panicum and Andropogon grasslands are quite extensively used for beef production, but legumes have proved difficult to maintain (CIAT, 1982).

Nitrogen fixation under trees

In the humid tropics there are few examples of unpland food crop production systems which involve regular cultivation. Tree crops of course are widely and successfully grown, and shifting cultivation practiced in which infrequent arable crop production is combined with periods of natural forest regeration. Tree crops combined with arable crops, either in indigenous systems such as oil palm-yam farming system of eastern Nigeria, or the "alley-farming" system studied at IITA (Kang et al., 1981), offer more productive alternatives.

The stability of the shifting cultivation system is dependent on the regeneration of soil conditions under the forest fallow. The early work of Bartholomew, et al. (1953) in Zaire, which showed a rapid accumulation of nitrogen and other nutrients in the regenerating forest vegetation, has recently been confirmed in a similar study in Colombia (De las Salas, 1978).

Table 2. Nitrogen accumulation in tropical forest vegetation.

Location	Approximate age (yrs)	Biomass (t/ha)	N content (kg/ha)	N accumulation rate (kg/ha/an)	Ref.
Yangambi, Zaire	5	86	389	78	1
	18	143	555	31	
Cerare, Colombia	5	68	357	71	2
	16	203	712	45	
Kade, Ghana	40	330	1,797	45	3
Marafunga, New Guinea	40	592	1,415	35	4

Ref. 1: Bartholomew et al.,1953
2: De Las Salas, 1978
3: Greenland and Kowal, 1960
4: Edwards, 1973.

Several studies on older forest vegetation (Table 2) show the extent of nutrient accumulation in tropical forests. The high levels of nitrogen in the soils supporting the forest show that the nitrogen accumulation in the vegetation is not at the expense of the soil, and indicate a high biological nitrogen fixation rate under the forest. Robertson and Rosswall (1984) estimate the annual gain in the ecosystem to be between 15 and 100 kg/ha/an.

Much of the nitrogen accumulated in the vegetation is lost when it is burnt prior to crop establishment, but the accumulation in the soil, at least partly arising from cycling between vegetation and soil during the forested period, will be mineralized to the advantage of a subsequent crop. Immediately following clearing the availability of nutrients in the soil may be adequate for one or two substantial crops, but the subsequent rapid decline in yields has been well documented. In the subhumid (Alfisol) areas use of nitrogen, phospherus and potassium may be adequate to maintain yields for several years (Figure 2a) but in the perhumid areas lime and trace elements are also likely to be necessary (Fig. 2b).

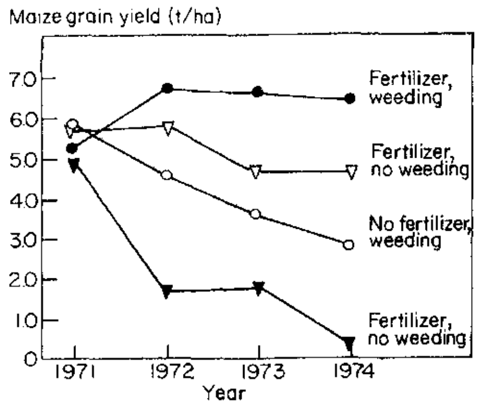

Fig. 2a. Maize yield changes in successive years after forest clearance at IITA, Ibadan, Nigeria, and the response to fertilizers and weeding (Kang et al., 1977).

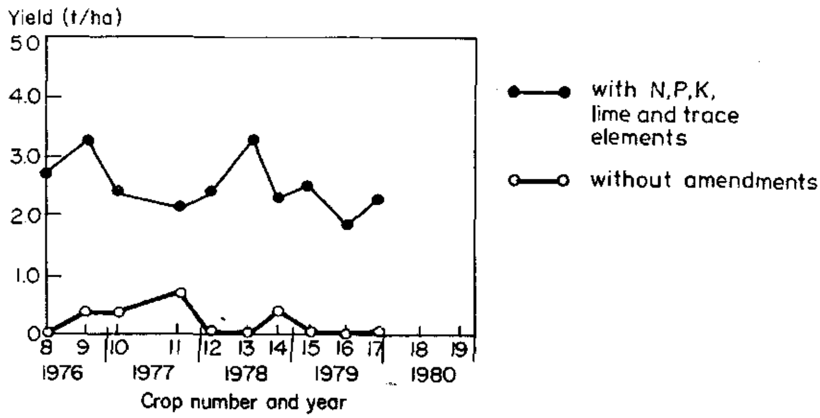

Fig. 2b. Yield of upland rice grown in rotation with groundnuts and soybeans, with N, P, K lime, and trace elements. (Technical report, 1980-81, Sp. Science Dept. North Carolina State Univ. and Inipa, Peru).

The great disadvantage of the natural rotation system in the forest areas is the largely non-productive use of land under the regenerating forest vegetation. Although the forest is a valuable source of many fruits and medicinal plants, as well as firewood and timber, it is much less productive than cultivated land. Many attempts have therefore been made to develop more intensive land use systems, and in many parts of the humid tropics the need for more continuously productive systems is becoming imperative because of developing population pressure.

The proposed "rationalization" of shifting cultivation in the "corridor system" described by Jurion and Henry (1967) was a first attempt in this direction, but lacked sensitivity in respect to ecological factors. It also required rigid control of land ownership, and did not provide any great advantage in terms of land use intensity. Nevertheless there are many advantages to be obtained by combining trees with arable cultivation, not least their ability to recycle basic cations from subsoil to surface and so minimize acidification of the surface soil (Greenland, 1975).

Deliberate planting and coppicing of selected tree species for improving soil fertility is an indigenous practice in eastern Nigeria. The species utilized include both non-legumes such as Acioca barterii and legumes (Okigbo and Greenland, 1976; Okigbo, 1983). The advantage of these species probably lies in their ability to root deeply in acid soils.

Tree legumes have been as yet little studied (Huxley, 1983). Leucaena leucocephala has received the most attention in recent years. It is best adapted to moderately acid soils (Brewbaker and Hutton, 1979) where it has the ability to accumulate up to 500-600 kg N/ha/an (Rachie, 1983). Scientists at IITA (1981-82) have shown that it can be very successfully utilized in "alley cropping" systems, and these have subsequently been studied in Latin America and Indonesia (Rachie, 1983).

The relatively few studies which have been completed demonstrate the potential of different combinations of trees with arable farming. Legumes have the great advantage of contributing large amounts of nitrogen to the ecosystem, and may be used as browse plants, and can provide timber, stakes and fuelwood, as other species can. The success which Leucaena leucocephala has already achieved implies that active efforts need to be made to extend the range of conditions in which it can be successfully grown, to seek alternative species for different conditions where it is not well adapted, and to obtain data from long-term experiments on problems of competition with food crops for nutrients and water, the interaction with pests and diseases of food crops, and optimum fertilizer and other management techniques. The tree crops are valuable not only to maintain the nitrogen and organic matter status to soil movement, and as a provider of surface mulch.

The mulch will help to maintain an organic matter supply for microorganisms, as well as minimize temperatures at the soil surface and reduce evaporation, thereby enhancing non-symbiotic nitrogen fixation. However, such evidence as is available suggests that the magnitude of biological nitrogen fixation from non-symbiotic sources in cultivated soils, even when mulched, is low.

Grain legumes

There is a substantial body of evidence now available to show that grain legumes grown as a sole or mixed crop in association with others may make a measurable contribution to the nitrogen economy (Agboola and Fayemi, 1971; Oelsligle, et al., 1976), although this is not always so (Henzell and Vallis, 1977). Comparative studies with and without the legume, and with and without nitrogen fertilizer, indicate that up to 50 kg N/ha may be contributed to the associated or succeeding non-legume crop. Thus the total fixation by the rhizobia, which also supply most of the nitrogen absorbed by the legume itself, an from which there are likely to be some simultaneous losses, may be two to three times this amount.

Green manures

There have been many studies of the potential of legume green manures for use in cropping systems of the humid tropics. *Pueraria* spp., *Crotolaria* spp. and *Centrosema* spp. amongst others have been frequently studied as green manures for arable crops. In general their use has not proved economic, although their contribution of nitrogen to a succeeding arable crop has often been found to be of the order fo 50 kg/ha or more (Sprague, 1975; Juo and Lal, 1977; App et al., 1980). The green manure crop often requires phosphorus if it is to contribute this much nitrogen (Ponnamperuma, 1984) some of which may be available to a succeeding crop. The amount of nitrogen will almost certainly need to be supplemented with inorganic fertilizer if the yield potential of a subsequent cereal crop is to attained -- a 5 ton/ha crop of maize requires at least 100 kg N, and so yields of this order or more will only be obtained if inorgic fertilizer is used, or if soil nitrogen reserves can supply considerable nitrogen.

Live mulches and legume fallows

Use of leguminous "live mulches" such as *Arachis repens*, *Desmodium triflorum* and *Indigofera spicata*, grown simultaneously with a cereal crop, may contribute similar amounts of nitrogen to the cereal as a preceding green manures (Akobundu and Okigbo, 1984). They are also effective weed suppressants, but may compete with the crop for nutrients, notably phosphorus, and water. Many studies of systems where arable production alternates with planted legume fallows have been made (Jones and Wild, 1975). This system has not been widely adopted because it has not usually been possible to utilize the legume fallow economically, and it then offers little advantage over natural bush vegetation.

THE WETLANDS

Rice farming in the wetlands of Asia has been the one system of continuous arable use of land in the humid tropics that has undoubtedly succeeded. It has been practiced for serveral thousand years (Chang, 1976). The success of the system, in contrast to arable cropping in the uplands, derives from the higher natural availability and replenishment of nutrients in the lowlands, combined with a lesser susceptibility to erosion, strengthened by the common practice of bunding and teracing to retain water on the land. Nutrient replenishment comes from inward moevement of water and silt, and a significant contribution from biological nitrogen fixation.

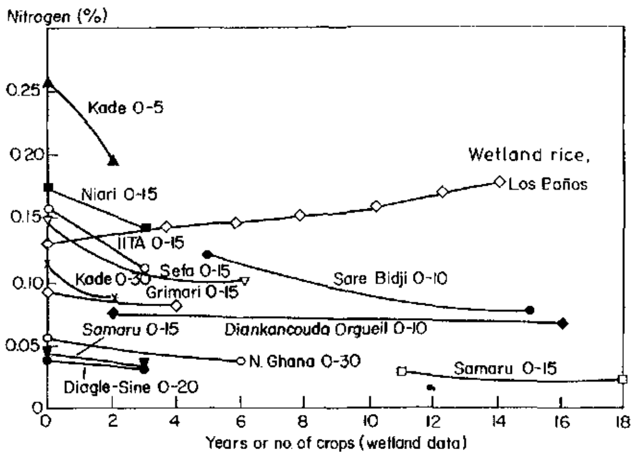

Fig. 3. Nitrogen changes in upland soils after clearing from natural vegetation (Nye and Greenland, 1964; Jones and Wild, 1975; Juo and Lal, 1977), and of wetland soil cultivated to rice (Greenland and Watanabe, 1982).

Many studies of the rapid decline of soil nitrogen levels when upland soils are cultivated in the humid tropics have been reported. The halflife of 14-C labelled ryegrass in the Egbeda soil at IITA was found to be 30 days (Jenkinson and Ayanaba, 1977). It has been thought by many that in the wetlands the reduced conditions will retard mineralization (e.g. Buresh et al., 1980), but in recent studies using 14-C labelled rice straw (Neue, 1985) a half-life of 43 days was found, in the Maahas Clay (Tropaquept) at IRRI. Thus in some flooded soils at least mineralization may proceed as fast as in well aerated soils, although the products are different. Mohr and van Baren (1954) did in fact indicate, that at temperatures above 30 C this was to be expected. Nevertheless there are major differences in nitrogen changes found for wetland soils and upland soils after many years of cultivation (Fig. 3).

The reason appears to be due to the difference in inputs, rather than differences in the rate of mineralization and subsequent nitrogen loss. The question most often posed regarding nitrogen in wetland soils is "Where did it come from?" and not "Where did it go to?", which is that most frequently asked regarding the nitrogen balance of upland soils in the humid tropics (Greenland and Watanabe, 1982).

It is of course well known that biological nitrogen fixation rates tend to be high in paddy soils. The topic has been reviewed several times, most recently by Roger and Watanabe (1985). Several studies conducted over many years in a range of conditions have shown biological nitrogen fixation during the cropping period adds around 50 kg/ha of nitrogen to the soil crop ecosystem (Table 3).

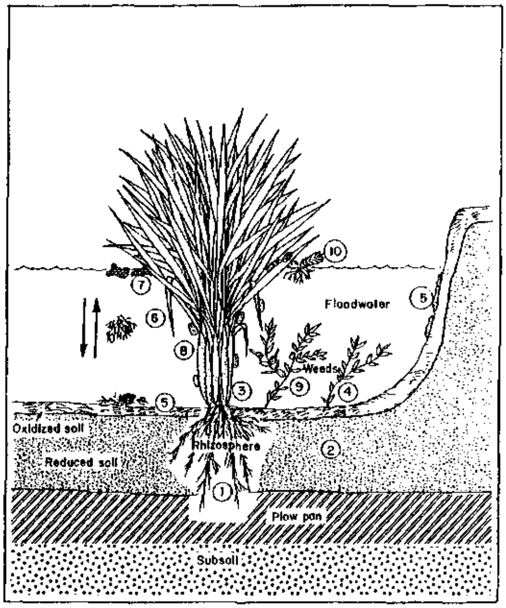

Fig. 4. Diagram of environments and N -fixing components in a rice field ecosystem. N -fixing bacteria: 1) associated with the roots; 2) in the soil; 3) epiphytic on rice; 4) epiphytic on weeds. Blue green algae: 5) at soil-water interface; 6) free floating; 7) at air-water interface; 8) epiphytic on rice; 9) epiphytic on weeds. Azolla:10 (Roger & Watanabe, 1985).

Several mechanisms contribute to the fixation, notably contributions from blue green algae living in the paddy water and on and around the rice plant, and contributions from non-symbiotic nitrogen fixing bacteria living in the rhizosphere, and in the soil, and epiphytic on rice and weeds growing in the paddy water (Fig. 4).

Table 3. Soil N changes and N removal in paddy rice fertility experiments. (Greenland and Watanabe, 1982).

Site	Annual cropping pattern	Duration (yrs)	Treatmt.	N fert. added	Soil change	Plant uptake	Balance (N2-N1)=C*
				Kg N/ha/year			
Aomori(a) Japan 41 N)	Wetland rice	21	PK	0	-20	45	+25
			NPK	57	-35	66	-25
Kagawa(b) Japan (34 N)	Wetland rice and barley	21	PK	0	-42	80 (55)**	+38
			NPK	157	-18	154 (96)	-21
Sorachi(c) Japan (45 N)	Wetland rice	12	PK	0	-44	142	+98
			NPK	39	-51	136	+46
Ishikawa (d)Japan (36 N)	Wetland rice	22	Unfert.	0	-34	53	+19
			PK	0	-30	64	+34
			CaPK	0	-34	72	+38
			NPKCa	100	-15	119	+4
Shiga(e) Japan (35 N)	Wetland rice and wheat	40	Unfert.	0	-1.7	41 (30)	+39
			PK	0	-13.1	67 (51)	+55
			NPK	152	+2.2	112 (74)	-37
Los Banos Philippines (14 N)(f)	Wetland rice	12	Unfert.	0	+30	116	+146
Maligaya Philippines (14 N)(f)	Wetland rice	8.5	Unfert.	0	+30	91	+121
Chainat(g) Thailand (15 N)	Wetland rice	2	-N	0	+47	58	+63
		2	+N	240	+39	139	-62
	Wetland rice and fallow	2	-N	0	-28	36	+57

* N1 = final soil N content; N2 = initial soil N content;
C = N removed in crops.
The positive figures in the final column are the amount of N fixes, less any losses by leaching or volatilization.
**: Figures in parentheses are N uptake by rice.

References:
(a): Koyama and App (1979); (b): Ando (1975); (c): Inatsu and Watanabe (1969); (d): Konishi and Seino (1961); (e): Takahashi (1979, personal communication); (f): Koyama and App (1979); (g): Firth et al. (1973).

Fertilizer responses

Yields of the order of 10 tons/ha are frequently obtained from paddy rice production, when water is well controlled. The nitrogen inputs required may be quite modest, of the order of 150 kg N/ha (e.g. in the Nile delta in Egypt, as well as many locations in northern India, east and southeast Asia). Perhaps more interesting is the fact that yields of 2 to 4 tons/ha are widely obtained in south and southeast Asia with much smaller inputs of nitrogen fertilizers, ranging from 0 to 50 kg N/ha. The net nitrogen balance is usually found to be positive (Koyama and App, 1979; Greenland and Watanabe, 1982) indicating that the extra nitrogen removed in the rice crop has not come from the soil.

Table 4. Estimates of rice area harvested, type of water regime, percent MV, yield, and average N use for selected areas in Asia (Stangel, 1979)

Country/ Region	Harvested rice area	Yield of rice	Irr.	Rainf.	Upl.	Planted to modern var.	Average N use based on arable land
	('000 ha)	(mt/ha)	(%)	(%)	(%)	(%)	(kg N/ha)
Group 1 (high rice yields)							
Japan	2,764	5.5	94	2	4	100	149
S. Korea	1,218	5.9	85	14	1	90	209
Taiwan	787	5.2	83	14	3	95	149
Group 2 (moderate rice yields)							
China	35,390	3.2	76	4	20	80	32
Indonesia	8,369	2.6	58	21	21	40	26
W. Malaysia	585	2.8	48	47	5	38	115
Iran	461	3.5	90	0	10	NA	12
Group 3 (low rice yields)							
India	39,688	1.8	43	47	10	25	13
Pakistan	1,710	2.3	80	0	20	43	38
Bangladesh	10,329	1.9	5	65	30	14	16
Philippines	3,579	1.8	45	35	20	56	28
Vietnam	5,310	2.2	16	81	3	17	36
Thailand	8,383	1.8	37	48	15	5	12
Burma	5,069	1.8	16	66	18	6	4
Sri Lanka	597	2.0	66	32	2	60	42
Afghanistan	210	2.1	6	50	44	NA	3
Nepal	1,256	1.9	10	81	9	19	4

In spite of the relatively high rates of nitrogen fixation in paddy soils, nitrogen fertilizers are almost universally used on rice. The rates currently used are very high in countries such as Korea and Taiwan, and in parts of India (Table 4). In areas with poor water control they tend to be lower, and are negligible for upland rice and deepwater rice.

Grain legumes

Mungbeans, cowpeas, soybeans and other grain legumes grown in rotation with a rice crop can contribute significant amounts of nitrogen to the succeeding rice crop (Pandey and Morris, 1983). Establishment of the legume at the close of the monsoon, and in a soil that has been puddled for rice, is often unsatisfactory. However, the introduction of short duration, high yielding rice varieties such as IR36 and IR56, has enabled the legumes to be established earlier. The unfavorable physical condition of the soil after it has been puddled for the rice crop can make establishment difficult. Minimum tillage techniques are often better than more intensive cultivation practices (Syarifuddin, 1982), and conserve the residual water better (Angus et al., 1983).

Azolla

One ecological niche which has recently received much attention is that beneath the fonds of the water fern Azolla, where the blue green algae *Anabaena azollae* finds conditions particularly well suited to rapid nitrogen fixation (Lumpkin and Plucknett, 1980). Azolla occurs naturally in most parts of the tropics. It undoubtedly provides great opportunity for further development of its potential as a green manure crop, as it has the ability to fix several hundred kilograms of nitrogen per hectare under appropriate conditions -- which include an adequate phosphorus supply. Lumpkin and Plucknett (1982) have recently reviewed its potential as a green manure very thoroughly.

Other green manures

Legumes grown before a rice crop, or legumes such as the stem-nodulated *Sesbania rostrata* which are tolerant of wetland conditions (Rinaudo et al. 1982) have also been widely examined. Where economic factors related to the labor requirement for their production are favorable, green manuring is a common practice. In China it is currently practiced over eight million hectares (Qi-xiao Wen, 1984) and the extent to which it is used has been increasing rapidly in recent years. Other forms of organic manures are also utilized to contribute to rice production (Table 5).

	Quantity available (10^6t)	Nutrient content			Loss of	Nutrients (10^3t)	
		N	P	K	(%)	N	P
Human feces	34.6	1.0	0.22	0.31	40	207	76
Human urine	84.0	0.5	0.06	0.16	50	210	47
Cattle feces	162	0.32	0.11	0.12	35	337	176
Cattle urine	32.2	0.5	0.01	0.79	40	97	4
Pig feces	148	0.5	0.18	0.42	40	444	259
Pig urine	152	0.3	0.03	0.33	50	227	39
Goat and sheep feces	6.7	0.65	0.22	0.21	40	26	14
Goat and sheep urine	0.6	1.40	0.01	1.74	50	4	-
Plant residues	32.6	0.6	0.09	1.08	-	195	28
Straw ash	70.1	0.6	0.09	1.08	-	-	55
Green manures	11.9	2.74	0.31	1.59	-	327	36
Azolla	8.8	0.22	0.02	0.07	-	19	1
Rape seed cake	1.3	4.6	1.10	1.16	-	60	13
TOTAL						2153	754

Table 5. Estimated use of organic manures in the main rice-growing region of China, 1979. (Qi-xiao Wen, 1984).

Organic manuring is less common in tropical regions, perhaps because of the alternative demands for the organic materials e.g. for fuel and animal feed, as in India (Venkatamaran, 1984). Even in China the amount of nitrogen added to paddy soils in various forms of manures, about 60 kg/ha/an, is rather less than the average amount of inorganic fertilizer nitrogen applied (c. 100 kg N/ha/an). Nevertheless it can be readily demonstrated that many legume green manures contribute nitrogen to a succeeding rice crop (Pandey and Morris, 1983; Pandey and Pendleton, 1984).

When legumes or azolla are used as green manures for rice, yields of 3-4 t/ha can be maintained. But their use is demanding in labour terms, and can only expand where the cost of labour is cheap relative to the cost of land and fertilizer. Straw incorporation promotes heterotrophic nitrogen fixation (Matsuguchi, 1979) and it may increase rice yields significantly (Ponnamperuma, 1984). Its use is limited, again because of the high labour demand for incorporation, and alternative uses of the straw.

N fixation in the rice rhizosphere

Some rice varieties have recently been shown to stimulate nitrogen fixation more than others (Rinaudo, 1977; Dommergues, 1978; IRRI, 1983). The full significance of this finding is yet to be explored. If varieties can be selected which encourage greater nitrogen fixation and still yield well --IR42 appears to be one such variety-- then the finding is of considerable importance.

Algal inoculation

Results of algal inoculation of paddy fields have been highly conflicting, showing large advantages in some instances, and none in others (Roger and Kulasooriya, 1980). The reasons for the differences may be associated with factors controlling the establishment of a vigorous algal population. These are at present little understood. Algalization merits further study because of the low labour requirement.

Roger and Watanabe (1985) conclude, "BNF is purposefully used in only a small percentage of rice fields, in a few countries and rice farmers are far from realizing its potential. This underutilization is due to ecological and socioeconomic factors and lack of technological development and knowledge. On a short to medium term basis, BNF has underexploited potential where fertilizers are not available or affordable. On a long term basis, integrated management should permit high yields with lower N fertilizer application."

Considerable potential exists for biological nitrogen fixation to contribute to food production in the tropics, in the semi-arid as well as the humid zone, and in the drylands as well as the wetlands (Table 6).

In the drylands of Africa shifting cultivation provides a system of low productivity whereby nitrogen fixed under the natural fallow is utilized in subsequent cultivation periods. More productive systems are essential to support increasing populations. For the savanna regions it should be possible to develop alternate pasture-crop systems which are able to contribute much more nitrogen to the crop from nitrogen fixed under the pasture, than does the natural fallow rotation system. Similarly in forest areas, alley-farming promises to provide a productive system in which leguminous tree crops can be combined with arable crops. The nitrogen contribution is not obtained without cost. It requires land and labor, and usually phosphorus and perhaps other additions to ensure that nitrogen fixation proceeds actively. The pasture or tree legume may itself be utilized to provide animal feed to offset these costs. But the net cost must always be compared with that of inorganic nitrogen fertilizers. In many instances, inorganic fertilizers are the cheaper source of nitrogen for the crop. In the wetlands, in spite of the relatively high rates of nitrogen fixation, yield responses to applied nitrogen are almost always found.

The optimum economic response to nitrogen fertilizers are obtained when they are used as efficiently as possible, and in such a way that biological nitrogen fixation processes are not reduced. For wetland rice it has been found that placement of nitrogen fertilizer in the soil, rather than distributing it in the paddy water, not only leads to much higher recoveries of fertilizer nitrogen (De Datta and Gomez, 1981; De Datta et al., 1981; INPUTS, 1979) but also involves minimal interference with biological nitrogen fixation by blue- green algae (Roger, et al., 1980). Thus nitrogen fertilizer placement in paddy soils provides an "integrated nitrogen management technique".

Inorganic nitrogen is also known to inhibit nitrogen fixation by rhizobia (see for example Kang, et al., 1975). Thus, while "starter" nitrogen -- a small application of inorganic nitrogen around seeding time -- is widely used with grain legumes, it is likely to reduce the amount of nitrogen fixed. Where legumes and cereals are grown in alley systems, in mixed cultures, or in succession, there is need for much further study to determine optimal use of the fertilizer. Where phosphorus is also needed, optimum placement and timing of the phosphorus application needs to be established.

For both dryland and wetland areas, the importance of the interaction between nitrogen and water, and where phosphate is also severely deficient, between phosphorus and nitrogen, cannot be overemphasized. Response to nitrogen is extremely common for fully irrigated rice crops. However, seventy percent of the area where lowland rice is grown in the tropics is not fully irrigated, but is

Table 6. Estimates of biologically fixed nitrogen in food crop production systems in the tropics.

	N fixed (kg/ha/an)	Comments
A. Semi-arid tropics		
1) Natural (grassland) fallow	0-20	Soil accumulation only
2) Legume based pasture	30-60	Satisfactory legume to be identified
3) Non-legume crops	0-10	Residual soil N only
4) Grain legumes	10-40	Need adequate P and favorable rainfall
B. Humid tropics		
1) Regenerating forest fallow	40-100	
2) Grass fallows	20-40	
3) Legume fallows	50-100	Difficult to maintain
4) Non-legume crops without mulch	0-10	
with mulch	10-30	Residual soil N only
5) Grain legumes	10-50	Need adequate P
6) Live (legume) mulches	20-40	
7) Green manures	30-60	Values refer to single crop, grown 40-80 days
8) Alley farming with leguminous trees	(300-600) X	X = fraction of land occupied by leguminous trees
C. Wetlands		
1) Fully irrigated rice	(10-30) x 3	
2) Grain legume after rice	40-80	
3) Azolla applied to rice	60-100	
4) BGA inoculated rice	10-40	
5) Green manure before rice	(30-80) + 50	

Data from Robertson and Rosswall (1984); Roger and Watanabe (1985); and others.

dependent on rainfall entrapped by bunds, and diverted from seasonal streams. In this type of rice production, referred to as "hydromorphic rice" in West Africa, and rainfed lowland rice in Asia, little nitrogen fertilizer is currently used. Much further work is needed to establish optimum management conditions for rice and other crops in such soils.

The problem of acidification is a general one for upland soils. In the wet lands natural inward movement of cationic nutrients usually prevents it from becoming serious. In upland areas managed under shifting cultivation, recycling of cations through forest or savanna vegetation will correct the acidity. Use of lime, or where this is uneconomic, inclusion of planted trees in the cropping system as in alley farming, may provide an alternative solution.

CONCLUSIONS

To produce the food crops needed from the soils of the tropics will require very large quantities of nitrogen. In the semi-arid savanna regions there is little prospect at present of achieving greater production through enhanced biological nitrogen fixation. Much further research is needed to find well adapted pasture and grain legumes which can contribute. The work by several national programs, and at ICARDA, ILCA, and ICRISAT, may change the situation if it is continued for a sufficient period. Where rains are concentrated in a short wet season, it is probable that proper use of nitrogen fertilizers will give economic yield increases. As Penning de Vries and Djiteje (1982) have shown, fertility rather than water shortage is often the major limitation to plant growth. Where the rains are less concentrated, and fall over a longer period, it may be possible to develop a suitable legume-based pasture rotation with arable cropping, in which much of the necessary nitrogen is accumulated under the pasture (Srague, 1975). In the wetter savanna areas, as in Brazil and parts of Colombia, vigorous grass species such as *Brachiaria* spp. and *Andropogon* sp. support economic beef production, and some nitrogen fixation. Some progress has been made in the identifiction of pasture legumes for these areas (CIAT, 1982) and grain legumes have been shown to contribute nitrogen to associated or succeeding crops. But here also fertilizer nitrogen is likely to be required at least as a supplement if high yield levels are to be obtained.

In the intermediate, forest-savanna transition zone, and in the forest areas with less acid soils, alley-farming appears to offer a system in which major contributions from biological nitrogen fixation may be made. Alley farming offers further advantages of supplying mulch material cheaply and conveniently, of recycling nutrients to reduce acidity, and controlling erosion. Nitrogen fixation is further enhanced if grain legumes are included in the cropping system. It still has to be established how far alley cropping can meet the nitrogen requirements of high yielding varieties of cereals over an extended period. It is probable that it is an appropriate method to combine with use of nitrogen fertilizers. Legumes as live mulches or as green manures, and grain legumes may also contribute. Some nitrogen is accumulated under non-leguminous fallows of trees or vigorous grasses. Although the amounts are relatively low, and adequate for low population densities, it cannot support high yields without sufficient supplementation of inorganic nitrogen.

Wetland rice production systems benefit from significantly larger amounts of biologically fixed nitrogen than do dryland cropping systems. There are several sources of the nitrogen, and the total can be enhanced by growing green manures in succession to rice. Nevertheless rice production would be well below quantities required to meet present needs if the fixed nitrogen were not supplemented by substantial quantities of inorganic fertilizers, and lesser amounts of other organic manures.

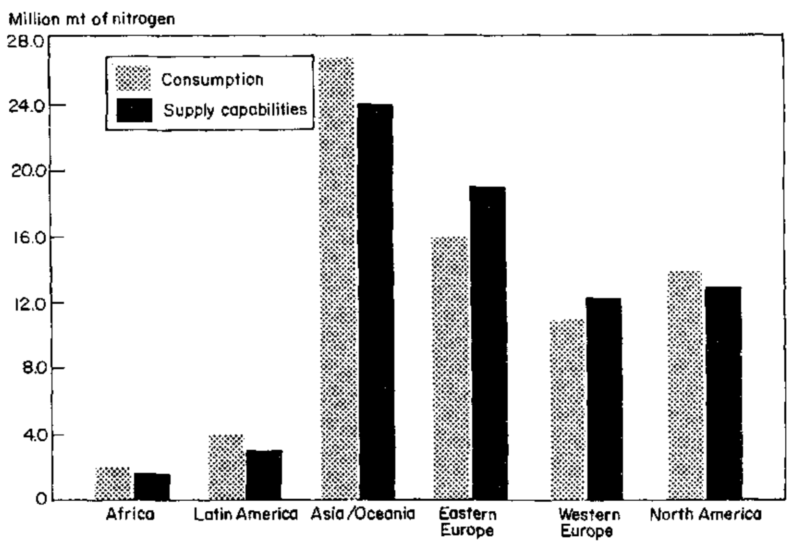

Fig. 5. World nitrogen fertilizer supply and consumption by region, 1985/86.(Source: FAO/UNIDO/World Bank working group on fertilizers, 1981. Current fertilizer sitation and outlook, Rome, Italy).

The additional crop production that will be needed to meet the food requirements of Africa, Asia, and Latin America will only be obtained if greatly increased quantities of inorganic nitrogen fertilizers are used. In Asia, notably in India and China, where the needs will be greatest, large increases in nitrogen production capacity are planned (Fig. 5).

For Africa, and to a lesser extend Latin America, it is necessary to plan now for substantially greater use of nitrogen fertilizers. At present in Africa nitrogen from fertilizers is less than 0.5 percent of nitrogen fixed each year (Robertson and Rosswall, 1984). This may be compared with Soderlund and Svensson's global estimate of 50 percent. Of course as much advantage as possible needs to be taken of biological nitrogen fixation as fertilizer use is increased. Integrated nitrogen management practices must be developed, to allow nitrogen ferti lizers to be used in such a way that they do not inhibit the natural fixation processes. Much further research is needed, in the field as well as the laboratory, and predominantly involving long term rather than short term studies, and requiring studies in a wide range of environments. Hopefully the political will exists to ensure national and international efforts can be supported and sustained to ensure the research will be successful.

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ORGANIC MATTER AND NITROGEN TURNOVER IN SOILS

Key Words: Microbial biomass Nitrogen Organic matter Soil
Tropical

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SUMMARY

The concepts used to describe the turnover of organic matter and nitrogen in soils, based on experimental data, are reviewed. Improved models developed recently are discussed. Limitations and inadaquacies of the older but still widely used equations are indicated.

The long-term "equilibrium" level of soil organic matter can be an important determinant for sustained agricultural use of the soil. Soil fertility depends more on the level of "young soil inorganic matter" formed by microbial transformation of crop residues during the previous 25 years, than on the total soil organic matter level. Besides, a large fraction of old soil organic matter may be present that releases little or no plant nutrients.

Rapid biodegradation of crop residues and manures takes place during the first year, followed by much slower degradation of turnover products formed from these organic materials. The role of the soil microbial biomass in the simultaneously occurring mineralization and immobilization processes is stressed. Model calculations are illustrated for a resistant plant residue with a C/N ratio of about 100, and for a more easily degradable plant residue with a C/N ratio of 31. The model used is based on growth of microbial biomass on added substrates with simultaneous evolution of carbon dioxide and production of "young soil organic matter". The contribution of various fractions to nitrogen mineralization and immobilization is shown.

INTRODUCTION

Processes of decomposition and accumulation of organic matter in soils have been studied extensively and have been reviewed by Jenkinson (1981), by Lathwell and Bouldin (1981), and in several FAO Soils Bulletins (1975, 1977, 1980). The nitrogen balance in tropical agricultural systems has been reviewed by Wetselaar and Ganry (1982).

In this paper, concepts used to describe the turnover of organic matter and nitrogen in soils based on experimental data are reviewed. Improved models have been developed recently and their relevance is discussed. Limitations and inadequacies of the older but still widely used equations are indicated.

DECOMPOSITION OF SOIL ORGANIC MATTER

According to Henin and Dupuis (1945) an amount of soil organic matter y_0 present at time t = 0 decomposes at a constant relative rate k. This process may be described by using the equation for firstorder kinetics:

$$dy/dt = -ky \qquad (1)$$

On integration this equation yields:

$$\ln y = \ln y_0 - kt, \text{ or } y(t) = y_0 \cdot e^{-kt} \qquad (2)$$

However, long-term field experiments have shown that k decreases with time under fallow conditions as well as in cropped soil.

DECOMPOSITION OF SINGLE APPLICATIONS OF FRESH ORGANIC MATERIALS

Kolenbrander (1974), studied the decomposition rates of single applications of various organic materials and found a striking similarity in the experimental results obtained by different research workers. The various organic materials were found to differ widely in "humification coefficient" (h), i.e. the fraction of organic carbon added to the soil as fresh organic material and still present in the soil organic matter one year after its application (Jenkinson's isohumic coefficient, 1981). There was also a wide range in the first order decomposition rate constants (k) of the humified fraction (calculated from table 1). Rate constants proved time-dependent and decrease gradually with the number of years after application.

Table 1. Organic matter (% of amount applied) retained after a single application of various organic materials (after Kolenbrander, 1974).

	Years after application					
	0	1*	2	3	5	8
Green foliage	100	20	10.5	7	4.5	3
Straw	100	38	23	18	14	10
Litter of deciduous trees	100	57	43	34	23	14
Farmyard manure	100	60	42	33	25	19
Fir needles	100	72	55	44	32	27
Sawdust	100	75	63	54	40	27
Peat	100	85	77	71	61	51

* humification coefficients (%)

Values for k in a time interval Δt have been derived from equation 2, when calculating y for t = t and $t+\Delta t$, respectively, which leads to the equation:

$$\ln \frac{y_t}{y_{t+\Delta t}} = k.\Delta t \qquad (3)$$

Jenkinson (1977) described the loss of (labeled) carbon from added plant material as a two-compartment model, i.e. two exponential functions, in which 70% of the plant material decomposes with a half life of 0.25 years and the remainder with a half life of 8 years. Interestingly, this model developed at Rothamsted (UK) also gave a good fit to data obtained in the humid tropics, if the decomposition rate for each compartment is increased four times. However, this model is considered an oversimplification of the real processes of decay as it takes no account of the formation and decay of biomass and very inert material, as determined with radio-carbon dating. A more comprehensive model was therefore developed (Jenkinson and Rayner, 1977), which will be discussed later.

The degradation pattern shown in table 1 and that found by Jenkinson (1977) are readily understood. The easily degradable fractions of the organic materials are rapidly decomposed, leaving the less degradable parts to decay slowly. As time goes on, the activity of the microbial biomass responsible for the decomposition will slow down due to lack of substrate.

ACCUMULATION AND DECOMPOSITION OF SOIL ORGANIC MATTER, FOLLOWING ANNUAL APPLICATIONS OF THE FRESH ORGANIC MATERIALS

With an annual supply of fresh organic material x, the annual increase in humified material (or soil organic matter), dy equals hx (Henin and Dupuis, 1945). As the newly formed soil organic matter decomposes according to equation 1, the ultimate change in y is described by the equation:

$$\frac{dy}{dt} = hx - ky \qquad (4)$$

and upon integration:

$$y = \frac{hx}{k} (1 - e^{-kt}) \qquad (5)$$

for $t = \infty$, y attains a maximum equilibrium value

$$y_{max} = \frac{hx}{k} \qquad (6)$$

Kolenbrander (1974) showed, that the effectiveness of various fresh organic materials in increasing soil organic matter cannot be predicted on the basis of their performance in the first year, that is by their humification coefficient. In fact, the process of humification is not completed in one year, which causes the decomposition rates of the added organic materials to diverge widely, also in subsequent years. For instance, in the long run (ten years) added farmyard manure proved four times more effective than plant foliage in in creasing soil organic matter content, and not three times as estimated from the humification coefficients in table 1.

<u>YOUNG AND OLD SOIL ORGANIC MATTER</u>

Henin and Dupuis (1945) and Kortleven (1963) described trends in soil organic matter level, as affected by accumulation of humified organic materials from added organic matter and decomposition of the native soil organic matter as measured under fallow conditions, by combining equations 2 and 5.

$$y = \frac{hx}{k}(1 - e^{-kt}) + y_o e^{-kt}, \text{ or } y = y_{max}(1 - e^{-kt}) + y_o e^{-kt} \qquad (7)$$

For t = ∞, y attains an equilibrium (maximum or minimum) y_m This is in fact a two-compartment equation, consisting of an accumulation (equation 5) and a decomposition (equation 2) compartment, assuming that the k-values in each compartment are identical, and independent of organic matter age.

However, the above postulation that young and old soil organic matter decompose at the same rate is not tenable in the light of Jenkinson's (1977) findings for the decomposition of labeled fresh plant material and unlabeled (native) soil organic matter. This is also in agreement with data from Sauerbeck and Gonzalez (1977), Greenland (1980) and Ayanabe et al., 1976. The bulk of the soil organic matter, and the carbon and nitrogen it contains, mineralizes slower than the labile pool of freshly added plant residues and their humified turnover products. This also holds for soils cleared for cultivation after a long fallow period under natural forest or grassland. During clearing operations large amounts of relatively fresh plant material are added to the soil. As based on Greenland's (1980) data for West-Africa, there is a high rate of organic nitrogen mineralization, 14% of the original material present, mineralized in the first year of cultivation, slowing down to 5% after two and 3% after eight years of cultivation.

Further evidence for the existence of different pools of soil organic matter has been gained from long-term field experiments at our institute. Fig. 1 illustrates the soil organic matter decay pattern of a reclaimed peat soil, in the absence or presence of added farmyard manure, i.e. 40 t./ha every second year since 1944, or 3,000 kg/ha organic material annually. The curves for the two treatments are very similar and the inter-distance represents the build-up of "humified" farmyard manure, disregarding possible differences in amounts of plant residues resulting from the treatments. Calculations of the rate of soil organic matter decomposition for both treatments with equation 3 produces almost identical k-values of 0.014-0.015 per annum as an average over a 23-year period.

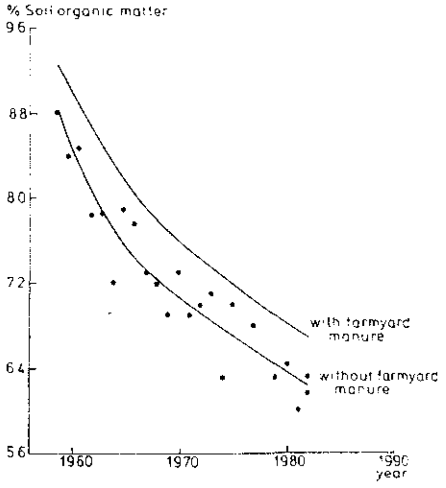

Figure 1. Soil organic matter decomposition in the top 25 cm of a reclaimed peat soil in The Netherlands, in the absence or presence of added farmyard manure (40 tonnes/ha every second year since 1944). Scattering of the points is presented for the lower curve only.

When estimating k for soil organic matter derived from farmyard manure with equation (6), a value of 0.144 is obtained.

y_m = (6.7 - 6.2) = 0.5% soil organic matter or 12,500 kg/ha in 1982 (fig. 1)

h = humification coefficient 0.6 (table 1.)
x = annual supply of fresh organic material, 3,000 kg/ha.

It is concluded, therefore, that the "old", native, soil organic matter in the farmyard manure treatment, i.e. 6.7% - 0.5% = 6.2% of the soil (dry weight), decomposes at about one tenth of the rate of the "young" soil organic matter derived from farmyard manure (0.5% of the soil weight).

The foregoing is further corroborated by estimating the soil organic nitrogen build-up and mineralization rate. Changes in soil organic nitrogen resulting from an input of fresh organic materials may be described by the equation

$$\frac{dN}{dt} = A - kN \text{ (Jenkinson, 1981)} \qquad (8)$$

and at equilibrium

$$\frac{dN}{dt} = 0 = A - kN_{max} \qquad (9)$$

where N treatments the amount of N in young soil organic matter, A the (constant) annual input of nitrogen via fresh organic materials, and N_{max} the equilibrium content. Without further inputs it follows from equation 8 that

$\frac{dN}{dt} = -kN$, or upon integration, $N_t = N_0 e^{-kt}$.

Equation 8 does not comprice a humification coefficient. This is because most fresh organic plant materials have wider C/N ratios than the microbial biomass and, normally, nitrogen is retained in the system during the early stages of the decay process because of the microbial need for this element (Jenkinson, 1981).

In the present example N_m is calculated from equation 9:

$N_{max} = A/k = 690$ kg/ha/year , or 0.0276% expressed on a soil dry weight basis,

where

A = 100 kg organic nitrogen/ha/year , derived from 40 t farmyard manure, with 0.50% organic nitrogen, applied every two years.

k = 0.144, assuming that young soil organic matter decay and nitrogen mineralization occur at the same rate.

The build-up of nitrogen contained in young soil organic matter is calculated with equation 5:

$$N_t = N_{max} (1 - e^{-kt}).$$

Data for t = 8,16 and 23 years, respectively, are shown in table 2 that also presents total soil organic nitrogen contents. Values for organic nitrogen contained in old soil organic matter are obtained by difference an may be used for calculation of the mineralization rate for old soil organic nitrogen, using equation 2:

$$y_t = y_o e^{-kt} .$$

For the periods 0-8, 8-16 and 16-23 years the following k-values are found: 0.022, 0.016 and 0.010, respectively, with a mean k of 0.016 for the whole 23-year period.

According to this model, the rate of decomposition (nitrogen mineralization) of soil organic matter derived from inputs of fresh organic materials is much larger than that of old soil organic matter. This means that the higher the relative contribution of young soil organic matter to nitrogen flow, the greater and also the faster the loss in soil fertility when the supply of fresh organic materials is neglected.

Table 2. Total, "young" and "old" soil organic nitrogen, as a percentage of soil dry weight, following biannual applications of 40 t FYM (0.50% organic N) since 1959.

	Year			
	1959	1967	1975	1982
Total soil org. N	0.257	0.235	0.217	0.205
"Young" soil org. N		0.0192	0.0244	0.0266
"old" soil org. N		0.2158	0.1926	0.1784

Further evidence for the different behaviour of young and old soil oranic matter based on experimental results from our institute, is supplied by Dijk (1982) and Janssen (1984). The data of Gokhale (1959), used as an example by Lathwell and Bouldin (1981), should be reconsidered. The use of only one first-order rate constant k = 0.091 for N-mineralization of fresh litter as well as for young and old soil organic matter seems questionable. The decline in soil organic N may be better described using a k of about 0.2 for the N-mineralization of fresh litter and the young humus derived from it, and average first oder k-values of 0.066, 0.042 and 0.019 for mineralization of old soil organic matter for periods of 0-7, 7-10 and 10-26 years. In figure 2 is shown the large difference between the two interpretations: According to Gokhale (1959), young soil organic matter constitutes 85% of the soil organic matter, our calculations show only 35%. Data on the age of soil organic matter fractions determined by radiocarbon dating can show which interpretation is correct. The data can also show whether tropical soils differ much with respect to the composition (age and degradability) of their soil organic matter fractions from temperate soils, as shown by Jenkinson (1969).

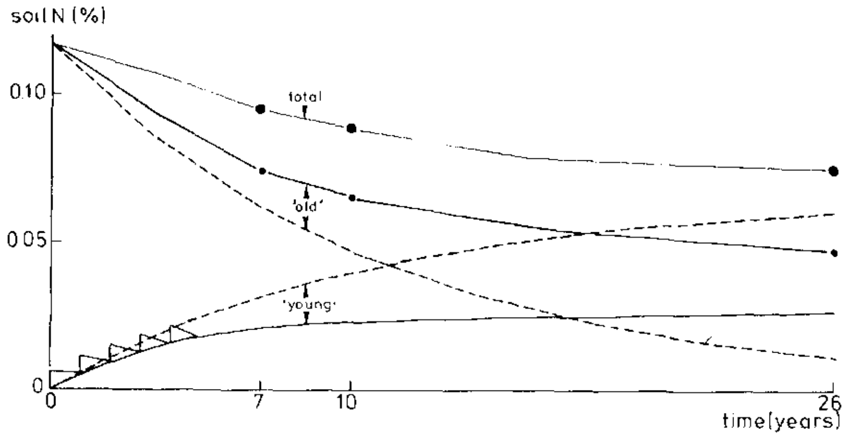

Figure 2. Accumulation of young soil organic nitrogen and decline of old soil organic nitrogen, using one first-order rate constant k = 0.091 (------) or different k-values, as discussed in the text.

Apart from the young soil organic N, the soil will contain old soil organic N, soil organic N (%) as shown earlier. The first rapid decline of soil organic N in figure 2 should be seen as a degradation of young soil organic N, accumulated before the start of Gokhale's experiment. The slow degradation at the end of the curve more truly represents the decay rate of old soil organic matter. Turnover times of young and old soil organic N in this example were calculated to be about 5 years and more than 50 years, respectively.

Jenkinson and Rayner (1977) developed a model for organic matter turnover in soil that included a microbial biomass compartment. Plant residues added to the soil are divided into two fractions: (rapidly) decomposable plant material (DPM) and resistant plant material (RPM) with a much lower decomposition rate. Their model further included "physically stabilized organic matter" (POM) and "chemically stabilized organic matter" (COM). Biodegradation of DPM, RPM, POM and COM resulted in the formation of CO_2, microbial biomass (BIOM), POM and COM. With this model equilibrium levels of organic matter in the various compartments can be calculated, that agree well with experimental and radiocarbon dating results. First-order rate constants were used to describe the transformation of organic matter in each of the compartments. The overall contribution of the five compartments to nitrogen mineralization can be calculated from their transition matrixes, and a balance account for a one-year period can be constructed, as shown in tables 3a and 3b.

TABLE 3a. Transition matrix (carbon budget in kg $C.ha^{-1}$) for a temperate soil.

Amounts at t = 0		Amounts 1 year after annual input							
		DPM	RPM	CO_2	BIOM	POM	COM	Turnover	k (y^{-1})
DPM fresh input	837	12.5	-	656	62.7	103	2.9	824	4.2
DPM residue	12.7	0.2	-	10	1.0	1.6	0.0	12.5	4.2
RPM fresh input	163	-	121	34	3.2	5.3	0.2	42	0.3
RPM residue	466	-	345	96	9.2	15.1	0.4	121	0.3
BIOM	284	-	-	76	196	12	0.3	96	0.41
POM	11300	-	-	125	12	11162	0.5	157	0.014
COM	12200	-	-	3	0.3	0.5	12196	4.3	0.00035
Total amounts at t = 1		12.7	466	1000	284	11300	12200	1258	

TABLE 3b. Transition matrix (nitrogen budget in kg $N.ha^{-1}$) calculated from table 3a with the use of C/N ratios.

		DPM	RPM	N_{min}	BIOM	POM	COM	Turnover
DPM fresh input	41.8	0.62	-	24.5	7.84	8.59	0.24	41.2
DPM residue	0.64	0.02	-	0.3	0.12	0.13	0.00	0.62
RPM fresh input	1.63	-	1.21	- 0.42	0.40	0.44	0.02	0.42
RPM residue	4.66	-	3.45	- 1.16	1.15	1.26	0.03	1.21
BIOM	35.6	-	-	10.0	24.52	1.0	0.02	12.0
POM	942	-	-	10.0	1.50	931	0.04	13.2
COM	1016	-	-	0.26	0.04	0.04	1016	0.36
Total amounts at t =1		0.64	4.66	43.5	35.6	942	1016	69.0
C/N ratios used		20	100		8	12	12	

humification coefficient of the fresh input: 0.31 = (1000 - 656 - 34)/1000

As calculated from table 3b, 53% of the nitrogen mineralized comes from the last fresh addition, BIOM and POM each contribute 23%; only 0.6% of N_{min} originates from the old COM. Data also show that one year after the last addition 6.6% of the added carbon and 19% of the added nitrogen is present in the microbial biomass; the difference in retention of C and N reflects in C/N ratios of the input (=23) and BIOM (=8).

From table 3a a humification coefficient of 0.31 was calculated. After one year, however, 60% of the carbon from the last addition is still present in the soil in the form of transformation products POM, COM and BIOM, and only 40% in DPM- and RPM- residues.

During the biodegradation of DPM a net mineralization of nitrogen occurs, whereas with RPM a net immobilization takes place (table 3b).

What happens during the year after the annual addition of fresh plant residues is not shown by this model; especially the turnover of BIOM is underestimated. To get an idea about the dynamics of BIOM, the growth of BIOM should be coupled with the degradation of organic materials. Calculations based on literature data, show, that carbon assimilation efficiencies of biomass growth of 40% for DPM, 20% for RPM and 10% for growth on POM appear to be reasonable estimates. Biomass growth on COM is not considered as it is negligible compared with growth on other substrates. Thus we get the following equations for bio mass growth:

$$100\ DPM\text{-}C_1 \rightarrow 40\ BIOM\text{-}C + 60\ CO_2\text{-}C \tag{10a}$$

$$100\ RPM\text{-}C_2 \rightarrow 20\ BIOM\text{-}C + 60\ CO_2\text{-}C + 20\ POM\text{-}C \tag{10b}$$

$$100\ POM\text{-}C_3 \rightarrow 10\ BIOM\text{-}C + 80\ CO_2\text{-}C + 10\ COM\text{-}C \tag{10c}$$

$$100\ COM\text{-}C_4 \rightarrow 100\ CO_2\text{-}C \tag{10d}$$

As a first approximation we describe the rates of substrate degradation by first-order rate equations, using the same rate constants as reported by Jenkinson and Rayner (1977):

$$-\frac{dC_n}{dt} = k_n C_n \quad \text{with } n = 1, 2, 3, 4 \tag{11}$$

or in integrated form

$$C_n(t) = C_n(0).e^{-k_n t} \tag{11a}$$

The growth rate of BIOM on the different substrates is taken to be equal to the sum of the disappearance rates of substrate, multiplied by their growth efficiency:

$$\frac{d(\text{BIOM-C})}{dt} = \varepsilon \frac{Y_n}{100} . k_n C_n = \text{growth rate of BIOM} \qquad (12)$$

where Y_n is the yield percentage for growth on substrate C_n. The reverse proces s, the loss of BIOM for maintainance (endogenous respiration) and death is des cribed as proportional to the amount of BIOM present:

$$\frac{d(\text{DEBIOM-C})}{dt} = k_d . \text{BIOM-C} = \text{rate of biomass loss} \qquad (13)$$

The lost BIOM is supposed to be transformed into carbon dioxide and POM:

$$100 \text{ DEBIOM-C} \rightarrow 80 \text{ } CO_2\text{-C} + 20 \text{ POM-C} \qquad (14)$$

Combining equations 12 and 13 we get the overall rate of change of BIOM:

$$\frac{d(\text{BIOM-C})}{dt} = \varepsilon\left(\frac{Y_n}{100} . k_n C_n\right) - k_d . \text{BIOM-C} \qquad (15)$$

Schematically our simplified version of Jenkinson and Rayner's model is shown in figure 3. This model is used for the following calculations.

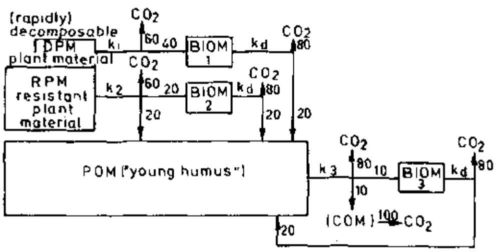

Figure 3. Simplified model describing the dynamics of microbial biomass.

In table 4a the result of our calculations for the example of table 3a is shown. The total amount of BIOM synthesized during the year is 0.4 x 837 + 0.2 x 163 + 0.1 x 120 = 379.4. The same amount of BIOM must be lost due to death and maintenance, if BIOM at t = 1 equals that at t = 0. Now by trial and error a value of k_d is found that gives the same equilibrium BIOM as in table 3a.

The size of the POM pool is calculated from the annual production of POM, that should equal the amount mineralized from POM by equation 16:

$$\text{POM at equilibrium} = \frac{\text{POM formed per year}}{(1 - e^{-k_3})} \qquad (16)$$

The greatest difference between tables 3a and 4a is in the turnover of BIOM: 96 versus 379. The value of k_d in table 4a is therefore also higher. The POM pool in table 4a is smaller than in tabel 3a because less POM is produced according to our equations.

TABLE 4a. Carbon budget showing the dynamics of the microbial biomass (cf. table 3a) in a temperate soil.

Amounts at t = 0		Amounts one year after the annual input (kg C.ha^{-1})						
		DPM	RPM	CO_2	BIOM	POM	Turnover	k (y^{-1})
DPM fresh input	837	12.5	-	495	330	-	825	4.2
DPM residue	12.7	0.2	-	7	5	-	12	4.2
RPM fresh input	163	-	121	25	8	8	42	0.3
RPM residue	466	-	345	72	24	24	121	0.3
BIOM	284	-	-	304	-95	76	379	±1.05
POM	8630	-	-	96	12	8510 (*)	120	0.014
Total amounts at t = 1		12.7	466	1000	284	8620	1500	

(*COM 12)

TABLE 4b. Carbon budget for a 'tropical soil'.

Amounts at t = 0		Amounts one year after the annual input						
		DPM	RPM	CO_2	BIOM	POM	Turnover	k(y^{-1})
DPM fresh input	837	0	-	502	335	-	837	16.8
RPM fresh input	163	-	49	68	23	23	114	1.2
RPM residue	70	-	21	30	10	10	49	1.2
BIOM	13	-	-	304	-367	76	379	4.2
POM	2200	-	-	96	12	2080 (*)	120	0.056
Total amounts at t = 1		0	70	1000	13	2190	1500	

(*COM 12)

humification coefficient of the input: about 0.16 = (49 + 108)/1000

In table 4b the result of our calculation is given for a tropical soil with the same annual input. The first-order rate constants have been assumed to be four times as large as for the temperate soil, because of the higher temperature during the year. Jenkinson and Ayanaba (1977) showed that the degradation of ryegrass in a Nigerian soil could be described by the same equation as the degradation in a Rothamsted soil by multiplying the rate constants by four.

The following differences between tables 4a and 4b are apparent: no residue is left from the added DPM and a much smaller residue has built up from added RPM in the tropical soil. Whereas in the temperate soil most of the RPM mineralized comes from the accumulated residue, in the tropical soil more fresh RPM is mineralized than residue.

The carbon turnover of BIOM is the same in both soils, being determined by the size of the annual input and assuming equilibrium values being reached in both soils. However, because of the higher decay rate this turnover is accomplished with a much smaller BIOM in the tropical soil.

The amount of POM is about four times as large in the temperate soil as in the tropical soil, although the mineralization from this pool is equal for both soils. From tables 4a and 4b it follows that there is little need for a COM pool to balance the budget. About 1% of the carbon dioxide involved might come from this COM pool, contributing about 1 kg mineral N. If both soils contain the same amount of organic matter, the more or less inert COM pool must be larger in the tropical soil than in the temperate soil.

A larger input of plant residues (Poulain, 1980), especially if they are not rapidly degradable, will lead to a higher build-up of the RPM and POM pools. In table 5 the carbon budget has been calculated for an annual input of 4280 kg C/ha, with 78% in the form of RPM, e.g. the input of sorghum plant residues.

No COM pool has been calculated because of the uncertainty in the value of its degradation rate; instead the percentage CO_2 in eq. 10c has been increased to 90%. The amount of BIOM at $t = 1$ is about 10 times as high as in table 4b.

If carbon and nitrogen are mineralized in a constant proportion, the amounts of nitrogen of the pools can be calculated by deviding the carbon amounts by the C/N ratio. Because of the high C/N ratios of both DPM and RPM, degradation of these materials leads to N-immobilization in the form of BIOM and POM. The pattern of mineral N during the year is shown in figure 4.

It takes almost a year before a net immobilization of mineral N turns into a net mineralization of N. As can be seen from figure 4, N_{min} is the resultant of mineralization of DPM and RPM and immobilization by BIOM and POM.

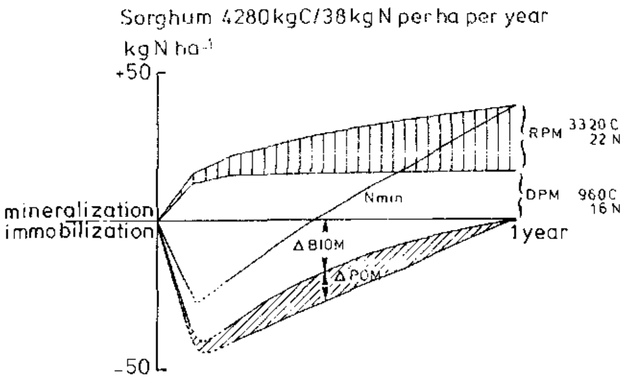

Figure 4. Mineral nitrogen as the resultant of mineralization and immobilization of N from annual addition of crop residue.

Table 6 and figure 5 show the results of annual additions of 3340 kg C/ha, e.g. the input of cotton plant residues. This material with a rather low C/N ratio gives a much shorter immobilization period (abouth 1 month). Because of the smaller percentage RPM, the RPM residue and POM pools are smaller than in table 5. Immobilization of mineral N may prevent losses by leaching for some time.

TABLE 5. Carbon budget for a tropical soil with an annual input of 4280 kg $C.ha^{-1}$ by sorghum plant residues; rate constants used are the same as in table 4b.

Amounts at $t = 0$			Amounts one year after the annual input (kg $C.ha^{-1}$)							
	C	(N)	DPM	RPM	CO_2	BIOM	POM	C-turnover	$t_{\frac{1}{2}}(y)$	N_{min}(kg $N.ha^{-1}$)
Fresh input										
DPM	960	(16)	0	-	576	384	-	960	0.04	- 32
RPM	3320	(22)	-	1000	1392	464	464	2320	0.58	- 81
RPM residue	1430	(9.5)	-	431	600	200	200	1000	0.58	- 35
BIOM	140	(18)	-	-	910	-997	227	1137	0.165	+123
POM	16360	(1360)	-	-	802	89	15470	891	12.4	+ 56
Total C	17900 + COM		0	1430	4280	140	16360	6310	appr.9	+ 38

$BIOM_{max}$ at t = 0.1 y contains 440 kg C (55 kg N) per ha

$t_{\frac{1}{2}} = (\ln 2)/k$

TABLE 6. Carbon budget for a tropical soil with an annual input of 3340 kg $C.ha^{-1}$ by cotton plant residues; rate constants used are the same as in table 4b.

Amounts at $t = 0$			Amounts one year after the annual input (kg $C.ha^{-1}$)							
	C	(N)	DPM	RPM	CO_2	BIOM	POM	C-turnover	$t_{\frac{1}{2}}(y)$	N_{min}(kg $N.ha^{-1}$)
Fresh input										
DPM	2340	(98)	0	-	1404	936	-	2340	0.04	- 19
RPM	1000	(10)	-	301	419	140	140	699	0.58	- 22
RPM residue	432	(4)	-	130	181	60	60	302	0.58	- 9.5
BIOM	61	(8)	-	-	944	-1119	236	1180	0.165	+128
POM	8020	(669)	-	-	393	44	7584	437	12.4	+ 31
Total C	8500 + COM		0	432	3340	61	8020	4960	appr.11	+108

$BIOM_{max}$ at t = 0.1 y contains 704 kg C (88 kg N) per ha

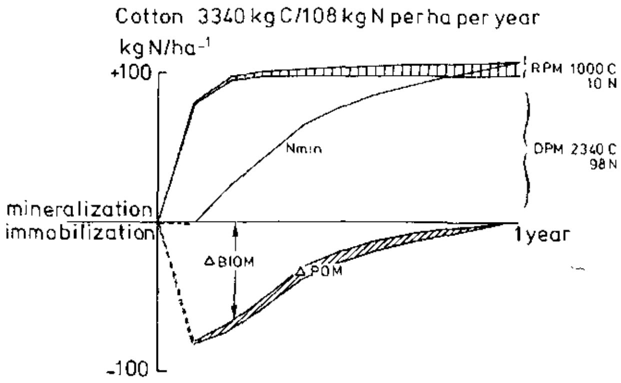

Figure 5. Mineral nitrogen as the resultant of mineralization and immobilization of N from annual addition of crop residues.

To produce a more realistic picture of organic matter and microbial dynamics during the year, factors affecting the activity of the biomass like moisture, pH and availability of mineral nitrogen should be taken into account. Methods of residue management such as burning, may lead to an increase in the fraction of rather inert organic matter, and a temporary increase of pH due to ash addition may favor nitrification and subsequent loss due to leaching or denitrification.

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INORGANIC NITROGEN LOSSES THROUGH LEACHING AND DENITRIFICATION IN SOILS OF THE HUMID TROPICS.

KEY WORDS: Leaching Denitrification Lysimeter Soil solution probes

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SUMMARY

In the humid tropical climate, leaching and denitrification losses of inorganic-N occur almost entirely during the growing season (i.e. rainy season). The rate of nitrate leaching in the kaolinitic Alfisols and Ultisols in the forest region was found to be much slower than one would expect on the basis of high rainfall and good soil permeability. Such soils, particularly those recently cleared form bush fallow, contain a large proportion of transmission pores (>50μ). The rapid downward movement of excess water through the transmission pores or macropores allows little time to equilibrate with the soil solution in the storage pores.

Leaching processes are being studied at IITA by means of monolith lysimeters and field installation of soil solution probes and tensiometers. The latter allows a quasi-continuous monitoring of ammonium-N and nitrate-N in the soil solution as well as the soil water regime throughout the growing season.

Vast areas of tropical Africa and Latin America are situated on well-drained landscape with deep and strongly weathered soils. The loss of inorganic-N through denitrification would be relatively insignificant particularly in soils having poor aggregation and high proportion of air-filled macropores.

INTRODUCTION

The predominant form of inorganic nitrogen in upland soils - except when urea, or ammonia containing fertilizers are applied to an acid soil - is nitrate. Leaching and denitrification concerns nearly exclusively nitrate. For these reasons this paper will deal only with nitrate in upland soils.

Since inorganic nitrogen is a major yield determining factor in crop production, its availability in sufficient quantity throughout the growing season is essential for optimum growth. Unfortunately its availability does not only depend on the N-mineralization of soil reserves, on fertilizer and manure inputs, but also on losses. Losses may occur through leaching and denitrification and may reduce the available quantity to a level below that required for optimum growth. These two processes are assumed to be major causes of inefficiency of nitrogen use in the humid and subhumid Tropics.

There are a number of field data available, which show large range of leaching losses. Sanchez (1976) has compiled results from various sources. Large variation of leaching losses occur depending on rainfall, plant cover and cropping conditions (Roose, 1974; Long,1981) and method of N-application (Arora and Juo, 1982). Unfortunately, only a limited number of systematic studies have been carried out in tropical regions, which could give a clear understanding on the quantitative effect of the various relevant factors on leaching process.

Results from temperate regions cannot be used for assessment for tropical conditions as conditions are not comparable. In temperate and subtropical climates e.g. Europe most of the leaching losses - if any - are recorded during the winter season, when 50% or more of the rainfall occurs and when there is no water consumption by plants. Thus in these regions leaching affects only residual fertilizer N and native N mineralized after harvest. Denitrification losses are minimal under arable cropping because the prerequisite conditions for denitrification - low temperature in the soil > 10-15 °C, low oxygen concentration, the presence of easily decomposable organic matter and sufficient NO_3 in the soil - do not often occur at the same time (Strebel et al., 1980). In the tropics, however, leaching and denitrification are assumed to compete with plant uptake.

SOME RELEVANT CHARACTERISTICS OF MAJOR SOILS OF THE HUMID TROPICS

The highly weathered upland soils of the humid and subhumid tropics have some characteristics which set them apart from other soils. They are characterized by low nutrient reserves and low nutrient and water holding capacities. The lack of easily weatherable minerals, dominance of low activity clay and rapid turnover of organic matter are primarily responsible for the rapid decline of the nutrient status of these soils with cropping.

As nitrate is mainly present in the soil solution and interacting only little with the solid soil components, the chemical properties of the soils are of only minor importance.

In contrast the physical soil properties play a more important role. One typical characteristic is the high sand and a low silt content. This has an effect on soil aggregation and stability as well as on porosity.

Table 1 Comparison of pore size distribution in two Alfisols from West-Africa (Ustalf) and Central Europe (Udalf)

	Pore size (μ)	Pore volume (%) Egbeda soil series, Nigeria A-hor.	B-hor.	Loess, Germany A-hor.	B-hor.
Trans-mission pores	> 300	15	3	1	1
	50-300	12	5	5	2
Storage pores	10- 50	6	3	10	10
	0.2- 10	3	10	20	15
	< 0.2	6	22	10	20
	Σ	42	43	46	48

The amount of leaching depends on the amount of rainfall, rainfall intensity, water consumption by plants and on soil porosity. Porosity determines water holding capacity, water conductivity and aeration. A typical example of the pore distribution and the corresponding water retention characteristics of tropical soils is given in Table 1 and Fig. 1 and is contrasted with a typical soil from central Europe. One notices the comparatively small proportion of storage pores (< 50 μ) and the high proportion of transmission pores (> 50 μ) in the A-horizon of the tropical soils. This situation prevails (in non-eroded soils) down to 35-50 cm in the Alfisol and is responsible for the low water holding capacity within the main rooting zone and the rapid drainage of excess water after a rain. Similar pore size distributions are encountered in many oxisols (not shown) but the proportion of very fine pores (< 0.2 μ) and hence unavailable (or rather difficultly available) water is higher then in the Alfisol (Table 1).

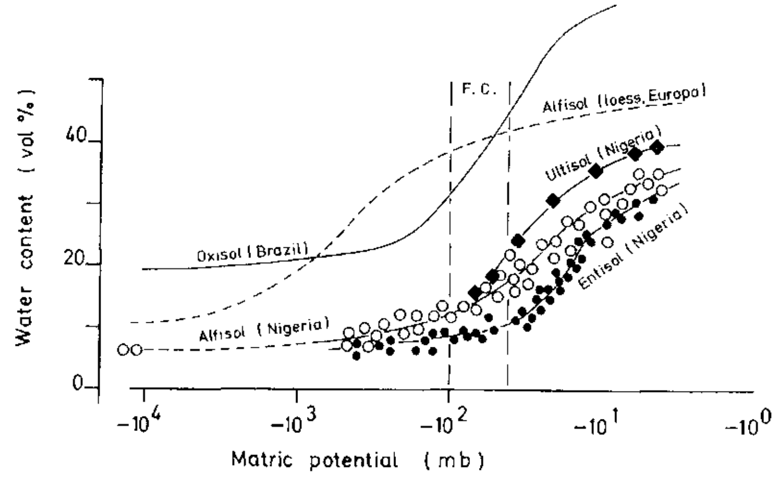

Fig. 1 Soil water retention curves for some typical tropical soils compared with a typical soil from central Europe.

Except for the very low suction range (< -3000 Pa) and the permanent wilting point the data in fig. 1 are field data determined on cropped soils in 30 cm depth. Field capacity was found to be in the range of -5000 and -10000 Pa whereas in temperate soils it is taken to be between -10000 and -30000 Pa.

In a soil of this type, a rain of 50 mm would theoretically displace completely the water present in the soil 0-50 cm layer and with it the solutes contained in it.

METHODS FOR STUDYING LEACHING LOSSES

Broadly speaking, three approaches are possible for studying leaching losses under field conditions: (1) The auger method, (2) use of lysimeters, and (3) use of porous cups as soil solution probes in combination with tensiometers and/or equipment for determining soil moisture at frequent intervals such as neutron probes.

Method 1, requires only minimal instrumentation and still can yield meaningful results, whereas method 3, which is a more elaborate approach, may yield the most comprehensive set of data.

Table 2 Estimated recovery of applied N (%) by crops and retention by soil (0-120 cm). Data are mean values of both limed and unlimed plots*. Arora and Juo (1982)

N treatment	Recovery by crops Maize	Rice	Recovery by two crops	Retention by soil** 0-120 cm	Total recovery	Total loss
One application	22	31	25	22	47	53
Two splits	35	39	36	20	56	44
Three splits	41	61	49	23	72	28
L.S.D. (0.05)	11	7	8	-	-	-

* 150 kg N/ha of CAN applied to maize and 90 kg N/ha of CAN applied to rice.
** Sample taken at the end of the second cropping season.

The auger method

The auger used should be as narrow as possible. Preferably, it should be one that allows core sampling to at least one meter depth and can be extended for sampling to two meter depth. The cores can be sectioned into the required depth intervals for analysis. Changes in NO_3 content can be attributed to losses or gains. The displacement whithin the profile from one layer to the other can only be obtained if either the changes are larger or the nutrient considered is completely dissolved in the soil solution.

This is unfortunately a destructive method, which does not allow frequent sampling without making the plot unsuitable for further experimentation.

Arora and Juo (1982) using this method, recovered 47-72 % of N applied (150 + 90 kg N applied as CAN in two seasons) (Table 2), of which 25-49% were recovered in the aboveground parts of the crops and 20-23% were retained by the soil mainly in the layer below 40 cm. This amount can be available to the next crop, unless it will move down further beyond the rooting zone during the next raining season. Splitting the fertilizer dose significantly increased recovery. On a bare plot losses were the highest (> 60%).

Lysimeters

When it comes to obtaining practical data that have a bearing on actual field conditions only monolith lysimeters are of any value. They must be provided with either porous plates or porous cups at the bottom, so that corresponding suction as observed in the field at respective depth can be applied. Otherwise the water regime will be modified to such an extent with respect to the actual field situation, that data collected can be misleading. This is especially true in soils with frequent wetting and drying cycles such as observed in the savannah areas (Pieri, 1979).

If the above conditions are met, lysimeter studies can give very precise results about leaching losses, but not on NO_3 distribution in the profile. It provides a total balance between input and output.

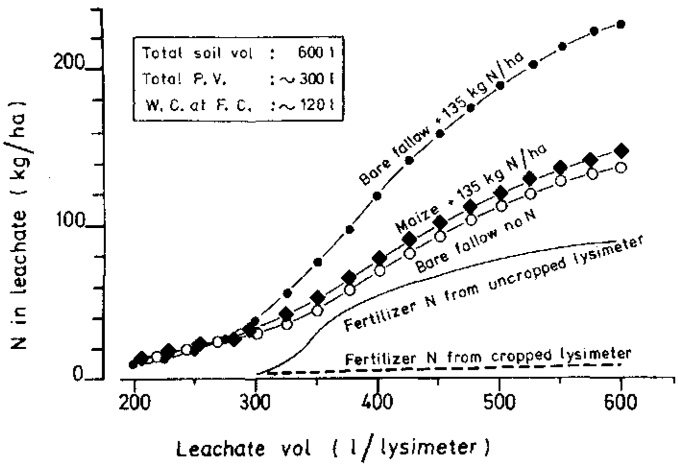

Fig. 2. Cumulative NO_3 leaching curves from monolith lysimeters with differen treatments (South-east Nigeria, Ultisol, ∿ 2400 mm rain) (M. Wong, A van der Kruijs and A.S.R. Juo, unpublished data).

Figure 2 gives the results of a lysimeter experiment which was carried out at the high rainfall Station of Onne in South Eastern Nigeria. Here again high leaching losses occurred. Significant NO_3 leaching occurred only after one total pore volume TPV had been displaced from the lysimeter which is equal to 2.5 times the amount of water corresponding to field capacity. It appears, that water percolation down the profile bypassed the larger part of the NO_3 apparently held in microsites which is not readily equilibrated with the percolating water which moved through the macro or transmission pores.

This indicates, that leaching losses are less than one would expect on the basis of rainfall, water holding capacity and nitrate concentration alone.

Soil solution probes and tensiometers

Using soil solution probes and tensiometers is an alternative method allowing quasi-continuous monitoring of nutrient concentrations and of the soil water regime with a minimum disturbance of the soil. This method also allows gathering of data over unlimited time from the same field. This method relies on seperate determination of nutrient concentration in the soil solution and water flow.

Suction probes have been in use for quite some time (Strebel et al., 1973), but it is the simultaneous combination of soil solution sampling and determination of water movement that makes the method attractive (Strebel et al., 1973; Renger et al., 1975; Strebel et al., 1980).

Suction probes and tensiometers are installed at various depth according to the design of the experiment. Soil solution can be sampled at any time the soil contains sufficient water at a matric potential $>-7x10^4$ Pa. The maximum suction that can be applied to the probes is usually around $-8x10^4$ Pa and depends largely on the quality of the porous cups.

Whether a sufficient amount of water is extracted depends, of course, on the amount of water held by the soil in the working range of the soil solution probes, and on the hydraulic conductivity in this range of matric potentials. It is possible to get a good resolution in time and depth and thus a very detailed picture of what is going on in the soil. Phosphorus and heavy metals cannot be studied with this method since these elements interact strongly with the ceramic or (as an alternative) the nickel sinter material of the porous cups.

The method allows calculation of total water flow (w_{tot}) = flow through roots (v_r) + capillary flow (v_{cap}) as a function of depth and time:

$$w_{tot} = v_{cap} + v_r \quad (1)$$

By differention one obtains the water uptake rate of the roots. Written in the form of finite differences, it reads as follows (z = depth):

$$r = \frac{\Delta v}{\Delta z} \quad (2)$$

The capillary flow is determined using Darcey's law;

$$v_{cap} = -k\ (\psi)\ \frac{\Delta\psi}{\Delta z} \quad (3)$$

k = soil water conductivity as a function of ψ
ψ = matrix potential
z = gravitational potential (or depth resp.)
ϕ = hydraulic potential ($\psi+z$)

The total flow is calculated using the continuity relationship.

$$v_{tot_2} - v_{tot_1} = \sum_{z_1}^{z_2} \frac{\Delta\theta}{\Delta t} \Delta z \qquad (4)$$

(θ = water content, t = time)
Nitrate massflow to the roots can then be calculated for each depth interval using the relationship

$$r_{NO_3} = v_r \cdot conc_{NO_3} \qquad (5)$$

and the amount of NO leaching from a given compartment or layer of a soil can be calculated as follows:

$$l_{NO_3} = v_{cap} \cdot conc_{NO_3}$$

In order to be able to calculate v_{cap} and v_{tot}, one needs to know volumetric soil water content and the soil water matric potential both as a function of time and depth. In addition for each soil layer the relationship between soil water conductivity and soil water matric potential needs to be known. Water conductivity can be either determined in the laboratory or in the field.

An installation of this type was set up on two sites at the IITA mainstation of Ibadan, Nigeria in 1983. The first results are available. However, soil water conductivity has not yet been determined so that no complete analysis of the nutrient dynamics could be carried out.

Figure 3 shows the distribution of NO_3 concentrations with depth in an Alfisol under maize. The initially very high concentrations in the topsoil decrease very rapidly with time and depth. There was some displacement into deeper layers, but apparently without loss beyond the rooting subsoil zone, since during this time there was no downward movement of water, but the hydraulic gradient was directed towards the surface.

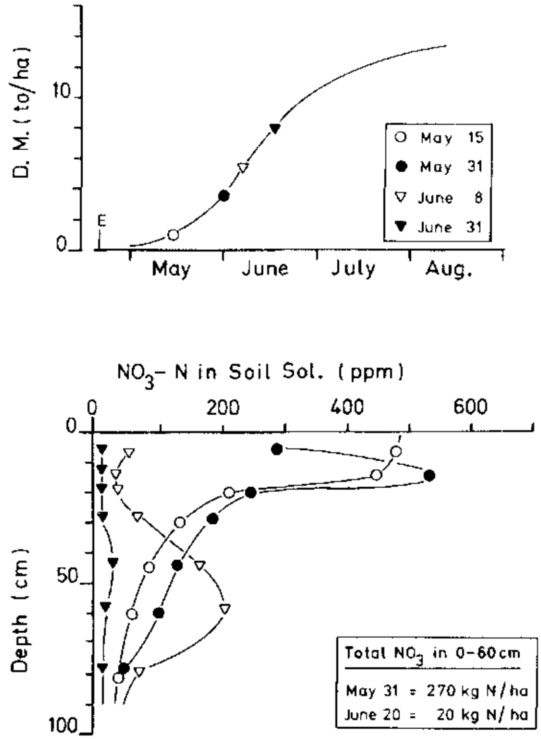

Fig. 3. Nitrate concentrations in the soil solution of an Alfisol (Egbeda series, Ibadan Nigeria) under maize at different times during the growth period and the growth curve of maize (total dry matter). The symbols on the growth curve indicate the growth stages at which the soil solution composition was analysed. Maximum and minimum NO_3-N content in the 0-60 cm layer (rooting zone) are also given.

Figure 4 shows this relationship clearly. From last part of May onwards there were for about 4 weeks with no leaching conditions. At the beginning of this period the total NO_3-N present in the rooting zone (0-60 cm) attained its maximum and then declined rapidly towards the end of June. This corresponded to the time of maximum uptake rate.

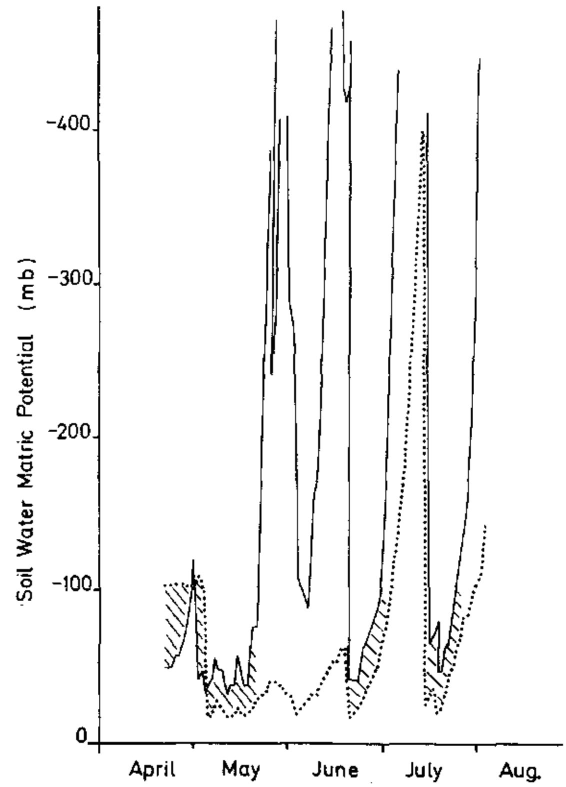

Fig. 4. Soil water matric potential in two different depths in an Alfisol (Egbeda series, Ibadan, Nigeria) profile under maize during the main rainy season. Shaded areas indicate periods with downward hydraulic potential, periods during which leaching could take place. (H. Grimme and A.S.R. Juo, unpublished data).

Although the leaching losses - if any - cannot yet be quantified, it appears they were low. This conclusion would agree with the findings of Pieri (1979), Vachaud et al (1982) and Chablier (1984), who observed with rainfall of up to 1200 mm a year, leaching losses of only 8-15 kg N/ha/year .

General remarks

In principle, leaching losses from a given soil layer depend on the amount of water moving out of this layer and the concentration of NO_3 in the soil water. Since the NO_3 concentration changes with time frequent measurements are necessary, unless it is possible to collect and analyse the whole leachate as done in a lysimeter. The lysimeter, however, does not give any insight into processes inside the lysimeter. The NO_3 concentration is affected by mineralization, fertilization, denitrification and plant uptake. This affords some means for minimizing losses to some extent by appropiate agronomic measures, such as timing of fertilizer application, adjusting planting dates and using for the first season crops that have a rapid early uptake period.

Under high rainfall conditions (> 2000 mm) leaching losses seem to be unavoidable because rainfall substantially exceeds the water storage capacity of the soils prevailing under these conditions and the evapotranspirative demand. But as the NO_3 leaching lags behind water percolation there is probably still some room for keeping losses within reasonable limits. On the whole compared with temperate regions only few reliable field data are available to make a sound general assessment of the situation.

LOSSES THROUGH DENITRIFICATION

Only denitrification in upland soils will be dealt with in this chapter. There exists a large body of information on the principles governing denitrification in soils but there are only little reliable data on actual losses in the field particularly for tropical soils. Hoffmann and Pagel (1979) compiled data on denitrification losses under field conditions, but they could quote only one paper on denitrification losses under tropical conditions. With such a dearth of hard facts this review must of necessity remain rather general.

According to the literature, denitrification losses vary from 0 - 100% of fertilizer nitrate added, but many of the results have been obtained under rather artificial conditions or are only estimates (Hoffmann and Pagel, 1979). The factors governing the process of denitrification in soils are well known. Apart from the presence of NO_3, presence of readily decomposable organic matter as an energy source, absence of oxygen and temperatures > 10 °C are needed for denitrification to take place at a significant rate.

CONTROLLING FACTORS

Temperature

The denitrification rate increases above 10-15 °C exponentially up to 75 °C (Knowles, 1981), so that temperature will hardly be a limiting factor in tropical regions. An interesting observation was made by Misra et al. (1974), who pointed out that in their column experiments at 34.5 °C the reaction rate was independant of the oxygen concentration in the soil, whereas at 19.5 °C it decreased with increasing oxygen concentration. They attributed this result to an increase in the efficiency of the anaerobic component of the microbial population in comparison to the activity of the aerobic ones. This seems to be rather farfetched considering the fact that oxygen represses nitrate reductase and especially nitrogen oxide reductases. But since oxygen solubility in water decreases with rising temperature and soil bacteria depend on the oxygen dissolved in the soil water, it is possible that in combination with root and microbial respiration it generated anaerobic pockets in the soil causing denitrifiers to switch their metabolism from aerobic to anaerobic. If this finding could be corroborated, one would have to assume the possibility of denitrification losses under tropical conditions during most of the growing season, the main limiting factor then being nitrate concentration in the soil.

Soil water content and oxygen

Denitrification takes place only in the absence of oxygen. Thus denitrification is usually associated with at least temporary water-logging conditions. But significant denitrifaction rates recorded at soil water contents far below field capacity (Ekpete and Cornfield, 1964; v. Rheinbaben and Trolldenier,1984), which were attributed to the existence of anaerobic microsites in highly aggregated soils with a discontinuous pore system. It has been observed, that there may also be an anaerobic environment along plant roots even in a well aerated soil (Woldendorp, 1963).

On the other hand temporary water-logging which occurs during and after a tropical storm need not necessarily lead to anaerobic conditions, since air will be trapped in the soil and the rain water (which has a low temperature) will be saturated with oxygen. It will take some time before the conditions will be favourable for denitrification. But in general the changes for denitrification to take place increase with increasing soil water content.

Organic Carbon

The denitrification potential decreases with depth (Dubey and Fox, 1974; Cameron et al., 1978). This is due to the gradually decreasing organic matter content with depth. The denitrifiers depend on soluble organic matter for their energy supply (Bremmer and Shaw, 1958; Stanford et al., 1975), which is correlated with total organic matter content and biological activity.

But the growing plant itself is a source of available carbon (Trolldenier, 1971, 1981; Kraffczyk et al., 1984) in the form of exuded sugars, organic acids, mucilage and sloughed off root cells. In fact, the rhizosphere is a preferential site of denitrification with a higher denitrification rate than the surrounding soil (Trolldenier, 1981; v. Rheinbaben and Trolldenier, 1984).

General remarks

From the above discussion it would appear, that it is not possible to judge from measurements of soil water content, oxygen concentration, pH, and organic matter content, the possibility of denitrification losses since these measurements reflect only the macroscopic or average situation in the soil. The condition in aggregates and adjacent to roots may be very different from the average. On the other hand conditions favouring denitrification (lack of oxygen, soluble organic matter) at microsites may be very transient.

Time is usually not taken into consideration as a factor, but might yet be of importance. In the tropics rain comes mostly as heavy storm which may cause temporary water-logging. But apart from the fact that oxygen occluded in the soil and contained in the rain water has first to be used up, the denitrifiers need some time to adjust their metabolism to anaerobic conditions which takes approximately 8-15 hours (v. Rheinbaben and Trolldenier, 1984). After this time conditions may already be unfavourable for denitrification.

The plant serves a twofold function in this context. By taking up nitrate, it reduces the quantity available for denitrification. By withdrawing water it improves the aeration of the soil especially in the vicinity of the roots. On the other hand the exudation of soluble organic compounds and the presence of mucilage create a favourable environment for denitrification so that denitrification is particularly high when abundant living roots are present in the soil (Dilz and Woldendorp, 1960; v. Rheinbaben and Trolldenier, 1984).

Denitrification is controlled by several independant factors which undergo seasonal as well as very rapid fluctuations and which interact with each other. This explains why denitrification in soils does not happen as a continuous process but is usually recorded as individual events which take place at irregular intervals depending on the constellation of the relevant factors. Thus it is extremely difficult to predict, for a particular environment, the overall denitrification rate (Knowles, 1981).

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MODELLING OF TRANSPORT, TRANSFORMATION AND UPTAKE OF NITROGEN IN AN ULTISOL FOR HIGH RAINFALL CONDITIONS

Key words - Leaching Modelling Nitrification Nitrogen uptake Soil nitrogen

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SUMMARY

The most important processes in the soil nitrogen cycle of arable soils in the humid tropics are leaching, mineralization/immobilization, nitrification and crop uptake. In this paper these processes are discussed for conditions as they prevail at the high rainfall agricultural station in Onne (Nigeria).

The soil is an Ultisol, characterized by low pH and small amounts of exchangeable bases.

To get a better understanding of the interaction of the separate processes, they were integrated in a computer model. With this model some exploratory calculations were made about the influence of soil pH, thickness of the root zone, and split application of fertilizer.

The calculations showed a.o. that more benefit can be expected from splitting the fertilizer application than from liming the soil.

1. INTRODUCTION

Because of the great agronomic interest many attempts to develop models on the nitrogen cycle in the soil (see Tanji and Gupta, 1978; Frissel and van Veen, 1981; de Willigen and Neeteson, 1985) have been made. Due to the number and complexity of the processes involved usually one has to fall back on the brute force of the computer to evaluate the models quantitatively. In doing so it is possible to integrate the knowledge of the effect of various processes and to incorporate these into a single model. It is, however, pointless to aim at a complete model i.e. a model in which all conceivable processes are incorporated even if this would be possible. The words of van Wijk (1963) on what he calls the physicomathematical method apply to modelmaking as well: "The very pur pose ...... is to isolate the essential characteristics of the problem and to abstract them of the less essential ones". Which processes are considered essential and which are not depends on the objective of the model and on the personal preference and scientific background of the modelmaker. So some of the numerous models on the soil nitrogen cycle emphasize either the microbiological transformations (Van Veen and Frissel, 1981; Paul and Juma, 1980), or the physical and chemical aspects of nitrogen movement and adsorption (Tanji et al, 1981; Wagenet, 1981), or the agronomic applicability (Addiscott, 1982; Zandt and De Willigen, 1981).

In this paper we will present and discuss a tentative computermodel in which the processes which are regarded as being of prime importance for the nitrogen cycle of arable soils in the humid tropics (Wetselaar and Ganry, 1982; Greenland, 1978) are integrated:

1. Transport of mineral nitrogen in the soil, generated by soil water movement and concentration gradients.
2. Mineralization/immobilization of nitrogen, accompanying microbial decomposition of organic matter.
3. Nitrification, the oxidation of ammonium to nitrite and subsequently to nitrate.
4. Uptake of nitrogen by the crop.

Parameter values and environmental conditions in the model are chosen so as to correspond to the situation in Onne (Nigeria) as much as possible. (See Pleysier and Juo, 1981 and Van der Heide et al., 1985 for a description of some physical and chemical properties of the soil here, and Lawson (undated) for a description of the climate).

2. DESCRIPTION OF THE MODEL

In the model a soil column of 1.20 m length is considered. The column is divided from top to bottom in 4 layers of 5 cm, 4 layers of 10 cm, and 3 layers of 20 cm thickness. All processes taking place in a given layer, as well as the transfer of water and nutrients from one layer to another, are described by rate equations, which are numerically integrated.

The velocity of water flow is calculated as the difference between average rainfall and evapotranspiration over the various months. Data concerning precipitation and evaporation were taken from Lawson (undated), and are displayed in fig. 1. For those periods in which rainfall exceeds evapotranspiration, the column is assumed to have a water content of 0.2 ml/cm^3 throughout, corresponding to the water content at field capacity (Arora and Juo, 1982); when evapotranspiration exceeds precipitation the water content is put at 0.1 ml/cm^3, the value at the wilting point (Lal, 1979).

Transport of solutes through the soil is described as consisting of two components, mass flow and dispersion flow. The former is calculated as the product of flow of water and the local concentration, the latter is proportional to the concentration gradient, the proportionality constant being found as the product of the velocity of the water flow and a so-called dispersion length (Frissel et al, 1970).

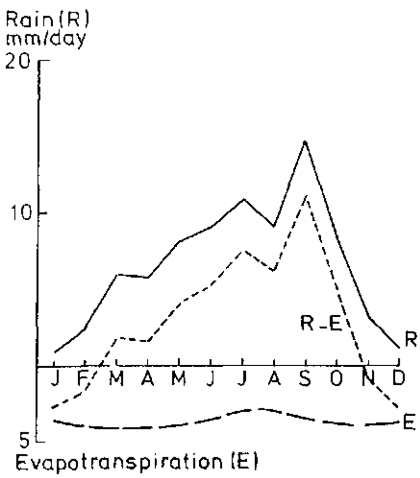

FIG. 1. Average precipitation (R), evapotranspiration (E), and net precipitation (R-E) at Onne (after Lawson).

The value of this last parameter was put at 3 cm after Frissel et al. (1970). Adsorption of nitrate was assumed to follow a linear adsorption isotherm, with an adsorption constant of 0.3 ml/cm^3 (Pleysier and Juo, (1981)).

For ammonium adsorption the findings of Pleysier et al. (1979) were used as the starting point. They present data on the exchange equilibria of various cation pairs of the Onne soil, and calculated selectivity coefficients of Ca/K-, K/Na-, Al/K-, and Al/Ca-exchange. From these data the distribution coefficient, giving the ratio of adsorbed ammonium to ammonium in solution, was calculated as a function of total amount of ammonium and the electrolyte concentration of the soil solution. In doing so, it was assumed that ammonium behaves like potassium as far as its exchange properties are concerned that the only cation competing with ammonium for the exchange complex is Al, and that 70% of the exchange complex is occupied by aluminum (Pleysier et al, 1979; Arora and Juo, 1982). In the computer model a two-way table is used containing the results, so that at any moment during the calculations the distribution coefficient can be calculated from the electrolyte concentration and the total amount of ammonium in a certain soil layer by interpolation of this table. The concentration of nitrate in the soil solution is calculated from the nitrate content divided by the sum of the adsorption constant and water content. The concentration of ammonium in the soil solution is calculated similarly, using the distribution coefficient. The concentration of ammonium in the soil solution cannot exceed that of nitrate, as the latter is assumed to be the only anion present.

All microbial transformations of nitrogen (mineralization, immobilization and nitrification) are assumed to take place in the upper 20 cm only. Mineralization and immobilization of nitrogen is calculated according to the method of Van Faassen and Smilde (1985).

In Europe, for soils under cultivation, conditions are usually such that nitrification proceeds at a much faster rate than the release of ammonium due to organic matter decomposition. Under such conditions all mineral nitrogen can safely be assumed to occur in the form of nitrate only, as indeed is done in many models. But in Onne the prevailing pH of the soil - which is one of the important rate determining factors for nitrification - is 4.5 or lower (Van der Heide et al., 1985), much lower than in arable soils in Europe. Arora and Juo (1982) present data on the production rate of nitrate of the Onne soil as a function of soil pH. If the oxidation of ammonium to nitrite is considered as the rate-limiting step in the nitrification process, which implies that no nitrite will accumulate, relevant processparameters can be calculated from their data as follows. When the ammonium concentration is higher than 5 mg/kg the growth rate of the population of ammonium-oxidizing bacteria can be assumed to be proportional to the size of the population (Van Veen, 1977). The decay rate can also be assumed to be proportional to population size. The net increase of ammonium oxidizers accordingly can be given as follows:

$$dM/dt = (m-k)M \quad (1)$$

where M is the number of bacteria cell/g soil
m is the specific growth rate 1/day
k is the specific decay rate 1/day
t is time day
Integration of (1) leads to:

$$M = M_0.\exp[(m-k)t] \quad (2)$$

where M_0 is the number of bacteria present at $t = 0$.

The disappearance rate of ammonium is formulated as:

$$dNH_4/dt = -m.M/Y$$

where Y is the growth yield, giving the number of cells produced per unit of ammonium oxidized. If no nitrite accumulates, the production rate of nitrate equals the disappearance rate of ammonium:

$$dNO_3/dt = m.M/Y \qquad (3)$$

Substituting (2) in (3) and integrating yields:

$$NO_3 = \frac{m.M_0}{y(m-k)} \left[\exp\{(m-k)t\}-1\right] \qquad (4)$$

Data collected by Van Veen (1979) shows, that a probable value for k is 0.12 day^{-1}, and that Y is of the order of 10^8 cell/g. Using these values, m and Mo were estimated by trial and error from the data of Arora and Juo (1982). In table 1 the estimated values are given.

TABLE 1. Initial Number (M_0) and Specific Growth Rate (m) of Ammonium Oxidizers as Function of pH (after Arora and Juo, 1982).

pH	M_0 cell/g	m day^{-1}
4.1	$1.3*10^4$	0.15
4.8	$1.6*10^4$	0.18
6.1	$2.0*10^4$	0.27

In fig. 2 the production of nitrate calculated according to (4) using above mentioned parameter values and those given in table 1 is shown together with the measured production.

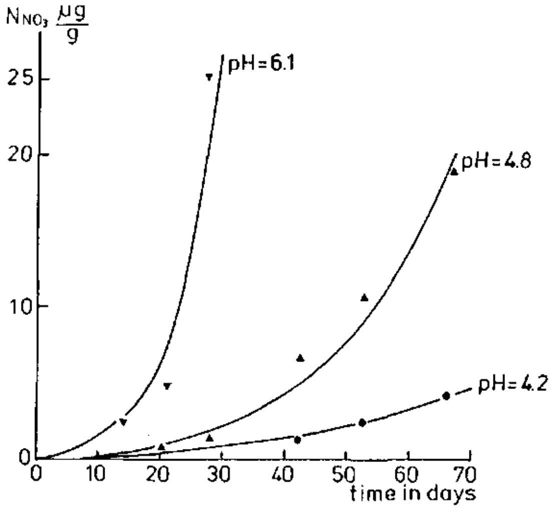

FIG. 2. Nitrate production of the Onne soil at different pH-values. Points are results of Arora and Juo (1982), lines are calculated with equation (4).

It is apparent that the course of nitrification is reasonably well described by equation (4). Accordingly in the model nitrification was described by the rate equations (1) and (3), where m is taken to be proportional to the ammonium concentration when the latter drops below 5 mg/kg.

The rate of nutrient uptake and of nitrogen in particular, is largely determined by plant demand rather than by the concentration of the nutrient in the soil solution (Clarkson and Hanson, 1980; Scott Russell, 1982). It can be shown that even in the case of a high nutrient demand and a low root density, both effecting a high uptake requirement, the mobilitity of nitrate in soil is high enough to ensure transport to the root at the required rate (De Willigen, 1981). This is illustrated by fig. 3 which shows the fraction of nitrate (Fd) in soil which can be taken up at the required rate as a function of root density (W, expressed as root length/volume of soil).

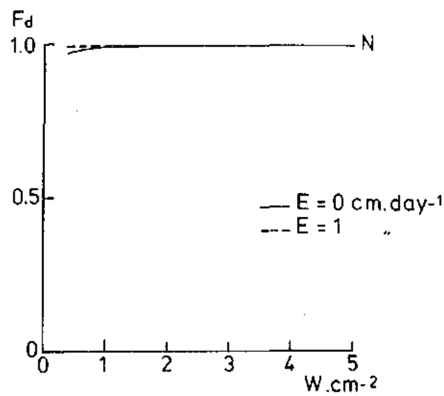

FIG. 3. Fraction (Fd) of soil nitrate available for uptake as function of root density when transport to the root is by diffusion only (E=0) or by diffusion and massflow.

With a low root density of 0.5 $cm.cm^{-3}$ more than 95% of the nitrate present can be taken up at the required rate, even when transport to the root is by diffusion only. In the model the demand of the crop (maize) was assumed to be as depicted in fig 4. This figure represents a smoothed curve of data collected by Van der Heide et al. (1985). All nitrate and ammonium in the soil solution of the root zone was assumed to be completely available to the crop. The ratio of ammonium uptake to nitrate uptake was taken to be the same as the ratio of ammonium/nitrate concentration in the soil solution as was observed by Warncke and Barber (1973).

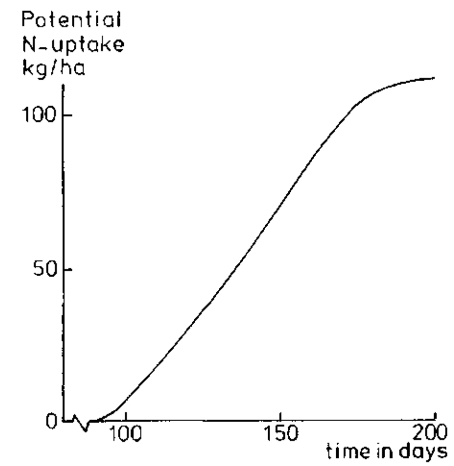

FIG. 4. Assumed potential uptake of a maize crop at Onne.

Uptake of nitrogen is calculated as follows; if the amount of nitrogen in the soil solution of the top layer of the root zone is high enough to satisfy the demand, uptake is confined to this layer; if not, the amount present is taken up, and it is checked if the next layer contains sufficient nitrogen to fulfill that part of the crop requirement not satisfied by uptake from the first layer and so on until the last layer of the root zone is reached. The root zone is assumed to have constant thickness, the root density is 1 cm/cm^3 soil throughout the root zone, and the roots are assumed to have a radius of 0.02 cm. Care is taken that the uptake rate does not exceed the maximum uptake rate per cm^2 of root surface as found by Warncke and Barber (1973). The initial condition as far as the different fractions of soil organic matter are concerned was chosen in correspondence with an equilibrium situation where crop residues in the form of 3400 kg dry matter (maize stover) are added annually to the top layer of the soil profile. The initial nitrate and ammonium content were put at 1 kg N/ha for each layer of the profile. The addition of crop residues, as well as that of fertilizer (150 kg/ha N as ammonium nitrate) takes place just before the maize crop was planted (mid-March).

3. RESULTS

First the effect of rooting depth and soil acidity were investigated. Runs were made for three values of root zone thickness (15, 30 and 60 cm) and three pH-values (4.1, 4.8 and 6.1). The values of the root-zone thickness were chosen, because maize roots have never been found to penetrate deeper than 60 cm in the Onne soil.

Fig. 5 shows the nitrate content in the soil profile at harvest for 15 and 60 cm rooting depth (RODE).

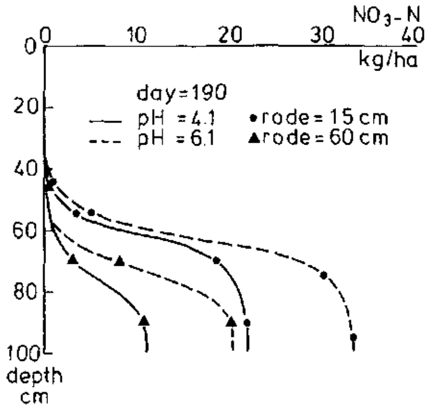

FIG. 5. Nitrate content as a function of depth for different rooting-depth and soil pH.

The results for RODE 30 cm fall between those for 15 and 60 cm. Whatever depth is reached by the roots, the upper 40 cm contains hardly any nitrate due to the combined effect of uptake and leaching. In the deeper layers the differences are rather large. The front is steeper for the lower rooting depth, the more so as the pH is higher.

The effect of pH (via the nitrification rate) can also be observed in fig. 6 where the course of the amount of ammonium in the root zone is given, for RODE = 15 cm.

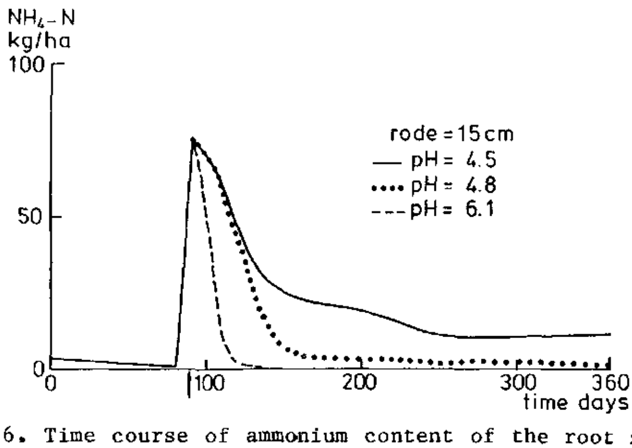

FIG. 6. Time course of ammonium content of the root zone for two values of the soil pH. Arrow indicates time of fertilizer application.

The average level of ammonium at high pH is quite low because of the high nitrification rate, at low pH the decrease is much slower. At harvest (day 190, day 1 being January 1) there still is about 25 kg NH_4-N in the upper 20 cm.

The influence of pH and rooting depth on nutrient uptake is shown in fig. 7.

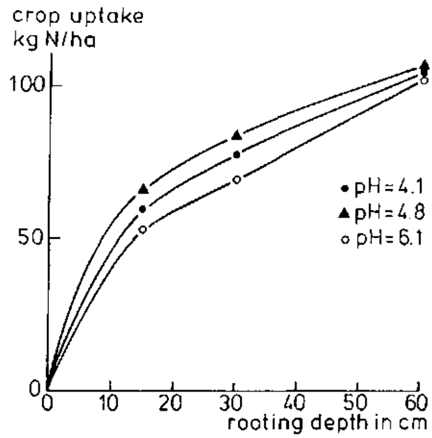

FIG. 7. Crop uptake as a function of rooting depth and soil pH.

A large rooting depth considerably enhances the uptake possibilities, as nitrogen (mainly in the form of nitrate) leached from the upper layers is intercepted by roots in deeper layers. At a pH of 4.8 nitrogen uptake is highest for all rooting depths considered. At this pH at the later stage of crop uptake (after day 140 see fig. 6) there still is some ammonium left in the root zone which is oxidized to nitrate, at a rate sufficient to make up the loss of nitrogen from the soil solution by leaching and uptake. At the lower pH more ammonium is present, but the nitrification rate is quite low, while at the high pH at day 140 all ammonium has been converted to nitrate and has subsequently leached out of the root zone.

Other calculations were made about the effect of split application. The amount of fertilizer nitrogen was split into two or three equal fractions which were applied at day 81 (the day of sowing), day 109 and day 137. The results of RODE = 15 cm with respect to uptake are shown in table 2. Splitting the application has a favorable effect on nitrogen uptake which is further enhanced by a higher soil pH. According to the calculations splitting the fertilizer application has more effect than increasing the soil pH, which was also observed by Arora and Juo (1982).

TABLE 2. Effect of Split Application on Nitrogen Uptake (in kg/ha), for a Root Depth of 15 cm.

	pH		
Split	4.1	4.8	6.1
1	60	66	53
2	66	78	60
3	82	95	84

4. DISCUSSION

A model necessarily is a simplification of the real system, the behaviour of which one wants to study. The choice how and where to simplify is made at two levels. First one has to decide which processes are to be included in the model. The justification for the choice made here was taken from Wetselaar and Ganry (1982), and Greenland (1978). One should at first sight expect that denitrification would play an important role since conditions as they prevail in the wet season in Onne must be favourable for denitrification: high temperature and abundant precipitation. But as Grimme and Juo (1985) make plausible, other conditions are so unfavourable that denitrification can be ignored quantitatively.

In addition to the determination of the processes which are to be incorporated in a model, one has to decide how the various processes should be described. The relative merits of some of the simplifications in this respect shall be discussed below.

Net precipitation and evaporation were taken to be as depicted in fig 1, e.g. in the model it is raining continuously in the wet season. From Lawson's data, however, it appears that the mean number of rain days in the growing season is less than 20 per month. In order to take the effect of dry days into account one would not only have to know the number of dry days, but also their distribution. An uninterrupted dry spell of e.g. five days would exert a greater influence than five dry periods of one day evenly distributed over an otherwise wet period. As no information of the average length of dry periods in the wet season was available the procedure mentioned above was employed.

As to the assumption of constant water content during the wet (and also the dry) season, Arora and Juo (1982) found the water content of the soil in April to be about 2% less and in August about 2% more than the value at field capacity, so this assumption would not seem unreasonable.

The soil chemical processes have been drastically simplified in the model. The complete neglect of cations other than Al and NH_4 leads to an overestimation of the adsorption of ammonium. The error is especially large where it is assumed that due to liming the soil pH has increased. Use of exchange equations as determined by Pleysier et al. (1979) would be an alternative, but this would make the calculations quite complicated. On the other hand, at high soil pH the nitrification rate has increased so much, that possibly no large errors are made when it is assumed that ammonium is immediately transformed into nitrate. If such an assumption is justified, one would not have to bother about ion exchange or adsorption other than nitrate adsorption.

In the model it has been assumed that changing the pH by liming only affected on the rate of nitrification. In reality many other processes and soil properties are more or less pH-dependent: root growth, nutrient uptake, the effective CEC, mineralization rate, etc. All these effects are neglected in the present approach, as it is believed that the dominant effect of changing soil pH as far as the soil nitrogen cycle is concerned, is that of changing the nitrification rate.

The potential nitrogen demand as a function of time was established by taking the highest values of crop uptake as determined by Van der Heide et al. (1985). An alternative would be to calculate the potential dry-matter production in Onne with models developed by De Wit and coworkers (De Wit, 1978), and to estimate the potential nitrogen uptake from these figures.

Root growth was not simulated. As mentioned before, the root system is assumed to have reached its definitive depth at the time of sowing. This obviously is not true, but experiments of Lal and Maurya (1982) have shown that root growth rates of about 5 cm/day under optimum conditions, as far as water and nutrient supply are concerned, are possible, so for shallow root systems the maximum rooting depth will be reached quite soon.

Though the results obtained with the model are plausible, this does not mean that the model in its present form can be used for quantitative predictions, as there are still many uncertainties with respect to the validity of the treatment of the various processes, even if the simplifications discussed above seem more or less justified. The model presented here is only a first approximation, and should be validated thoroughly by comparing model predictions with results of detailed experiments. In such experiments special attention should be given to root growth and development, to soil chemical processes, and soil microbiological processes.

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NITROGEN STATUS IN THE EARLY SUCCESSION OF TWO FOREST TYPES IN EAST KALIMANTAN, INDONESIA .

Key words: Early succession Kerangas forest Mixed dipterocarp forest Nitrogen

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SUMMARY

Changes in nitrogen status in topsoil (0-10 cm) and leaves of a mixed Dipterocarp forest (MDF) and a Kerangas forest (KF) after 1.5-year secondary succession were studied in East Kalimantan, Indonesia. Primary and 35-year old secondary forests were used as control plots.

N-content changes in soils and leaves in MDF and KF differed. In MDF, the soil N-content in primary forest < young secondary forest < old secondary forest, and in leaves N-content of young secondary forest > old secondary forest > primary forest. In KF soil N-content in primary forest > young secondary forest and old secondary forest and in leaves N-content of young secondary forest > primary forest > old secondary forest.

Soil and vegetation types, species and age of plants determine the N-contents in soils and leaves. Some non-leguminous species (e.g. dipterocarp species) are found to be able to extract more N than the others. The agricultural significance of these species is discussed.

INTRODUCTION

The tropical rainforest is biologically and ecologically the most complex and diverse plant community on earth. Species diversity is especially marked for trees, woody climbers and epiphytes. This complex forest is in a dynamic state and yet stable over a long period of time. It has a closed nutrient cycling including nitrogen (Odum 1969).

Tropical soils vary considerably, some are leached, acidic and poor in nutrients. One extreme is the bleached white sand podzols (spodosols) which are extremely poor in nutrients and support depauperate forests (Richards 1941, 1952, Klinge 1965, Whitmore 1975 and Riswan 1981, 1982). Because of the low content in bases and the paucity of animal seed dispersers (Jansen, 1974), the succession on such soil is slow (Riswan 1981, 1982).

In contrast to the traditional held view, that succession in the temperate zone is a predictable linear process, succession in the tropical rainforest is dynamic (Riswan, 1982). Disturbances will influence succession, and large-scale clearing results in rapid losses of nutrient and other changes in soil properties.

Harcombe (1977a) suggested at least 2 factors that may be involved in ecosystem recovery. They are: (1) retention of available nutrient, and (2) accumulation of nutrients. Retention refers to holding the nutrients that are present at the time of disturbance, which prevent nutrient loss. Accumulation involves both utilization of nutrient inputs and those made available through weathering.

The degree of nutrient retention is determined by the rapidity of successional regeneration. This involves both rate of colonisation and growth rate of vegetation (Marks, 1974). Bartholomew et al (1953) stated, that prevention of nutrient losses occurred by virtue of plant immobilization and storage of nutrients in plant tissue.

Others consider succession to be a process through which a species accumulates enough nutrients to make possible the increase of succeeding species rather than only a process of nutrient retention (Pomeroy, 1970). Harcombe (1977b) observed, that succession was not influenced by fertilizer application.

Data on changes is soil nutrient levels following secondary successions are well documented, but data on nutrient status in leaves of successional species in the tropics are lacking (Snedaker and Gamble, 1969; Stark, 1970 and Golley et al., 1975). Riswan (1977) observed, that nutrient status in leaves varies with plant family and with the seral status; pioneer species have a higher nutrient status than the mature phase species.

The present study is aimed at investigating the relationship of nitrogen status in the soils and leaves following the early succession in Mixed Dipterocarp Forest (MDF) and Kerangas (heath) Forest (KF).

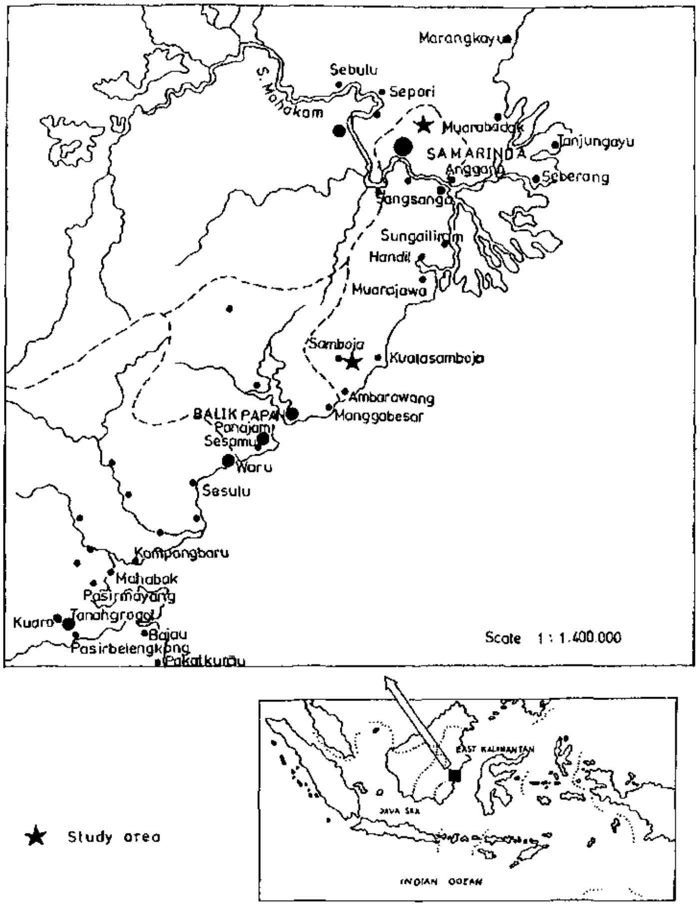

Figure 1. Map of study area Samarinda and Balikpapan and vicinity

DESCRIPTION OF STUDY AREAS

1. Mixed Dipterocarp Forest (MDF)

The study area is located at Lempake about 12 km, northeast of Samarinda, the capital city of the East Kalimantan province (Fig. 1). It lies within the 300-ha Mulawarman University forest, which is used as a teaching and research forest. It consists of primary, secondary and logged-over forests.

The Lempake area is covered by sedimentary rocks formed during the Upper Miocene period (Anonymous, 1965). Topography is undulating to somewhat hilly with an altitude of 40-80 m. The soil belongs to the Red-Yellow Podsolic Group (Hardjono, 1967).

The climate of this area is humid belonging to the rainfall type A with a Q value (ratio between the number of dry months and wet months) of 7.4 (Schmidt and Ferguson, 1951). Data of 38 years in the rainfall station near Samarinda, shows that the annual rainfall is 1935 mm with the monthly rainfall ranging from 97 mm in August to 206 mm in December (Berlage, 1949). The dry season occurs from July to September and the rainy season between October and June. The mean monthly temperature is 26.5 ^{0}C ranging from 24.5 ^{0}C in January to 28 ^{0}C July.

In a 1.6 ha of primary forest, Riswan (1982) recorded 209 tree species, twelve are dipterocarp species. Common species are; *Shorea polyandra*, *S. parvifolia* and *Hopea rudiformis*. Prevalent non-dipterocarp species dominated by the iron wood tree (*Eusideroxylon zwageri*), *Baccaurea macrocarpa*, *Cleistanthus myrianthus* and *Pentace laxiflora*.

2. Kerangas Forest (KF)

The study area is located in the kerangas forest at Gunung Pasir, Samboja, East Kalimantan, about 57 km north-east of Balikpapan (Fig. 1). The elevation ranges between 20 to 40 m above sea level.

The soils are white sand podzols derived from sedimentary rocks of the Upper Miocene formation (Anonymous, 1965). The climate is ever wet (Kartawinata, 1975), belonging to the rainfall type A with the Q ratio of 4.4 (Schmidt Ferguson, 1951). The 12 year records at Samboja show that the annual rainfall is 2347 mm, with a monthly rainfall ranging from 129 mm in October to 273 mm in April (Berlage, 1949).

Riswan (1979, 1982) notes, that the prevalent tree species in this forest type are *Tristania obovata*, *Cotylelobium flavum*, *Eugenia lepidocarpa*, *Brackenridgea hookeri*, *Eugenia claviflora*, *Cotylelobium malavanum*, *Callophyllum pulcherianum*, *Palaquium javense*, *Cotylelobium melanoxylon*, *Rapanea umbellate*, *Cratoxylum glaucum* and *Ormosia venosa*. In the primary KF, there are 24 tree species, while the secondary KF plot has only 8 species recorded (in 0.5 ha sampling plots).

EXPERIMENTAL METHOD

The Experimental Plots

Two experimental plots of 0.5 ha each, were established both in the primary MDF, and KF. The vegetation in these plots were clear-cut. One of the plots in each forest type had the debris burnt, while in the other plots debris were removed without burning. Each plot was devided into 100 subplots of 1 x 1 m^2.

Soil samples (10 x 10 x 10 x cm^3) were collected from a transect line at 20 m intervals. One composite sample of 1 kg was collected for analysis. Soil samples were taken at 6 weeks interval during the first six months, thereafter every six months. Total N was determined by Kjeldahl method .

Leaf sampling for N analysis depends on prevalence of species colonizing the ground during the early secondary succession. This consideration is based on the assumption that the prevalent species are responsible for the recovery of both the floristic and nutrient status of the forest ecosystems. Due to differences in the early succession in MDF and KF, only the following samples were taken for analysis: (1) leaf samples of dominant seedling in MDF, and (2) leaf samples of dominant resproutes in KF. N-content in the leaf was determined using a Technicon Autoanalyser II following acid digestions. The leaf is used as index, because it reflects a tissue that will reflect nutrient status of the plant, and it is also a suitable part of a plant for elemental analysis (Chapman and Brown, 1950; Smith et al., 1954).

THE CONTROL PLOTS

The control plots of MDF and KF were respectively a primary forest and a 35- year old secondary forest located close to the experimental area. The size of primary and old secondary forest control plots were 1.6 ha and 0.8 ha in MDF, and 0.5 ha each in KF. Methods for soil and plant sampling and analysis were similar. Leaf samples were collected from the most prevalent species in MDF and KF.

	Primary forest	Experimental plots (weeks)												30 - year old secondary forest
		Unburnt						Burnt						
		6	12	18	24	52	78	6	12	18	24	52	78	
I. MDF														
1. Number of samples														
- leaf (no of species)	35	9	10	28	28	22	23	9	24	27	29	35	41	32
- soil (0 - 10 cm)	9	7	7	7	7	7	7	7	7	7	7	7	7	6
2. N - content (%)														
- leaf	1.41	-	-	2.46	2.09	2.18	1.85	-	-	2.66	2.17	2.05	1.93	1.67
- soil (Total N)	0.18	0.19	0.17	0.21	0.19	0.14	0.17	0.16	0.18	0.21	0.25	0.16	0.17	0.24
II. KF														
1. Number of samples														
- leaf (no of species)	21	-	-	-	12	14	11	-	-	-	10	14	17	8
- soil (0 - 10 cm)	6	6	6	6	6	6	6	6	6	6	6	6	6	6
2. N - content (%)														
- leaf	0.99	-	-	-	1.01	1.01	0.95	-	-	-	1.16	1.05	1.04	0.81
- soil (Total N)	0.13	0.13	0.10	0.18	0.09	0.08	0.06	0.13	0.13	0.22	0.12	0.06	0.07	0.11

Table 1. Changes in N-levels in leaves and topsoils with time in primary and old secondary forests.

RESULTS

1. Vegetation recovery during early succession

The following results were observed by Riswan (1982) during early succession:

a. Mixed Dipterocarp Forest (MDF)

The early stage of secondary succession in burnt and unburnt plots showed, that the initial seedlings play a major role in the secondary vegetation. Resprouts of the original forest vegetation seem to be unimportant, only a few species with a few individual plants resprouted providing minimal vegetative cover.

A comparison between unburnt and burnt plots revealed, that the unburnt plot has a higher species number, higher percentage of vegetation cover and frequency for both seedling and resprouts. After 1.5 year, the total species number recorded in the unburnt and burnt plots were 149 and 110 respectively. They consist of trees, shrubs and herb seedlings and regrowth. The total number of tree species were 93 in the unburnt and 74 in the burnt plots. The number of primary forest tree species in the unburnt plot is twice the number in the burnt plot, but the number of secondary forest tree species is the same.

b. Kerangas Forest (KF)

Unlike the results observed in MDF, the early succession in both the unburnt and burnt plots are dominated by vegetative resprouts from the stumps of primary forest species. There were 23 species in the unburnt and 16 in the burnt plots. The floristic composition in unburnt and burnt plots after 1.5 year is quite similar. Dominant species are *Tristania obovata*, *Cotylelobium flavum* and *Eugenia spicata*.

2. Changes in soil - N content

The study was not restricted to that of soil-N, but also included determination of other chemical and physical soil properties. The results are summarized as below (Riswan, 1982):

- pH is very low; 3.6 to 5.0 in MDF and 3.4 to 4.0 in KF sites.
- The MDF site has higher clay (21-36%) CEC, exchangeable bases, and total P (115 tp 140 mg/kg) contents than the KF site dominated by red yellow podzoli soils, which showed much lower clay (< 10%) and total P content (6-18 mg/kg)
- Soil organic matter level in primary KF > secondary KF > secondary MDF > primary MDF.
- Soil-N in secondary MDF > primary MDF.
- C/N ratio in KF > C/N ratio in MDF sites.

The patterns of soil-N changes in MDF and KF following the early succession are summarized in Table 1. It shows that the soil-N content increases during the first 18 weeks in KF and 24 weeks in MDF. During the early succession, soil-N content declines faster in KF than in MDF.

Table 2 : The N – leaf concentration (%) in Primary MDF plot, Samarinda East Kalimantan

No.	Species *	Period of			Mean
		Feb. '78	Aug. '78	Feb. '79	
Dipterocarpaceae					
1.	Shorea leprosula	1.60	1.91	1.67	1.73
2.	S. assamica var. globifera	1.58	1.66	1.77	1.67
3.	S. parvifolia	1.70	2.19	1.52	1.80
4.	S. smithiana	0.95	1.34	1.17	1.15
5.	S. palembanica	1.37	1.95	1.95	1.76
6.	S. ovalis ssp. ovalis	1.35	1.52	1.32	1.40
7.	S. polyandra	1.48	1.76	1.90	1.71
8.	Dryobalanops beccarii	1.05	0.96	1.05	1.02
9.	Hopea rudiformis	1.90	2.20	1.77	1.96
10.	Dipterocarpus cornutus	0.86	1.08	0.84	0.93
Annonaceae					
11.	Monocarpia marginalis	2.30	2.92	2.42	2.55
Sapotaceae					
12.	Palaqium hexandrum	1.68	1.25	1.37	1.43
Tiliaceae					
13.	Pentace lariflora	1.85	2.25	2.02	2.04
Lauraceae					
14.	Litsea sp.	1.67	2.07	1.80	1.85
15.	Eusideroxylon zwageri	1.05	1.69	1.17	1.30
Myrtaceae					
16.	Eugenia suringarianum	1.27	1.49	1.65	1.47
17.	E. siculanensis	0.96	1.12	1.35	1.14
18.	Syzygium racemosum	1.08	–	–	1.08
Anacardiaceae					
19.	Koordesiodendron pinnatum	1.10	1.75	1.32	1.39
Moraceae					
20.	Artocarpus tamaran	1.70	1.90	1.82	1.81
Euphorbiaceae					
21.	Glochidion loistylum	1.25	1.60	1.34	1.40
22.	Mallotus muticus	1.27	1.32	1.50	1.36
23.	Baccaurea macrocarpa	0.95	1.07	0.92	0.98
24.	Cleistanthus myrianthus	1.19	1.65	1.27	1.37
Theaceae					
25.	Gordonia excelsa	0.76	0.79	0.90	0.82
Elaeocarpaceae					
26.	Elaeocarpus acmocefolius	1.35	1.50	1.32	1.39
Sapindaceae					
27.	Peranephelium sp.	1.54	1.32	1.21	1.36
Leguminosae					
28.	Intsia palembanica	2.02	2.30	2.10	2.14
Olacaceae					
29.	Ochanostachys amentacea	1.70	2.12	1.50	1.77
30.	Scorodocarpus borneensis	1.97	2.40	2.39	2.25
Dilleniaceae					
31.	Dillenia eximia	0.90	1.42	1.20	1.17
32.	D. excelsa	0.99	1.12	1.00	1.04
Ebenaceae					
33.	Diospyros macrophylla	0.90	1.30	1.46	1.22
Fagaceae					
34.	Quercus gemelliflora	[illegible]	1.76	1.47	1.45
Flacourtiaceae					
35.	Ryparosa javanica	1.95	1.40	2.20	2.18
	Mean ± standard deviation	1.41 ± 0.43	1.58 ± 0.49	1.51 ± 0.42	1.52 ± 0.41

Note : * Leaf samples were collected from the same tree.

Table 3 : The N – leaf concentration (%) in Secondary MDF Samarinda, East Kalimantan

No.	Species *	Period of			Mean
		Feb. '78	Aug. '78	Feb. '79	
Melastomataceae					
1.	Pternandra galeata	0.85	0.90	1.05	0.93
2.	P. rostrata	1.05	0.96	0.95	0.99
Rubiaceae					
3.	Nauclea orientalis	1.45	1.70	1.42	1.52
4.	Urophyllum polyneurum	2.25	1.67	2.34	2.09
5.	Anthocephalus chinensis	1.77	–	–	1.77
Moraceae					
6.	Artocarpus elasticus	1.42	1.70	1.12	1.41
7.	A. integer	2.24	2.15	1.75	2.05
8.	A. tamaran	0.92	0.91	0.85	0.89
9.	Cratoxylum sumatranum (Hypericaceae)	1.38	1.31	1.10	1.26
Leguminosae					
10.	Pithecelobium microcarpum	2.75	2.42	2.82	2.66
11.	Fordia gibbsiae	2.50	2.57	2.07	2.38
Lauraceae					
12.	Eusideroxylon zwageri	1.80	1.51	1.60	1.64
13.	Litsea costalis	2.07	1.40	2.00	1.82
14.	Lindera lucida	1.80	1.36	1.42	1.32
Euphorbiaceae					
15.	Macaranga gigantea	2.20	1.67	1.90	1.92
16.	M. winkleri	2.15	1.82	1.99	1.99
17.	M. conifera	1.57	1.28	1.37	1.41
18.	M. pruinosa	1.65	1.92	1.42	1.66
19.	Bridelia glauca	1.64	1.87	1.34	1.62
Myrtaceae					
20.	Syzygium racemosum	1.76	1.04	1.90	1.57
21.	S. lineatum	1.04	1.40	1.21	1.22
Actinidiaceae					
22.	Saurauia subcordata	1.42	1.30	1.36	1.36
Symplocaceae					
23.	Symplocos fasciculata	1.96	1.66	1.65	1.76
Sapotaceae					
24.	Payena lucida	1.94	1.37	1.05	1.45
Olacaceae					
25.	Strombosia javanica	1.48	1.60	1.65	1.58
Sapindaceae					
26.	Nephelium lappaceum	1.96	2.14	1.25	1.78
Burseraceae					
27.	Canarium littorale	1.43	1.25	1.42	1.37
Annonaceae					
28.	Canangium odoratum	1.38	1.52	1.19	1.36
Rhizophoraceae					
29.	Pellacalyx axillaris	1.44	1.52	1.15	1.37
Sonneratiaceae					
30.	Duabanga mollucana	0.30	1.95	0.67	1.31
Dipterocarpaceae					
31.	Hopea rudiformis	–	1.65	–	1.65
Melastomataceae					
32.	Pternandra azurea	–	1.17	1.47	1.32
	Mean ± standard deviation	1.67 ± 0.38	1.54 ± 0.42	1.48 ± 0.45	1.56 ± 0.10

Note : * Leaf samples were collected from the same tree

Table 4 : The N – leaf concentration (%) in Primary KF plot, Samboja East Kalimantan

No.	Species *	Period of January 1979	January 1980	Mean
	Dipterocarpaceae			
1.	Cotylelobium flavum	0.13	0.90	0.11
2.	C. malayanum	0.21	0.16	0.18
3.	C. melanoxylon	0.21	0.15	0.17
	Myrtaceae			
4.	Eugenia lepidocarpa	0.15	0.05	0.10
5.	E. claviflora	0.14	0.08	0.11
6.	Tristania obovata	0.25	0.10	0.17
7.	Rhodamnia cinerea	0.12	0.08	0.10
	Guttiferae			
8.	Callophyllum pulcherinum	0.10	0.11	0.10
	Ericaceae			
9.	Vaccinium bancanum	0.12	0.12	0.12
10.	Gratoxylum glaucum	0.21	–cut–	0.21
11.	C. formosum	0.31	–died–	0.31
	Sapindaceae			
12.	Nephelium maingayi	0.19	0.17	0.18
	Ochnaceae			
13.	Brackenridgea hookeri	0.19	0.12	0.15
	Lauraceae			
14.	Litsea cylindrocarpa	0.06	0.09	0.07
15.	L. firma	0.24	0.06	0.15
16.	Actinodaphne borneensis	0.09	0.10	0.09
	Anacardiaceae			
17.	Buchanania arborescens	0.18	0.16	0.17
18.	Rapanea umbellata	0.19	0.12	0.15
19.	Xylopia altissima	0.25	0.12	0.18
	Oleaceae			
20.	Olea javanica	0.19	0.14	0.17
	Tiliaceae			
21.	Pentace triptera	0.26	–died–	0.26
	Moraceae			
22.	Ficus sundaica	0.22	0.11	0.17
23.	F. sumatrana	0.17	0.09	0.13
	Sapotaceae			
24.	Palaqium javense	0.15	0.06	0.11
	Mean ± standard error	0.18 ± 0.06	0.11 ± 0.03	0.14 ± 0.05

Table 5 : The N – leaf concentartion (%) in Secondary KF Samboja, East Kalimantan

No.	Species *	Period of January 1979	January 1980	Mean
	Myrtaceae			
1.	Tristania obovata	0.70	1.00	0.85
2.	Eugenia claviflora	0.75	0.70	0.72
3.	Rapanea umbellata	0.85	1.20	1.02
	Guttiferae			
4.	Callophyllum pulcherinum	0.90	0.90	0.90
5.	Garcinia rostrata	0.81	0.94	0.87
	Aquifoliaceae			
6.	Ilex cymosa	0.72	0.70	0.71
	Anacardiaceae			
7.	Buchanania arborescens	0.85	0.96	0.90
	Ericaceae			
8.	Vaccinium bancanum	0.90	0.06	0.48
	Mean ± standard deviation	0.81 ± 0.08	0.81 ± 0.34	0.81 ± 0.16

Note : * Leaf samples were collected from the same tree

This may in part be due to differences of soil types and recolonization during early succession. Although the soil-N content in the burnt plot is consistently higher than in the unburnt plot, the changes do not differ.

The soil-N content in the primary MDF is lower than in the 30-year old secondary MDF or in the young secondary vegetation during the first 18-24 weeks. In KF, the soil-N content in primary forest is higher than in the old and young secondary KF. The soil-N content in MDF (primary young and 30-year old secondary forests) is higher to that in KF.

3. The changes of leaf-N content

Table 1 also shows that leaf-N content both in the MDF and KF increases during the early secondary succession and then declines. This appears to be related to differences in species composition during the early succession. In MDF, the pioneer or secondary species are dominant and in KF, the resprouts of the original plants are dominant.

The patterns of leaf-N, changes during the early succession of MDF and KF are similar for both the burnt and unburnt plots. In KF, it increases during the first 18 weeks and in MDF between 18 to 24 weeks.

The leaf-N content in MDF and KF are as follows: In MDF the leaf-N content of young secondary forest > 30-year old secondary forest > primary forest and in KF, the leaf-N content of primary forest > young and 30-year old secondary forests.

It is also apparent that in MDF the leaf-N content in every stage of succession in primary and 30-year old secondary forests is higher than in KF.

4. Status of leaf-N in various species

The leaf-N content of primary and old secondary control plots in MDF and KF shows seasonal fluctuation during the 1 year study period (Table 2 to 5).

The high leaf-N content is not restricted to leguminous trees (i.e. *Intsia palembanica* (primary MDF), *Pithecelobium microcarpum* and *Fordia gibbsiae* (old secondary MDF)), but also observed in non-leguminous species (i.e. *Monocarpia marginalis* (Annonaceae), *Scorodocarpus borneensis* (Olacaceae), *Pentace laxiflora* (Tiliaceae) and *Ryparosa javanica* (Flacourtiaceae) in primary MDF, and *Urophyllum polyneurum* (Rubiaceae) and *Artocarpus integer* (Moraceae) in old secondary MDF). The leaf-N content of the above tree is greater than 2%, other species have leaf-N contents ranging between 1 and 2%, this include species of Dipterocarpaceae and Lauraceae in primary MDF and Euphorbiaceae on old secondary MDF.

In KF, all tree species found in the primary and secondary forest were analyzed. The results show that leaf-N contents were lower compared to that in MDF. There are no differences in leaf-N content between the dominant and non-dominant species.

Similar patterns also occur during the early secondary succession (Table 6 to 9). It is apparent that the leaf-N contents in MDF and in KF are very high. Most species were resprouts from the original species. The peak of leaf-N contents occured between 18-24 weeks after treatments. In MDF, the non-leguminous species (e.g. *Trema orientalis*, *T. cannabina* (Tiliaceae), *Evodia latifolia* (Rutaceae), and *Callicarpa*

Note : Leaf samples were collected from the same tree

Table 6 : Changes in leaf – N content (%) in the experimental plot R, after clear-cutting without burning Mixed Dipterocarp Forest, Samarinda, East Kalimantan. (all species came from seedlings)

Family/Species	Period of time (weeks)			
	18	34	52	78
Euphorbiaceae				
Macaranga gigantea	1.98±0.03	2.00±0.07	2.52±0.21	1.79±0.05
M. quadricornis	2.02±0.05	2.04±0.09	2.35±0.03	2.45±0.14
M. hypoleuca	2.12±0.07	1.80±0.00	1.87±0.11	1.86±0.12
M. pruinosa	2.70±0.09	2.09±0.16	2.69±0.05	2.10±0.00
Endospermum diadenum	3.10±0.21	2.82±0.03	2.24±0.16	2.51±0.02
Mallotus muticus	-	1.85±0.03	-	-
Tiliaceae				
Grewia sp.	2.74±0.09	2.37±0.14	-	-
Trema cannabina	3.00±0.00	2.37±0.14	-	-
T. orientalis	3.67±0.11	3.05±0.00	2.41±0.05	1.70±0.07
Moraceae				
Ficus arfakensis	1.75±0.07	2.12±0.11	2.45±0.07	1.85±0.14
F. beccarii	-	-	1.41±0.05	1.70±0.07
Gramineae				
Paspalum conjugatum	1.70±0.11	1.72±0.00	-	-
Rubiaceae				
Uncaria ferrea	2.15±0.00	1.54±0.05	2.41±0.16	1.66±0.05
U. glabrata	1.77±0.03	1.91±0.02	1.92±0.09	1.61±0.02
U. gambir	-	1.31±0.09	-	1.91±0.05
Gardenia anisophylla	2.20±0.18	-	2.26±0.09	2.04±0.09
Anthocephalus chinensis	3.12±0.03	-	-	-
Uncaria setiloba	-	1.50±0.00	-	1.72±0.03
Melastomataceae				
Melastoma sp.	2.20±0.07	1.31±0.05	1.31±0.09	1.27±0.03
Melastoma affine	-	1.94±0.12	1.89±0.12	1.89±0.09
Rutaceae				
Evodia latifolia	3.20±0.05	2.81±0.02	2.70±0.28	-
Cyperaceae				
Hypolytrum nemorum	1.89±0.05	-	-	-
Verbenaceae				
Callicarpa pentandra	3.19±0.09	2.21±0.09	2.37±0.11	-
Compositae				
Trichtites valerianifolia	2.16±0.09	-	-	-
Blumea balsamifera	2.16±0.09	2.59±0.02	-	-
Dilleniaceae				
Dillenia eximia	2.30±0.11	1.54±0.16	-	-
Hypericaceae				
Cratoxylum sumatranum	2.50±0.21	1.74±0.02	-	1.56±0.02
Zingiberaceae				
Globba sp.	2.77±0.11	-	-	-
Curculigo glabrescens	2.20±0.03	1.86±0.09	-	-
Dipterocarpaceae				
Hopea rudiformis	1.47±0.00	1.67±0.00	1.85±0.11	1.52±0.03
Myrsinaceae				
Maesa polyantha	2.10±0.07	2.07±0.03	-	1.91±0.12
Fern				
Pteris tripartita	3.15±0.07	3.30±0.00	-	-
Symplocaceae				
Symplocos fasciculata	-	1.72±0.07	2.36±0.05	1.47±0.03
Annonaceae				
Polyalthia sumatrana	-	-	2.32±0.18	2.64±0.05
Aquifoliaceae				
Ilex cimoides	-	-	1.39±0.16	1.42±0.07
Sonneratiaceae				
Duabanga moluccana	-	-	1.04±0.09	-
Rhizophoraceae				
Pellacalyx axillaris	-	-	-	1.79±0.05
Mean for seedlings	2.46±0.58	2.39±0.37	2.18±0.48	1.85±0.15

Table 7 : Changes in leaf – N content (%) in the experimental plot S, after clear-cutting and burning in Mixed Dipterocarp Forest, Samarinda, East Kalimantan (all species came from seedlings).

Family/Species	Period of time (weeks)			
	18	34	52	78
Euphorbiaceae				
Macaranga conifera	3.47±0.00	2.16±0.02	2.15±0.03	1.64±0.05
M. gigantea	2.70±0.09	1.75±0.00	2.37±0.07	2.12±0.16
M. quadricornis	1.97±0.11	1.75±0.21	1.65±0.07	2.47±0.18
M. hypoleuca	2.04±0.05	1.46±0.02	1.82±0.11	1.05±0.07
M. winkleri	1.86±0.05	2.15±0.11	3.22±0.14	3.06±0.02
M. pruinosa	2.80±0.00	2.40±0.03	2.32±0.03	2.31±0.05
Endospermum diadenum	4.11±0.02	2.60±0.07	2.35±0.18	2.44±0.02
Mallotus paniculatus	-	-	1.70±0.07	2.12±0.03
Homalanthus populneus	-	-	3.12±0.03	3.17±0.18
Mallotus muticus	-	-	1.73±0.07	2.46±0.05
Urticaceae				
Pipturus argenteus	-	-	3.27±0.00	1.99±0.09
Debregeasia sp.	2.04±0.02	1.45±0.21	1.20±0.07	1.39±0.05
Tiliaceae				
Trema cannabina	2.86±0.02	2.07±0.03	1.94±0.09	2.15±0.11
T. orientalis	2.90±0.00	2.90±0.14	3.79±0.12	2.49±0.05
Moraceae				
Ficus arfakensis	2.07±0.03	1.88±0.02	1.74±0.09	1.87±0.00
F. variegata	-	-	-	2.21±0.09
F. uncinata	-	-	1.70±0.07	1.60±0.03
F. beccarii	-	-	1.31±0.12	1.52±0.07
Gramineae				
Paspalum conjugatum	2.00±0.06	1.91±0.02	-	-
Imperata cylindrica	-	-	-	2.13±0.02
Rubiaceae				
Uncaria ferrea	1.72±0.03	1.71±0.02	2.32±0.00	1.27±0.03
U. glabrata	2.47±0.03	1.70±0.07	1.70±0.03	1.26±0.05
U. gambir	2.15±0.07	1.40±0.07	-	-
U. sessilis	1.66±0.05	1.34±0.09	2.42±0.07	1.61±0.02
Nauclea orientalis	-	-	-	1.57±0.00
Anthocephalus chinensis	3.66±0.12	3.32±0.11	3.60±0.00	3.59±0.09
Fern				
Pteris tripartita	2.67±0.03	3.20±0.07	-	-
Dryopteris sp.	3.81±0.19	2.32±0.03	-	1.85±0.00
Pityrogramma sp.	2.09±0.16	-	-	-
Lygodium circinatum	-	-	-	1.79±0.02
Rutaceae				
Evodia latifolia	3.75±0.18	1.99±0.19	1.62±0.03	1.62±0.03
Myrsinaceae				
Maesa polyantha	1.72±0.16	1.25±0.00	1.55±0.00	1.46±0.05
Compositae				
Blumea balsamifera	2.53±0.00	3.12±0.03	2.70±0.11	2.25±0.05
Chrysophyllum sp.	3.72±	2.50±0.21	-	-
Verbenaceae				
Callicarpa pentandra	3.46±0.09	2.89±0.02	2.39±0.16	2.04±0.12
C. involucrata	-	-	2.27±0.11	-
Hypericaceae				
Cratoxylum sumatranum	2.16±0.05	2.15±0.05	1.30±0.07	1.69±0.03
Aquifoliaceae				
Embelia sp.	1.60±0.11	1.86±0.09	1.30±0.03	1.09±0.02
Ilex cymosa	-	-	1.64±0.05	1.25±0.00
Zingiberaceae				
Curculigo glabrescens	-	1.95±0.14	-	-
Globba sp.	-			
Melastomataceae				
Melastoma affine	-	2.67±0.03	1.12±0.07	1.41±0.05
Piperaceae				
Piper aduncum	-	3.00±0.18	1.60±0.07	2.39±0.05
Cyperaceae				
Hypolytrum nemorum	-			
Dipterocarpaceae				
Hopea rudiformis	-	-	1.75±0.00	1.57±0.00
Dilleniaceae				
Dillenia eximia	-	-	1.37±0.03	1.29±0.09
Rhizophoraceae				
Pellacalyx axillaris	-	-	-	1.62±0.18
Sonneratiaceae				
Duabanga moluccana	-	-	1.96±0.16	1.27±0.03
Annonaceae				
Polyalthia sumatrana	-	-	1.65±0.03	1.49±0.05
Mean for seedlings	2.66±0.77	2.17±0.60	2.05±0.68	1.91±0.77
	(n = 27)	(n = 29)	(n = 35)	(n = 44)

(n = 27) (n = 28) (n = 22) (n = 24)

Table 9 : Changes in leaf – N content (%) in the experimental Plot V, after clear-cutting and burning in Kerangas Forest, Samboja, East Kalimantan (all species came from stump resprouting)

Family/Species	Period of time (weeks)		
	24	52	78
Myrtaceae			
Eugenia spicata	1.50±0.07	0.87±0.03	0.92±0.03
E. claviflora	0.95±0.03	0.65±0.03	1.12±0.03
E. lepidocarpa	–	–	1.00±0.07
Rhodamnia cinerea	0.94±0.02	1.04±0.02	1.07±0.11
Tristania obovata	1.52±0.07	0.92±0.00	1.02±0.03
Verbenaceae			
Premna oblongifolia	1.21±0.02	1.10±0.00	0.80±0.03
Euphorbiaceae			
Glochidion rubrum	0.65±0.00	0.86±0.05	0.92±0.03
Daphniphyllaceae			
Daphniphyllum laurianum	–	–	0.86±0.05
Ericaceae			
Vaccinium bancanum var bancanum	1.31±0.09	0.31±0.09	0.32±0.00
Myrsinaceae			
Rapanea umbellata	0.74±0.02	1.04±0.02	0.79±0.02
Lecythidaceae			
Barringtonia reticulata	1.40±0.32	1.47±0.00	1.15±0.11
Dipterocarpaceae			
Cotylelobium flavum	1.42±0.11	1.00±0.00	0.91±0.02
Simaroubaceae			
Euryoma longifolia	–	1.51±0.12	1.49±0.09
Annonaceae			
Xylopia altissima	–	0.91±0.12	–
Guttiferae			
Callophyllum pulcherinum	–	1.30±0.00	1.42±0.03
Rubiaceae			
Ixora stenophylla	–	1.19±0.05	1.32±0.00
Ochnaceae			
Brackenridgea hookeri	–	–	1.06±0.02
Hypericaceae			
Cratoxylum glaucum	–	–	0.99±0.09
Mean for resprouts	1.16±0.52 (n = 10)	1.05±0.25 (n = 14)	1.04±0.21 (n = 17)

Table 8 : Changes in leaf – N content (%) in the experimental Plot T, after clear-cutting without burning in Kerangas Forest, Samboja, East Kalimantan (all species came from stump resprouting).

Family/Species	Period of time (weeks)		
	24	52	78
Dipterocarpaceae			
Cotylelobium flavum	0.74±0.02	0.09±0.14	1.17±0.03
Rubiaceae			
Ixora stenophylla	1.24±0.05	0.84±0.02	1.22±0.03
Myrsinaceae			
Rapanea umbellata	1.02±0.03	1.30±0.00	0.84±0.09
Daphniphyllaceae			
Daphniphyllum laurianum	0.92±0.00	0.74±0.05	0.76±0.02
Euphorbiaceae			
Glochidion rubrum	0.89±0.02	–	–
Ochnaceae			
Brackenridgea hookeri	1.05±0.00	1.07±0.00	1.07±0.03
Ericaceae			
Vaccinium bancanum var bancanum	0.97±0.03	1.22±0.11	0.84±0.16
Lecythidaceae			
Barringtonia reticulata	1.30±0.07	1.30±0.00	1.20±0.00
Myrtaceae			
Eugenia claviflora	0.34±0.05	1.05±0.00	–
E. spicata	0.36±0.05	1.10±0.03	–
E. lepidocarpa	–	0.32±0.07	0.77±0.12
Tristania obovata	1.22±0.03	1.06±0.02	1.06±0.02
Rhodamnia cinerea	–	0.35±0.03	0.38±0.02
Guttiferae			
Callophyllum pulcherinum	0.62±0.03	0.84±0.05	–
Simaroubaceae			
Euryoma longifolia	–	1.09±0.05	–
Leguminosae			
Pithecelobium microcarpum	–	–	0.83±0.02
Mean for resprouts	1.01±0.24 (n = 12)	1.01±0.18 (n = 14)	0.95±0.17 (n = 11)

pentandra (Verbenaceae) for trees and Erichtites valerianifolia (Compositeae), Pteris tripartia (Fern)). Even higher leaf-N content than leguminous species. it is also apparent that there are no differences of leaf-N contents in unburnt and burnt MDF plots.

In KF, where the early stages of secondary successions are dominated by resprouts of original plants, the leaf-N content is increasing, and is much higher compared with that in the control plots in primary and old secondary forests. However, it is much lower than in MDF.

DISCUSSIONS

1. Vegetation recovery during early succession

The Mixed Dipterocarp Forest (MDF) and Kerangas Forest (KF) differ in their structure, species composition, species diversity and species stratefication during the early secondary succession. During the first six months of secondary succession, the unburnt and burnt MDF are dominated be grass (Paspalum conjugatum), mixed with seedlings of woody species. The grass species die after having been shaded by woody pioneer species, such as Macaranga spp., Callicarpa pentandra, Trema orientalis etc. In contrast, in KF, resprouts of the original plants are dominant. It is apparent that the floristic composition of the secondary forest depend on the behaviour of species, with regard to their ability and mode of regeneration and their recovery following disturbances.

The distribution of species strongly determines their composition in MDF, but not so in KF. In the latter the edaphic condition appears to be the most important factor as suggested by Richards (1956). The 1.5 year early disturbance is the most dynamic period (Riswan, 1982). In both experimental plots in MDF all trees, shrubs and herbs species are found in the early stage of succession; stump resproutings are also present. If would appear that the Clemention concept of a succession of life-forms is too symplified and probably incorrect when applied to MDF and KF.

2.Status of Soil-N

An important part of the tropical forest ecosystem is the soil. Several authors (e.g. Popenoe, 1960; Cunningham, 1963; Sanchez, 1976 and Harcombe, 1977a, 1980) suggested that disturbance, removal or partial removal of the vegetation, will have deleterious effects upon the structure and fertility of soils. Riswan (1982) demonstrated that after cutting and burning of the vegetation, the soils impoverished quickly, particularly on the podsols in KF. Rapid changes in soil properties occur during the first six months of regeneration, which also seems to be a crucial period in the early secondary succession of the forest.

The soil nitrogen in the 30-year old secondary MDF > primary MDF > primary KF > 30-year old secondary KF. The high soil-N content of the red-yellow podsolic soils might be due to the high presence of leguminous trees and N-fixation of microorganism activities (Nye and Greenland, 1960; Jaiyebo and Moore, 1963; Rice, 1974 and Harcombe, 1977a).

In general the trends of N-soil changes are similar in both forest types i.e. MDF and KF. The trends were increasing in the first 18-24 weeks and then declining. In KF soils this trend is shown more drastically compared to MDF. This agrees with the results of Nye and Greenland (1964) in Ghana and Seubert (1975) in Peru. The demands of the young vegetation on soil nitrogen can also be very high as seen from the high leaf-N status in the Endospermum diadenum, Anthocephalus chinensis and Trema orientalis seedlings.

Although early there was a decrease in organic matter, there is an evidence that between 18-24 weeks the organic matter increases. This appears to be associated with very rapid regrowth and senescence of herbs and grasses or early litterfall, thus adding carbon and nitrogen to the soil. Beyond this point, an equilibrium sets in which presumbly will cause a long term increase in carbon and nitrogen contents.

3. Leaf-N status among species

The leaf-N status shows seasonal fluctuations of leaf-N during the study period. This agrees with reported studies in temperate zones (Likens and Borman, 1970) and in other tropical regions (Nye, 1961 and Golley et al., 1975). This was also observed with other nutrient elements (Nye, 1961; Ernst, 1973; Golley et al., 1970). Various factors influence the leaf-N status o.a. nutrient leaching species, differences and biological N-fixation. A good example is Intsia palembanica (leguminosae) which has a high leaf-N content. It also occurs in Fordia gibbsiae and Pithecelobium microcarpum, leguminous trees found in secondary MDF. Four other species have high leaf-N status above 2% in primary MDF; Monocarpia marginalis (Annonaceae), Scorodocarpus borneensis (Olacaceae), Ryparosa javanica (Flacourtiaceae) and Pentace laxiflora (Tiliaceae) and in two species in secondary MDF, Artocarpus integer (Moraceae) and Urophyllum polyneurum (Rubiaceae).

It can be inferred that those species with leaf-N content ranging between 1 and 2% play an important role in maintaining N status within the forest ecosystem. They can be perhaps used as an indicator species of rich soil-N content. Most tree species in the 30-year old secondary MDF, are fast growing pioneer tree species, have high leaf-N and other nutrient status (Riswan, 1977).

Artocarpus integer, a commercial and edible fruit tree, has high leaf-N P and K status (Riswan, 1982). This species can be recommended for use in agro-silviculture (Ashton, 1978), or in multiple cropping and taungya production systems. Other commercial fruit trees i.e. rambutan (Nephelium lapaceum) can be recommended for the same purpose. Other tree species which can be recommended for rehabilitation of degraded forest plantation sites in the lowland tropics are Fordia gibbsiae and Hopea rudiformis (fast growing primary species) and other fast growing secondary species, such as Trema orientalis, Callicarpa pentandra, Antocephalus chinensis, Endospermum diadenum and Macaranga spp. All of this species are not only high in leaf-N status, but also in other nutrients (P, K, Ca and Mg). The beneficial aspects of these species are that they are fast growing and have good ability to grow and utilize nutrients from the soil, and thus are very good for soil- restoration.

There is also a fluctuation of leaf-N status in both primary and secondary KF. There is no difference in leaf-N status between non-dominant species and dominant species. This suggests that the maintenance of leaf-N status in the KF ecosystem is due to both species. These differences in pattern might be related to the forest formation process. MDF is a forest in steady state on relatively rich soils and KF on very poor soil. The dominant species in the KF are more adapted to the very poor soil condition. High density of small individual trees is probably a mean to conserve N in the ecosystem.

Some species with the high leaf-N contents are Ormosia venosa (Leguminosae), Cotylelobium malayanum (Dipterocarpaceae) and Pentace triptera (Tiliaceae), in primary KF, and Rapanea umbellata (Myrsinaceae) and Callophyllum pulcherinum (Guttiferae) in secondary KF. For the leguminous species, it is not surprising that they have a high of leaf-N content. For Dipterocarpaceae and Tiliaceae the high N-status is similar to that in MDF.

The species succession in both experimental plots during the forest 1.5 year show, that there is a similarity of life-form colonization. In the first 24 weeks herbs are very dominant , plant cover with high leaf nutrient, although some pioneer species already occured. After 24 weeks most of pioneer herbs decline and senerced, and were replaced by pioneer trees.

Following are the most important successional species in both experimental plots with high leaf nutrient status (including N), i.e.:

1. Herbs : Paspalum conjugatum, is the most important herb with a peak in the first 6 months. It has very high leaf-P, K, Na and Mg levels.

   Blumea balsamifera, Pteris tripartita are also very high in leaf-P, K, and Na levels.

2. Shrubs : Trema canabina and Maesa polyantha, are very high in N, P, and K levels.

3. Trees : Trema orientalis, Anthocephalus chinensis, Callicarpa pentandra, Endospermum diadenum, Nacaranga spp. are very high in leaf-N, P, K, Na, Ca and Mg levels.

It appears, that the recovery process in KF is different from MDF, in the former resprouts being dominant. However, the leaf-N status shows a similar change pattern. The composition of resprouts, nutrient uptake and restoration pattern are constant for the different experimental plots. This suggests that resprouts adapt to soil conditions for their survival.

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NITROGEN CYCLING IN LEGUME-CEREAL ROTATIONS

Key Words: Legume-cereal rotations Nitrogen cycling, fixation release, uptake by crops, recoveries Soil biomass, ^{14}C, ^{15}N, nitrate, organic residues

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SUMMARY

^{15}N-enriched legume material and soil organic residues have been used to study some key processes pertinent to nitrogen cycling in legume-cereal rotations.

The amount of N_2 fixed by the pasture legume *Medicago littoralis* grown alone or with ryegrass (*Lolium multiflorum*) in two soils was directly related to legume dry weight. The percentage reduction in the amounts of N_2 fixed per legume plant in mixed systems was directly proportional to the percentage increase in plant dry matter due to the ryegrass component. Measurements of legume (*M.littoralis, Pisum sativum*) N derived from fixation and from uptake from soil demonstrated that net gains to or losses from soil on removal of plant tops depended on the soil used, and that losses increased with increasing amounts of soil nitrate.

Long-term studies of the decomposition in soils of ^{14}C, ^{15}N-labelled *M.littoralis* material showed that the net decay rates at a South Australian site were about one half those reported for ryegrass decomposition at Nigerian sites and about double those at some English sites. Decay rates doubled for an

8-9°C rise in mean annual air temperatures. About one third of legume N was released within the first few months, and about one third remained as stable organic residues after eight years. Measurement of isotope-labelled biomass provided a basis for modelling the turnover of C and N in decomposer populations accompanying organic residue decay.

Recoveries of legume N in first wheat crops ranged from 11 to 28% of input. Despite large grain yield differences in different seasons and at different sites, the percentage contribution of legume N to wheat N remained approximately proportional to legume N input (10% of wheat N per 50 kg legume N applied). The relative availability of legume N to a succeeding wheat crop halved. Total recoveries of legume N in crop plus soil generally exceeded 90% of input.

Legume material added to soil increased the amounts of soil-derived nitrate N in soil profiles, but not necessarily the amounts of soil-derived N taken up by wheat crops. The higher nitrate status of soils in the year following legume growth compared with that following wheat growth was due more to a greater accumulation of nitrate in soils at the completion of nitrate utilization by the legumes, than to the greater mineralization of nitrogen in soils containing legume residues.

INTRODUCTION

The long-term maintenance of nitrogen supplies for crop growth is met principally by fertilizer additions or by symbiotic N_2 fixation by legumes. For cereal production in southern Australia heavy reliance has been placed traditionally on N_2 fixation by mainly pasture legumes to offset nitrogen removed in grain or lost by other processes; rotation trials have demonstrated improved grain yields and net gains in soil organic N levels (Greenland, 1971; Clarke and Russell, 1977). In recent years, partly because of increased frequency of cereal cropping, and partly because of deterioration in legume pastures, increasing amounts of fertilizer N have supplemented N inputs due to symbiotic fixation.

Gross inputs and losses of nitrogen from legume sources, and efficiency of legume N use by cereals have not as yet been adequately quantified, although ^{15}N methodology is well suited to quantify key processes of the nitrogen cycle (Hauck and Bremner, 1976). Here we illustrate the usefulness of ^{15}N in studies of symbiotic N_2 fixation, N release from legume residues, N uptake by wheat, and N recovery in soil-plant systems relevant to the semi-arid, winter rain-fed systems of the cereal-growing areas of southern Australia. The use of ^{15}N-labelled legume material demonstrated an effect of added plant residues on the release of nitrogen from soil organic matter.

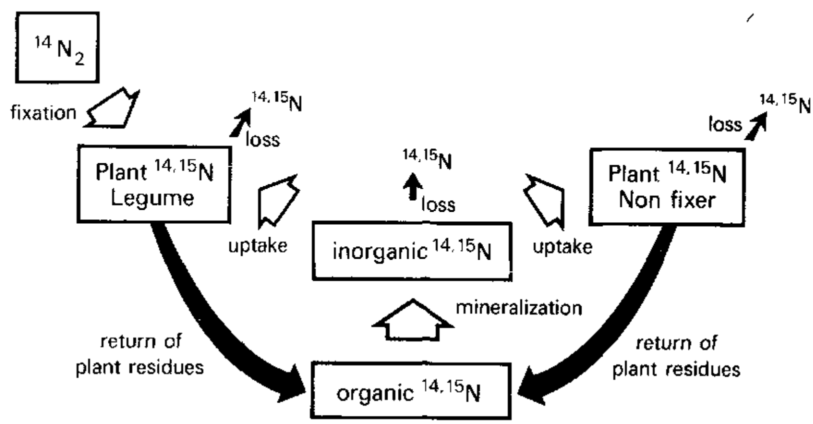

FIG. 1 Measurement of symbiotic N_2 fixation by a ^{15}N isotope-dilution technique: Principles and limitations.

NITROGEN FIXATION BY LEGUMES

Of several techniques described for measuring rates of N_2 fixation, the ^{15}N isotope-dilution method is particularly suited to studies with agricultural legumes, and provides integrated measures of N_2 fixed over entire growth seasons (Knowles, 1981). The principle and some limitations of the method are illustrated in Fig.1. The legume and a non-fixing reference plant are grown in soil whose available N pool is enriched, relative to that of atmospheric N_2, with the isotope ^{15}N. Ideally, the ^{15}N atom % enrichment of the soil available N remains constant throughout the experimental period, irrespective of changing concentrations of inorganic N in the soil profile. Measurements of legume N, and a comparison of its ^{15}N atom % enrichment with that of the N of the non-fixing reference plant, permit calculations of the distribution of fixed N and soil-derived N in the legume. Decomposition of legume residues returned to soil during the experimental period (either directly, or indirectly as wastes from grazing animals) would lower the enrichment of the available N, with perhaps important consequences for interpretation of data. Losses of legume N to atmosphere or soil (including incomplete recovery of intact root material) would underestimate the amounts both of N_2 fixed and N taken up by the legume, and thus would affect the estimates of net N gain to or loss from soil according to the return or removal of recovered legume plant

By labelling the soil organic N pool with residues from applied fertilizer or plant materials it is possible to achieve conditions under which the atom % enrichment of mineralized N remains approximately constant over several months, thus satisfying an important requirement for valid use of the ^{15}N dilution technique. For example, Fig.2, adapted from Butler and Ladd (1984a), shows that the amounts of NO_3^- N released from soil containing ^{15}N-labelled organic residues, may be doubled over a 12 week incubation period by frequent, intermittent drying and wetting of the soil, yet the ratio of the decay rates of organic

^{15}N and ^{14}N remained constant at about 2.5:1 irrespective of incubation conditions. Despite the greater availability of N released from labelled sources, the ^{15}N atom % enrichment of the norganic N was constant throughout the 12-week incubation

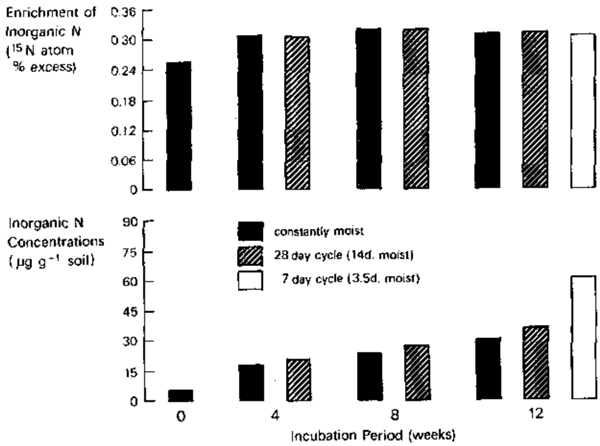

FIG. 2 **Release of inorganic N from ^{15}N-labelled organic residues in a soil incubated under moist and intermittently dry conditions.**

period. Such soils are clearly useful for N_2 fixation studies in pot experiments, or in the field where soil disturbance can be tolerated, e.g. in studies of the competitive effects of associated grasses on N_2 fixation and uptake of N by legumes according to NO_3^- movement in uniform soil profiles.

Labelling of soil organic N may also be a useful approach in some field situations where soil disturbance must be minimal. For example, Fig.3 (adapted from Ladd and Amato, 1985) shows data from a field experiment in which ^{15}N-labelled urea and legume material had been incorporated into topsoil and cropped with

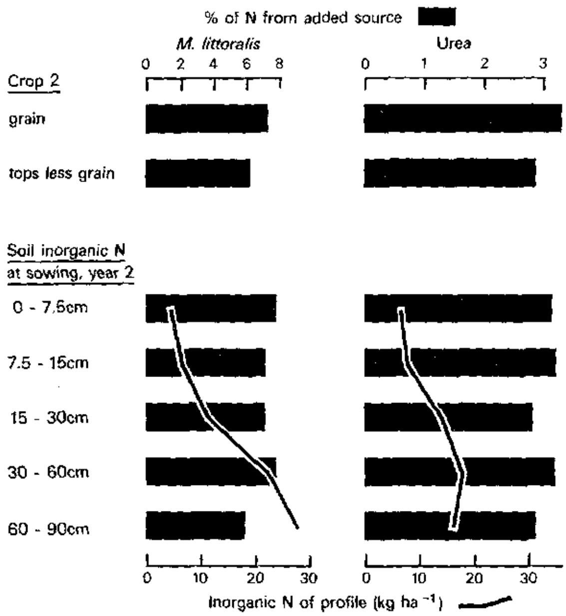

FIG. 3 Percentages of wheat N and of soil profile inorganic N derived from ^{15}N-labelled *M.littoralis* and urea residues in a soil previously cropped with wheat.

wheat. By the time of sowing in the year following the first wheat crop, the enrichments of inorganic N distributed throughout the soil profile were, for a given treatment, very similar; and similar also to those of the N of a second crop harvested six months later. Thus by the second year of the rotation experiment, conditions had been established which suited the use of the ^{15}N-dilution technique to measure N_2 fixation by legumes in the field, and where only minimal disturbance of topsoils was acceptable. In both experiments, as illustrated by data of Figs.2 and 3, the $\delta^{15}N$ *of the released* NO_3^- *N* exceeded 600, so errors due to isotopic-discrimination effects were considered to be unimportant (Knowles, 1981).

TABLE 1

The Effect of Some Plant and Soil Treatments on Nitrogen Fixation by *Medicago littoralis*.

Treatment	Trend	Reference
Legume plant part	Percentage of plant part N due to fixation increases in order: roots, leaves, stems, pods.	Butler and Ladd (1984a)
Increasing legume numbers per pot	Fixed N per pot generally increases, and fixed N per plant decreases. Fixed N directly related to legume dry matter yields.	Butler and Ladd (1984b)
Increasing competition from associated ryegrass	Fixed N per pot, and per legume plant decreases. Percentage decrease per plant for given soil directly related to percentage increase in ryegrass dry matter.	Butler and Ladd (1984b)
Increasing available nitrogen	Fixed N per pot, and per legume plant, decreases.	Butler and Ladd (1984a), Butler (pers. comm.)[1]
Regular clipping of plant tops	Clipping decreases fixed N per pot, with or without ryegrass competition.	Butler (pers. comm.)

1 Unpublished data presented in this paper derive from experiments conducted by M. Amato, J.H.A. Butler, R.B. Jackson and J.N. Ladd, Division of Soils, CSIRO.

Some results of pot studies of N_2 fixation by the pasture legume *Medicago littoralis* are summarized in Table 1. Plant parts differed consistently in the percentages of their nitrogen due to N_2 fixation; in the later stages of legume growth when most of the plant N is being acquired through the fixation process, there is a disproportionate direction of N to tops, and especially to the developing grain. Nodules, the sites of N_2 fixation, contain N derived both from this process and also from N taken up from soil. Fixation is a more important provider of nodule N than it is of root N.

The close direct relationship between the amounts of N_2 fixed by legumes and legume dry matter weight, irrespective of soil, plant numbers, and competition from ryegrass (*Lolium multiflorum*) is consistent with the prime role of photosynthate, both for plant growth and as a reductant in the N_2-fixation process. Competition from ryegrass decreases the amounts of N_2

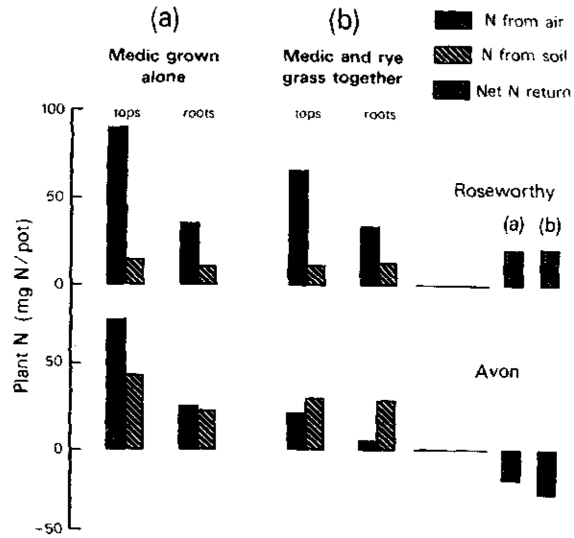

FIG. 4 Fixation and uptake from soil of nitrogen by *M.littoralis*, grown alone or with ryegrass in two soils of contrasting fertility.

fixed by legumes, although the proportions of legume N due to fixation are increased.

The distribution of fixed and soil-derived N in legumes (and associated plants, where applicable) clearly affects net gain or loss of N to or from soil according to the fate of plant residues. Fig.4 adapted from Butler and Ladd (1984a), shows data for fixed and soil-derived N in the tops and roots of *M.littoralis* grown either alone or as a 50:50 mixture with ryegrass in each of two soils. In the Roseworthy soil with about one half the total N and N mineralization capacity of the Avon soil, the legume grew better and fixed more nitrogen. For the former soil, failure to return any top growth nevertheless still resulted in a net gain of N to the soil, since fixed N in legume roots exceeded soil-derived N in the removed tops. Also, in Roseworthy soil competition from ryegrass was relatively slight resulting in only small decreases in the amounts of N_2 fixed, and in the soil-derived N of the total top growth. Thus the net gain of N to the soil after removal of plant tops was similar whether the legume was grown alone or with ryegrass.

By contrast, in the higher N status Avon soil, N_2 fixation decreased and N uptake from soil increased, resulting when no plant tops were returned in a net N loss from soil. Ryegrass dominated plant growth in the mixture so compared with the legume grown alone, N_2 fixation decreased by a greater extent than did the uptake of N in tops, resulting in an even greater deficit.

For a mature grain legume such as Pisum sativum (field pea), the amounts of N harvested in grain alone may account for 70% of the total plant N. The data for Fig.5, again adapted from Butler and Ladd (1984a), are for immature plants with pods and grain still forming at harvest; total tops N ranged from about 65% (Caliph, Roseworthy) to 80% (Avon ± NO_3^-) of plant N. Failure to return tops to soil resulted in a net gain of N to the less fertile soils (Caliph, Northfield), but as with the medic plants, a net N deficit was obtained in the more fertile Avon soil; the deficit increased as applied NO_3^- levels were increased.

The data serve to illustrate the usefulness of the technique in assessing N gains and losses according to the practice adopted, provided that assessments can be made of the distribution of N from the two sources in the various legume plant parts, and that losses of N from the plants are minimal during the experimental period. Wetselaar and Farquhar (1980) have shown that substantial losses of N from plant tops, possibly by volatilization, may occur during plant ripening. The ^{15}N dilution technique could be used to determine if losses of fixed N and soil-derived N of senescing legume tops were disproportionate.

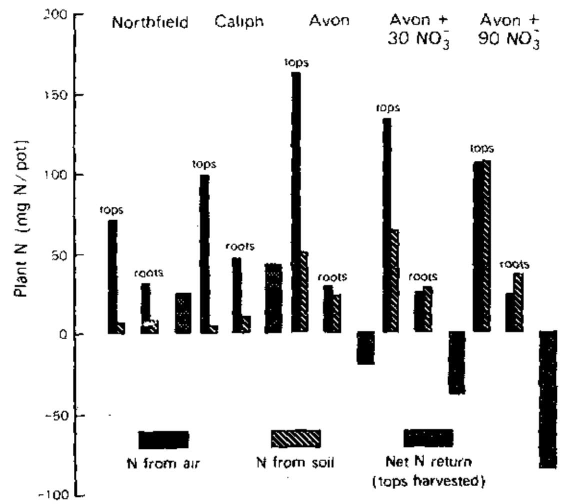

FIG. 5 Fixation and uptake from soil of nitrogen by *Pisum sativum* grown in three soils, and with NO_3^- amendment (30, 90 mg per pot).

DECOMPOSITION OF LEGUME RESIDUES

Field studies of the decomposition in soils of ^{14}C, ^{15}N-labelled legume materials over several years have direct relevance to their contributions to soil organic matter under natural conditions, and to the potential availability of plant residue N to crops. Fig.6 shows the percentage retention of ^{14}C and ^{15}N in organic residues from the decomposition over eight years of an unground mixture of tops and roots of *M.littoralis* incorporated at a field site (Roseworthy) in South Australia. Details of soil and plant properties, and of climate over the experimental period, have been reported elsewhere (Ladd *et al.*, 1981b; 1984). About 30% of legume ^{14}C remained in soils as organic residues after 0.3 years, declining to about 11% after eight years.

The initial rapid decline in organic ^{14}C, followed by a period of slow decrease, are characteristic of the patterns of decomposition of plant materials added to soils (Jenkinson, 1981). Decomposition of legume material at the South Australian site was almost identical to that of ryegrass, as established by Jenkinson and Ayanaba (1977) for sites in Nigeria and England,

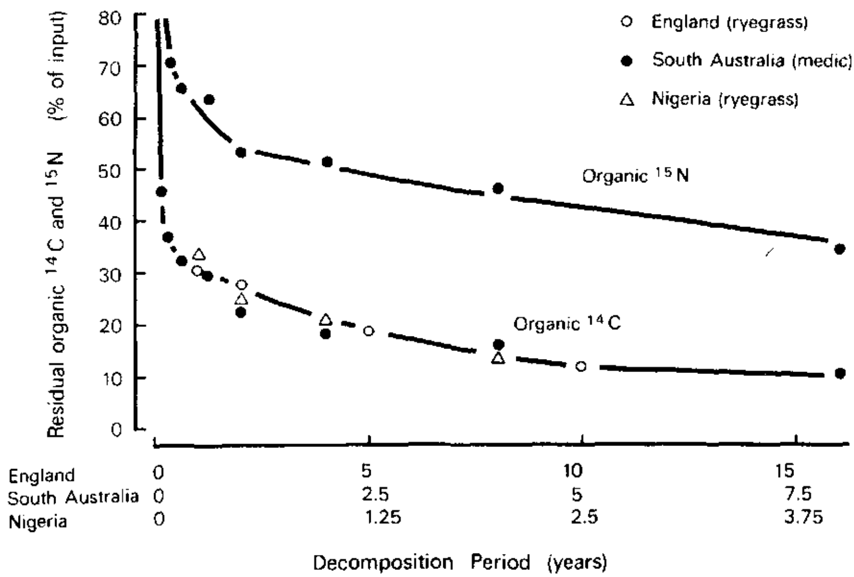

FIG. 6 Decomposition of plant materials in soils located in contrasting climatic regions.

except that differences in the time scales suggest that rates of reaction under the conditions prevailing at the Nigerian site were double those at the South Australian site, which were double those at the English sites. Interestingly, despite differences in plant and soil properties and climatic patterns, reaction rates doubled for an 8-9°C increase in the mean annual air temperatures (England 8.9°C, South Australia 17.0°C, Nigeria 26.1°C), indicating that temperature may have been the dominating factor in establishing the differences in the overall reaction rates.

The C:N ratio of the added legume material was 15.3:1, and since extraneous, unlabelled plant material was removed from soil at the time of incorporation of the labelled legume, it was anticipated correctly that net mineralization of legume N would occur concurrently with plant decomposition. After 0.3 years about two thirds of legume ^{15}N remained in soils as organic residues, declining to about one third after eight years (Fig.6). Thus under the conditions of our experiment whereby the soils in the field were undisturbed and kept free of vegetation, about 40% of legume N at a maximum could have been available for crop use in the year following the return of the legume material to soil; and only a further 25% made available over the next seven years.

Evidence from independent experiments (Ladd *et al.*, unpublished data) suggest that under our conditions, cropping had only a minor influence on the release of N (and C) from organic residues. For example, soil was labelled by addition of ^{14}C-glucose and $^{15}N-NO_3^-$, and sown with wheat five months later or kept unplanted. After more than four years, residual organic ^{15}N accounted for 45.8% of initial substrate ^{15}N in the soil which had grown four successive wheat crops, compared with 35.1% in soil kept unplanted. Some of the extra organic ^{15}N in the cropped soil can be attributed to ^{15}N in residual root material. The respective recoveries for organic ^{14}C in cropped and unplanted soils were 6.0% and 5.7% of input glucose ^{14}C.

The central role of the soil fauna and microflora in the decomposition and transformation of organic substrates has long been recognized. The release of nitrogen from organic residues (mineralization) and accumulation of nitrogen in forms suitable for plant growth are offset by nitrogen participation in other reactions, including synthetic reactions associated mainly with microbial growth (immobilization). Using techniques based on a preliminary high percentage kill of the soil biota by chloroform fumigation (Jenkinson and Powlson, 1976), it is possible to measure approximately the amounts of C and N in the soil decomposer populations.

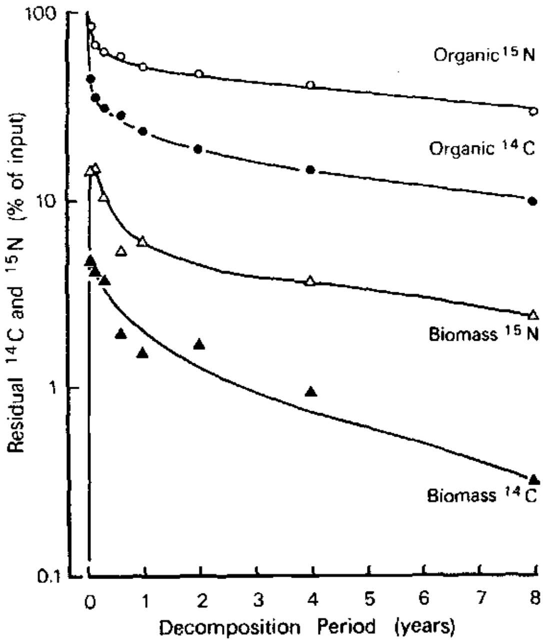

FIG. 7 Formation and decline of isotope-labelled biomass C and N during the decomposition of ^{14}C, ^{15}N-labelled plant material.

Fig.7 shows the increase and decrease of biomass C and N accompanying the decomposition of added legume material at the South Australian (Roseworthy) field site. All residues are expressed as percentages of input ^{14}C and ^{15}N (adapted from Ladd *et al.*, 1981a, 1984). After an initial rise, the amounts of biomass ^{14}C and ^{15}N decreased with time, and accounted for decreasing proportions of residual organic ^{14}C and ^{15}N.

The turnover of C and N through the decomposer populations has been included in models to describe more accurately the decay of organic substrates and the release of inorganic N in soils, (for example, Jenkinson and Rayner, 1977; Juma and Paul, 1981; McGill *et al.*, 1981; van Veen and Frissel, 1981; van Veen *et al.*, 1984). Rayner (in Jenkinson and Ladd, 1981) proposed a simple model to describe organic ^{14}C decline and the turnover of biomass ^{14}C in two similar soils located at sites in England and in South Australia (Northfield). Data from both locations were approximately superimposed by assuming that the processes of decomposition were twice as fast at the South Australian site (see also Fig.6 for data from different soils, supporting this assumption).

More extensive models take into account differences in the nature of the plant materials added to soil (specifically the proportions of C and N of plant constituents which are readily and less-readily decomposed), and the C:N ratios of the biomass, which clearly determine the N demand for a given efficiency of use of available C. Further, small differences in the extent of decomposition of organic substrates in clay and sandy soils may be due in part to differences in the stability of biomass C and N. A recent model by van Veen *et al.* (1984) formulates the concept that soils have characteristic capacities to preserve or protect decomposer populations.

AVAILABILITY TO WHEAT CROPS OF NITROGEN RELEASED FROM DECOMPOSING LEGUME RESIDUES

Table 2 summarises data from three field experiments showing recoveries of legume-derived N in wheat crops harvested when fully ripe, and in soil profiles. In each experiment ^{15}N-labelled *M.littoralis* material was mixed with topsoils confined within open-ended steel cylinders installed to 90 cm depth in undisturbed soil, and allowed to decompose for about 5-8 months before sowing the soils with wheat (Ladd *et al.* 1981b, 1983; Ladd and Amato, 1985). Where a second crop was grown, soils contained decomposing roots of crop 1 as well as other labelled residues. The amounts of legume N incorporated ranged from 25-100 kg N ha^{-1}, which were realistic levels for most field conditions of the southern Australian wheat belt.

TABLE 2

Recoveries of Applied Legume ^{15}N in Succeeding Wheat Crops and Soil Profiles

Experiment	*Site*	Crop No.	*Grain Yield* ($x10^3$ kg ha^{-1})	*N Recovery* (% of input) Crop	Crop + Soil	*Reference*
1	Caliph	1	1.05	13.8	93.1	Ladd *et al.*, 1981b
	Roseworthy	1	2.64	17.3	92.3	
	Northfield	1	4.91	10.9	87.7	
2	Avon	1	4.71	27.8	100.3	Ladd *et al.*, 1983;
		2	1.31	4.8*	96.4**	unpublished data
		1	1.50	20.2	n.d.	
3	Roseworthy	1	3.25	17.3*	83.6	Ladd and Amato, 1985
		2	2.22	4.2*	n.d.	

* Wheat tops only analysed
** Allows for N removed in crop 1 harvest

Recoveries of applied legume N in crop plus soil generally exceeded 90%, and were consistent with the high recoveries generally anticipated for winter-rainfed cropping systems in semi-arid environments (Noy-Meir and Harpaz, 1977). In one experiment (experiment 2, Table 2) unplanted soils were run as separate treatments. Here, recoveries of applied N in soil at a time equivalent to wheat harvesting were about 81% (cf. 100% in planted soil), the deficit being due probably to leaching of NO_3^- below sampling depth. In all cases where analysed, the great majority of legume-residue N recovered in soil after wheat cropping was in organic form.

Wheat yields ranged widely ($1.05\text{-}4.91x10^3$ kg grain dry matter ha^{-1}) at the different sites in different seasons, as did the percentages of legume N taken up by first wheat crops (10.9-27.8%). The percentage uptakes were not related to grain yields and were independent of the amounts of legume N applied in the range tested of about 25-100 kg N ha^{-1} (Ladd *et al.*, 1983;

Ladd and Amato, 1985). The percentage uptake of legume N (17.3%, experiment 3) by first wheat crops was about one third the percentage uptake of fertilizer N (41-50%) for a range (25-75 kg N ha^{-1}) of application rates. The availabilities of legume residue N and fertilizer residue N to a succeeding crop were similar, irrespective of initial application rates or forms of fertilizer (Ladd and Amato, 1985).

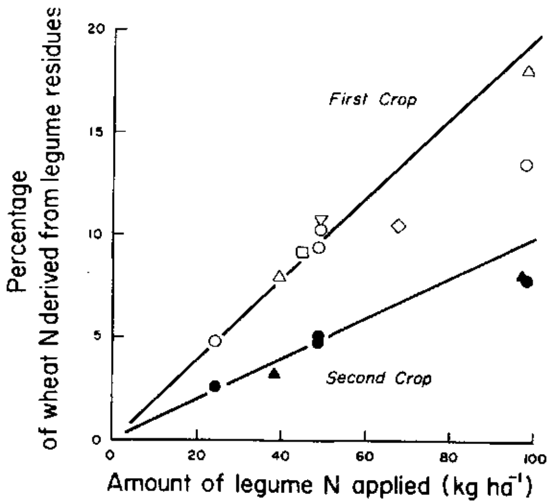

FIG. 8 Percentage contributions from decomposing legume residues to the nitrogen of successive wheat crops.

Not all of the ^{15}N released from decomposing legume residues is taken up by successive wheat crops. Evidence with planted and unplanted soils clearly indicates higher residual organic ^{15}N concentrations in soils under first wheat crops. Indeed, most of the extra organic ^{15}N in cropped soil is considered due to immobilization of $^{15}NO_3^-$ prior to wheat flowering (Ladd *et al.*, unpublished data). Undecomposed wheat roots contribute only a minority of the organic ^{15}N remaining.

A common feature of our experiments is that irrespective of wheat yields at the different sites, the nitrogen released from decomposing legume residues contributes only a minor percentage of the available N pool, as determined by analysis of wheat tops or tops plus roots. Fig.8, an amalgamation of data from experiments 1, 2, 3 of Table 2, shows that for our experimental conditions 50 kg of applied legume N contributes about 10% of the N in first wheat crops after legume incorporation in soils; the relative availability of legume N is halved for the succeeding wheat crop.

In these experiments the C:N ratio of the applied legume material ranged from 11 to 15:1. Under normal field conditions the C:N ratio of legume residues would be expected to range far more widely. For example in grazed pastures, some legume N would be returned as urea N in animal urine, and any urea N not lost as NH_3 by volatilization would have an availability approaching that of fertilizer N. By contrast, older plant residues, dried and weathered on the soil surface over summer prior to cultivation in the wheat growing year, may have higher C:N ratios (e.g. 26:1), and consequently may contribute less N to a first wheat crop than that indicated in Fig.8.

The relative contributions of legume materials and soil organic matter to the available N pool will also depend upon soil profile properties. The data for Fig.8 were obtained with sandy loams of similar pH and soil profile characteristics. Topsoil organic N contents were in the range 0.09-0.10%, except at Avon (0.17%). For a range of wheat-growing soils of southern Australia there is a direct relationship between organic N content of topsoils and inorganic N released in standard incubation assays; it is uncertain whether N released in assays is directly related to N uptake by crops. The observations illustrated in Fig.8 were obtained for a wide range of seasons suggesting that conditions affecting the release of nitrogen from legume residues and its subsequent uptake by wheat also apply to nitrogen from soil organic matter, at least for soils with similar profile properties.

RELEASE OF NITROGEN FROM SOIL ORGANIC MATTER AND UPTAKE BY WHEAT

Studies with ^{15}N-labelled fertilizers frequently show that fertilizer addition increases the amounts of soil-derived N taken up by crops (Hauck and Bremner, 1976). Several plausible explanations may account for these observations including (1) substitution of fertilizer N for soil-derived inorganic N in immobilization (and denitrification) reactions, and (2) promotion of root growth and of healthier roots, resulting in greater exploration by roots of soil profiles and more efficient utilization of the soil-derived inorganic N already present.

TABLE 3

Effect of the Incorporation of Legume Material on the Release and Uptake by Wheat Crops of Nitrogen from Soil Organic Matter

Cropping year	Legume N incorporated* ($kg\ ha^{-1}$)	Soil-derived N: Inorganic N at sowing in soil profile ($kg\ ha^{-1}$) 0-90 cm	30-90 cm	Wheat N ($kg\ ha^{-1}$) Grain	Tops less Grain
1	97	106	69.5**	51.7	18.4**
	39	101	51.6	63.4	19.3**
	Nil	77.7	41.7	51.6	13.8
2	97	66.8	45.9**	37.0	13.3
	39	61.0	37.0	32.5	11.4
	Nil	60.1	31.1	32.0	12.9
3	97	84.4	42.6	n.d.	
	39	71.9	30.4	n.d.	
	Nil	65.9	31.9	n.d.	

* Incorporated in year 1 only
** Significantly different ($P<0.05$) from unamended soils

Table 3, from Ladd and Amato (1985), shows the effect of incorporating legume materials in soils on the concentrations of soil-derived inorganic N in soil profiles at sowing in each of three successive years, and on the uptake of soil-derived N by two wheat crops. The addition of legume material at 97 kg N ha^{-1} (but not at 39 kg N ha^{-1}) significantly increased the concentrations of soil-derived NO_3^- in the profiles at 30-90 cm depth but for the first two years only. Both levels of legume input significantly increased the uptake of soil-derived N by wheat (tops less grain) in the first year.

The mechanism(s) for the increased release and uptake of soil-derived N are presently undefined. Climate during wheat growth, and soil profile characteristics determined that the increased amounts of soil-derived NO_3^- evident at depth before sowing the first wheat crop, were not fully utilized by either wheat crop subsequently. The effects of legume material (and of fertilizer) on the distribution of soil-derived NO_3^- are compared in more detail by Ladd and Amato (1985).

CHANGES IN SOIL INORGANIC NITROGEN CONCENTRATIONS DURING LEGUME-WHEAT ROTATIONS

Results calculated from isotope data as summarized in Fig.8 demonstrate that under our experimental conditions, nitrogen released from legume residues contributes minor percentages to the available N pool, even within the first year of their decomposition. These results, coupled with high total recoveries in soil plus crop, suggest that the value of legumes in the rotation lies in their potential ability to maintain or increase soil organic N levels. Nevertheless it is commonly found that the amounts of inorganic N in soils at sowing in a year following legume pasture exceeds that in soils following a wheat crop, and that the greater nitrate levels may be correlated with increased grain yields in the second cropping year.

Unpublished data by Ladd *et al.* are consistent with such observations (Table 4). Wheat grown in the year following a stand of the legume *M.scutellata* yielded 2.8-2.9x10^3 kg grain ha^{-1}, and the amounts of NO_3^- N in soil profiles to 60 cm at sowing were 108-111 kg ha^{-1}. By contrast, following a preliminary wheat crop, a second wheat crop yielded only 1.8-2.2x10^3 kg grain ha^{-1}, and NO_3^- N levels at sowing were equivalent to 62-66 kg ha^{-1}.

In plots sown with the legume in the year 1978, NO_3^- N concentrations fell (net) from 69 kg ha^{-1} (0-60 cm) to 41 kg ha^{-1}

TABLE 4

Changes in Soil Inorganic Nitrogen Concentrations in a Legume-Wheat Rotation

Time of Soil Sampling	Inorganic N in soil (0-60 cm) ($kg\ ha^{-1}$) Amount	Δ*	Amount	Δ*
	WHEAT, 1978		LEGUME, 1978	
sowing	75		69	
flowering	13	- 62	41	- 28
	WHEAT, 1979		WHEAT, 1979	
cultivation	36	+ 23	71	+ 30
sowing (a)**	66	+ 30	111	+ 40
(b)	62	+ 26	108	+ 37

* Change between sampling times
** Surface residues either (a) removed or (b) returned *in toto* at cultivation

shortly before the pasture legume became dry and brown with increasing moisture stress. In corresponding plots of wheat, NO_3^-N concentrations decreased in the same time interval, from an initial 75 $kg\ ha^{-1}$ to 13 $kg\ ha^{-1}$, corresponding to the late flowering stage of the cereal crop. Thus at this time the NO_3^- N levels in the soils under legume were greater by 28 $kg\ ha^{-1}$ than those of soils under wheat, and the difference increased by a further 17 $kg\ ha^{-1}$ by the time of wheat sowing in year 2 (1979).

Thus the greater NO_3^- N status of soils at sowing following legume was due more to the greater residual concentration in soils at the end of the first season, than to the greater mineralization of N in the soils containing legume residues compared to those containing wheat residues (Table 4). The data are compatible with information derived from the use of ^{15}N-labelled plant materials, and emphasize that the accumulation of plant available N in soils is the resultant of a number of competing processes; not least in our experiment are those processes operating prior to the decomposition of legume and wheat residues in soil and the net release of NO_3^- for crop use.

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CONTRIBUTION OF BIOLOGICALLY FIXED NITROGEN TO FOOD CROP PRODUCTION IN THE WEST INDIES

Key Words : BNF, Cowpea, soybean, groundnut, maize, rice

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SUMMARY :

Grain and vegetable legume crops are important in Caribbean agriculture but little research has so far been carried out to assess the direct role of these crops in the nitrogen economy of the particular soil/plant systems. Since 1972 there has been some systematic studies on biological nitrogen fixation and these were restricted to rhizobia associations with pigeon pea, cowpea, soybean and peanut. A substantial amount of evidence is available showing that these crops could successfully nodulate with rhizobia resulting in N-fixation. For infertile soils, soil amelioration is important even for cowpea. In stress situations due to infertility or other adverse soil conditions, local rhizobia strains, although not very prolific, are more effective in nodule formation and N-fixation, than improved introduced strains. Soybean is able to nodulate with local strains but the nodules develop late and supplemental N may be needed for early crop development. Peanut nodulates profusely with introduced and indigenous rhizobia but the indigenous strains are more effective over a wider range of soil conditions. Nodulation and biological N fixation in pigeon pea is only important in infertile soil conditions. The Plant shows considerable ability to utilize native mineral soil N. Evidence has been obtained that some N fixation occurs in the rice crop in Caribbean conditions and the amount, although not substantial, could be important in the productivity of this crop.

Biologically influenced losses of mineral N could be extremely important in Caribbean soils during the wet seasons due to alternating aerobic and partially anaerobic conditions. Slow release N fertilizers and nitrification inhibitors reduce these losses but due to cost they are not routinely used.

INTRODUCTION :

Indigenous systems of food crop production in the Caribben invariably involves inter-cropping of a cereal (mainly maize) or a root crop (mainly sweet potato, yam or aroids) with a legume (mainly pigeon pea, cowpea and red kidney bean). Recently, peanut has been gaining in popularity in the drier areas particulary on volcanic soils. Traditionally, this crop is grown in pure stand. Different legumes are important in various parts of the Caribbean. Pigeon pea (cajanus cajan) is favoured in Trinidad and Tobago and in the Leeward and Windward Islands, red kidney bean (Phaseolus vulgaris) is preferred in Belize and Jamaica and cowpea is popular in Guyana, Suriname and to a lesser extent in Barbados and the Leeward and Windward Islands. Throughout the region, with the exception of Belize, vegetable cowpea (Vigna unguiculata subspecies sesquipedalis) and suitable cultivars of V. unguiculata e.g. Bush Sitao are widely cultivated and used.

Traditionally, little or no fertilizers are applied in inter cropping and although yields are low, an acceptable level of production has been maintained. It is inconceivable that the legumes are not making an important contribution to the N economy in such farming systems, but the exact amount needs to be determined. It is farmer's common experience that inter-cropping with legumes can be carried out anytime throughout the year whenever soil moisture levels permit. However, sole cropping maize without added fertilizers is only attempted at the commencement of the wet season to take advantage of the naturally occurring high levels of mineral N in the soil (Hardy 1946, Cornforth 1971).

The contribution of legumes in the N economy of Caribbean agriculture is also well appreciate in livestock production. There are several prolific pasture legumes which can make significant contribution, which needs to be quantified. In some instances, the role of leguminous cover crops or shade trees in tree crop production (Macklin 1964, Hardy, F., Personal Communication) is well accepted. Macklin (1964) also observed more mineralised N in soils with leguminous cover crop.

Although it has long been recognised that legumes could be responsible for increasing N availability in Caribbean agriculture, no systematic studies on its exact contribution has been assessed until recently. Since 1972, there has been three major research inputs in biological N fixation. The first was sponsored by the Overseas Development Administration of the United Kingdom and it concentrated specifically on pigeon pea. The second was supported by the International Development Research Centre of Canada and dealt with the role of legumes in pasture improvement. More lately, in cooperation with Cornell University, studies on BNF were continued on a wider range of food legumes including cowpea, soyabean and groundnut and to some extent, *Phaseolus* bean.

INDIRECT CONTRIBTIONS OF N THROUGH BIOLOGICAL PROCESSES:

The fluctuations of NO_3N in Caribbean soils as affected by wet and dry seasons mentioned above, is partly biologically dependent. For instance, Macklin (1964) found larger amounts of mineralised N at the commencement of the wet season where there was a leguminous cover crop compared to grass cover. This N which is available in the soil at the commencement of the wet season, makes an enormous contribution to food crop production in this region. It is well established that food crops planted early in the season are above to produce satisfactory yields with no supplemental N. However, since the rainy seasons usually commence very wet, N is lost rather rapidly by denitrification and leaching, and therefore only the farmers that plant early will benefit substantially.

Collins and Donawa (1982) found that some soils of Trinidad and Tobago had appreciable nitrogenase activity especially if a source of energy is added. They reported that the low activity observed in several cases could be due to low levels of available energy. Activity was high in inundated situations such as mangrove swamps and paddy fields. De Souza (1966) listed 79 leguminous plants species in Trinidad which had active nodules and are apparently contributing to the N economy of the ecosystem including cultivated food crops.

From these trials, the conclusion can be made that there is a need to compare different strains of rhizobia for different soyabean varieties or on particular soils. Transferring a Rhizobium strains from one soil to to another may not be beneficial. The most effective strains for each soyabean variety for given soils should therefore the determined.

(iii) Peanut:

Results obtained (Graham, 1979; Graham and Donawa, 1981; Graham and Donawa, 1982) indicate that significant amounts of N could be fixed by rhizobia and made available to peanut but suitable rihzobia strains and soil conditions are important. Tables 4 and 5 show the effects:

TABLE 4: Effect of strains of rhizobia on yield of groundnut

Rhizobia strains	Yield (kg/ha)
22 Bk	929
AH 6K	838
5018 S	756
CB 756K	641
AH10bK	527
Uninoculated	511
SE P=0.05	133.8

+ Source: Graham and Donawa (1981).

TABLE 5 : Effect of PH on nodule number, nitrogenase activity and inoculant recovery +

Soil pH	Nitrogenase activity (pm C_2H_4/h)	Nodule NO. 1 plant	Inoculant recovery (%)
4.6	5.76	41	48
6.5	12.73	87	56
7.1	11.06	76	26
SE P=0.05	2.57	0.37	8.09

+ Source: Graham and Donawa (1981)

In Table 4 is shown the five strains used which were the most effective among 19 strains (14 local and 5 imported) that were tested. Yields were low due to excessively wet conditions.

N - CONTRIBUTION FROM RHIZOBIA

(i) Pigeon Pea:

Since nodulation is generally very low on this crop under traditional conditions, studies were initiated to investigate, and also to assess the effectiveness of both local and introduced strains for this crop. The results showed that there were no very effective rhizobia strains in Trinidad soils,(Quilt and Donawa, 1979b; Donawa and Quilt,1981) and if the crop is grown on relatively good soil, it apparently obtained its total N requirements from the soil N pool. In such soils, addition of mulch or bagasse which resulted in utilisation of excess mineralised soil N led to increase nodulation and presumably biological N fixation.

On very poor soils, pigeon pea does not normally develop nodules in Trinidad. However, when such soils are fertilized with major and minor elements and the plants inoculated, dramatic effects on nodulation were obtained. For example, an experiment with the extremely infertile Piarco fine sand with complete nutrients added showed increased shoot weight by 100 percent, nodule weight by 625 percent, nodule number by 325 percent and nitrogenase activity by 500 percent (Donawa and Quilt, 1981).

There was also an indication that other soil factors mainly available P and exchangeable Ca levels were limiting to N fixation with this crop. Little attention was given to the effect of soil moisture on N fixation, although this can be important. In Caribbean soils pigeon pea nodulates by indigenous promiscuous Rhizobium strains from the cowpea group with considerable variation in the degree of effectiveness of the symbiosis.

In one experiment aimed at indirectly assessing the contribution of biological nitrogen fixation with pigeon pea on an inter-crop of maize (Dalal, 1974) there was good evidence that the combination was mutually beneficial. The results are summarised in Table 1 below:

Table 1: Yield of maize and pigeon pea in various crop combinations

Crop combination	Maize ha	Pigeon pea kg|ha	Total	Crude protein %
Maize alone	3130 a*	–	3130	19.1a
Pigeon pea alone	–	1871a	1871	17.5a
Pigeon pea| maize planted together.	2025b	1710a	3735	24.6b
Pigeon pea| maize in alternate rows	2606c	1854a	4460	29.2c

*Means within each column not followed by common letters on siginficantly different at P= 0.05 according to Duncan's Multiple Range Test.

In this experiment, no N was added. It was also observed that maize and pigeon pea grown in alternate rows stimulated more uptake of K, Ca and Mg by both crops and the mineral N level of the soil was also significantly higher compared to other treatments at all times duuring the growth of the crop, indicating the important role of biological N fixation. Highest yields of pigeon pea were obtained with only 20 kg of N (3468 kg/ha) while maize needed 200 kg/ha for a maximum yield of 5310 kg/ha.

(ii) Soyabean:

Although soyabean production in Trinidad was investigated (Radley, 1968; Braithwaite,1972; Braithwaite *et al*,1974) for some time, little or no attention was given to nodulation and N fixation. Soyabean is generally assumed to be nodulated only by specific *Rhizobia* (*R. japonicum*)and therefore in areas where the crop is being introduced for the first time the organisms are often absent and inoculation with suitable strains is considered necessary. However, many strains classified as members of the cowpea miscellany group are capable of nodulating soyabean (Leonard, 1923; Wilson, 1944; Nangju, 1980). Nodulation of uninoculated plants in Trinidad was observed by Hosking and Buckley (1928) and Jones(1938) although not on all soils studied. More recently Mughogho and Lowendorf (1979b)found that although inoculation with introduced *R. japonicum* strains increased early nodulation in Piarco fine sand, uninoculated plants developed nodules especially late in the growth cycle. Such nodules were apparently effective, as the uninoculated plants produced significantly higher yields than inoculated plants. The strains of Rhizobium which formed nodules with pigeon pea readily formed nodules with cowpea. From this it is concluded, that indigenous strains of rhizobia capable of nodulating soyabean are likely to be well adapted to local conditions and could be more suitable than the exotic strains for use as inoculants.

Fertilizer N usually reduces nodulation and N fixation in soyabean(Allos and Batholomew, 1955 Hardy et al,1968) as this form of N tends to act as a substitute for N fixation rather than supplement it. Some N applied at planting or at flowering can be beneficial (Hatfield et al, 1974; Lawn and Brun, 1974;) and in Trinidad, Mughogho and Lowendorf(1979 a,b) obtained highest yields from uninoculated but well nodulated plants receiving 60 kg n|ha. The same observation was made by Kang (1975) in Nigeria.

In studies carried out by Mughogho and Lowendorf (1979b) and Awai (1981), response of soyabean to inoculation with an introduced strain of R. japonicum, a locally isolated strain, and to application of fertilizer nitrogen,were compared. The results obtained indicate, that the imported strains formed nodules earlier in the life of the crop but the nodule number and effectiveness decreased as the crop approached its reproductive phase. The native strains infected the plant later in its develpment and their effectiveness persisted for a longer period, resulting in the end in a higher yield of grain (Table 2). The late nodulation suggests a low population of the particular rhizobia. It may be concluded that in commercial production of soyabean in the Caribbean, inoculation with local strains well adapted to existing soil conditions could be beneficial. It is likely that the population of effective rhizobia would increase rapidly if the crop were grown regularly. The exotic rhizobia strains which were used showed insufficient ability to compete, persist and reproduce in the infertile acid soils of the Caribbean. However, there is some indication that local strains could survive and compete fairly well (Table 3). There has been no trials carried out on the better soils and it would beinteresting to study how these organisms would perform in better soil conditions.

TABLE 2: Effect of inoculation and N fertilization on nodule number, N content and grain yield of two soyabean varieties +

Treatments[a]	Nodule Number/* plant DAP	N content (%)	Grain yield* (kg/ha)
S_1 Rh_1 N_1	14.33	3.28	2454
S_1 Rh_1 N_2	6.33	4.08	2411
S_1 Rh_2 N_1	3.33	3.88	2663
S_1 Rh_2 N_2	-	4.33	2673
S_1 Rh_1 N_1	15.67	2.95	2472
S_2 Rh_1 N_2	2.33	3.95	2432
S_2 Rh_2 N_1	106.7	3.25	2431
S_2 Rh_2 N_2	43.6	3.65	2424
LSD. P=0.05	59.1	1.77	*no significant differences at P=0.(

+ Source: Mughogho and Lowendorf (1979a)

a S_1 = Jupiter variety
Variety
S_2 = Dapros variety
Rh_1 = No inoculation
Rh_2 = Inoculation with nodulating strain isolated from Piarco fine sand
N_1 = No fertilizer N
N_2 = 30 kg/ha N as urea

*Plants sampled at mid-growth stage.

TABLE 3: Effect of N application and inoculation on and re-inoculation on grain yield of soyabean on Piarco fine sand

Treatments[a]	Yield* - 1st Crop	Yield - re-inoculated, 2nd Crop	Yield - uninoculated, 2nd Crop
		(kg/ha)	
Rh_1 N_1	574	1572	1703
Rh_1 N_2	1142	1127	1586
Rh_1 N_3	1054	1448	1886
Rh_2 N_1	392	1621	1543
Rh_2 N_2	756	1344	1767
Rh_2 N_3	630	1696	1152
Rh_3 N_1	556	1382	1707
Rh_3 N_2	685	1431	1698
Rh_3 N_3	680	1633	1786
LSD P=0.05	393	827	727

[a]Rh_1 = no inoculation Rh_2 = inoculated with Piarco fine sand strains

Rh_3 = Princes Town soil strain; N_1,N_2 and N_3 = 0,60, and 120 kg/ha N as urea.

*Crop adversely affected by dry spell

It is to be noted that in all experimental work, the indication is that supplemental fertilizer N seems necessary for the best yields.

On a more fertile soil (River Estate loam) there was also some natural nodulation although the nodulating strain from Piarco fine sand was more effective. On this soil, there was generally low nodulation due to the higher available N in the soil. On this soil also, nodule numbers decreased with N fertilization. Varieties responded differently, inoculation Jupiter responding more positively in grain yield to inoculation than Dapros.

Lack of more dramatic respones to inoculation may have been due to adequate nodulation by native rhizobia, unfavourable conditions for survival of introduced Rhizobium strains and on failure of inoculant strains to compete for nodule sites with native strains. Natural nodulation was good as determined by the number of nodulated plants in uninoculated plots. The ability of the more effective inoculated strains to compete with indigenous but less prolific rhizobia is not established, as well as the optimum concentration of inoculating rhizobia.

The data in Table 5 suggest that under West Indian conditions there is an optimum soil pH for the mosttproductive and competitive nodulation. The decline in the recovery of inoculant strain as the soil pH increased from 6.5 to 7.1 can be explained on the basis that the optimum pH was exceeded. Increasing the inoculation rate from 10^6 to 10^9 cells per ml over the pH range 4.6 to 7.1 was associated with increased nitrogenase activity, shoot weight and recovery of the inoculant strain. It is concluded that soil pH and inoculum strains are related, and are two of the important factors which may be used for effective nodulation.

(iv) Cowpea:

On infertile acid soils, inoculation of cowpea proved beneficial (Mughogho and Lowendorf, 1979a). Uninoculated plants nodulated late and did not contribu much nitrogen in the early vegetative growth. Basal dressing of N (not more than 30 kg n/ha), lime and P are beneficial for nodulation and N fixation.

TABLE 6: Effect of inoculation and fertilizer N application on nodule count, N content and grain yield of cowpea grown in Piarco fine sand.

Treatments	Nodule No. /plant	N content (%)	Grain yield (kg/ha)
Rh_1 N_1	47	2.60	934
Rh_1 N_2	85	2.25	1013
Rh_1 N_3	70	2.58	1122
Rh_2 N_1	123	2.76	1158
Rh_2 N_2	54	2.82	1104
Rh_2 N_3	65	2.42	1117
LSD P=0.05	NS	NS	NS

Rh_1	=	no inoculation; Rh_2 = strain isolated from Princes Town clay (pH 7);
Rh_3	=	strain isolated from Piarco fine sand (pH 4.8)
N_1	=	No N; N_2 = 60 kgN/ha; N_3 = 120N/ha
NS	=	results not significantly different

All plots received basal lime at 3t/ha, KCI - 60 kg/ha, TSP - 100 kg/ha and $MgSO_4$ - 50 kg/ha.

Data in Table 6 show that on infertile soils which are ameliorated, inoculation is not needed for cowpea similarly. On more fertile soils i.e. River Estate loam, nitrogen fertilization and use of ground limestone are not needed, and with application of small amounts of P, K and Mg, there is usually also no response to inoculation.

Table 7 shows the effect of N application on pod yield, nodule number and nodule weight of Los Banos Bush Sitao No.1 grown on River Estate loam (Graham and Scott, 1984).

TABLE 7: Yield of cowpea, nodule number and nodule weight in response no N fertilization

Treatment (kg N/ha)	Nodule No. /plant	Nodule weight (g/plant)	Pod yield (kg/ha)
0	20a	0.38a	5109
30	10a	0.27ab	5095
60	12ab	0.08b	5354
90	11ab	0.07b	4948
120	8b	0.05b	5305
S-E(8 degrees of freedom)	3.4	0.11	335

* Means with common letters in the same column are not significantly different at the 5% level of probability as determined by Duncan's Multiple Range Test.

In this experiment, as the fertilizer N increased from 0 to 120 kg/ha, the plant became increasingly dependent on the fertilizer N and less dependent on biological N fixation. This is seen in steadily decreasing nodule number and nodule weight per plant, yet the yield remained more or less constant throughout the range.

Inoculation resulted in early nodulation so that at 28 days after planting, the inoculated plants had an average of 42 nodules per plant and the uninoculated, 26 nodules per plant. At this stage, 730 kgN|ha had no effect on nodulation. At 40 days after planting the early effect of inoculation on nodule number disappeared and the uninoculated treatment eventually out-yielded the inoculated (Graham and Scott, 1984).

There were varietal differences in nodulation and N fixation between varieties, Vita 1 California No. 5 and Bush Sitao No.1 being the most prolific (Grahman and Scott, 1983).

There is some indication that a cowpea crop could benefit a succeeding maize crop, maize following cowpea out-yielding maize following fallow, or maize following maize, with the maize crops receiving the same N rates. On the other hand, there was no indication of any beneficial effect with sorghum following cowpea (Mughogho and Lowendorf, 1979b).

(v) <u>Rice:</u>

It has been established that biologically fixed N is important in rice production in the Caribbean (Boddey et al., 1978). Although traditionally N fertilizers are not much used in rice production, the crop maintains reasonable yields. It is known that in submerged soils, NH_4N is usually present in relatively large amounts providing a major part of the N requirement of the rice crop. The NH_4-N concentration decreases with time, sometimes reaching critically low levels at important reproductive stages of the crop. Although it is not clear what processes are responsible for the increase in NH_4-N upon submergence, it is likely that biological processes are important. It was established (Ahmad , 1952) that N-fixing blue-green algae occur in the rice fields of Trinidad but the amounts fixed by these organisms have not been determined.

Recently Boddey (1981) investigated the N fixing potential of the rhizospher of local and IRRI rice varieties in Trinidad. Some of the results are summarised in Table 8.

TABLE 8 : Integrated nitrogenase activity and total dry matter and grain yields of some rice varieties grown on two soils in Trinidad.

	Cacandee Clay				Cunupia Clay		
	Rice Varieties				Rice Varieties		
	IR 5	IR22	Joya	Sughandi	IR 5	IR22	Joya
Acetylene reduced mole M^{-2} M^3	46.8	48.2	37.2	46.1	54.6	54.3	52.0
Total dry matter (kg|ha)	8810	9060	9540	10000	9760	8670	11400
S.E. of mean	±1350	±1350	±1350	±1350	±1190	±1190	±1190
Grain yield (kg|ha)	2740	2620	2470	2230	3160	2860	2650
S.E. of mean	± 180	± 180	± 180	± 180	± 270	± 270	± 270

It is interesting to note that the inferred N fixation varied with soils but did not seem to be too variety specific. One would have expected that the local Indica varieties Joya and Sughandi would have been better adapted and be therefore associated with more fixed N.

Boddey (1981) showed that Azospirillum type bacteria and Beijerincka were associated with roots of rice and that the nitrite reductase negative (nir−) types of Azospirillum brasilense predominated over other Azospirillum. (Table 9).

TABLE 9: Types of Azospirillum isolated from unwashed, washed and surface sterilised roots of IR 22 rice plants

Treatment	Number of isolates of each Azospirillum type (20 isolates/treatment)		
	A. lipoferum	A. brasilense nir^+	A. brasilense nir^-
Unwashed	9	11	0
Washed	4	16	0
Surface-sterilised	1	2	17

Comparisons of nitrogenase activity in the rhizosphere of different rice varieties measured at the same growth stage and grown on different soils showed little differences between varieties or soils as mentioned earlier. The activity was maximal at the flowering and early growth filling stages. Although the total amount of N fixed seems small (approximately 6 kg/ha) due to its availability during the full life of the crop and particularly at the flowering and ear-filling stages, its contribution to yield may be quite important. The estimations did not include any possible fixation in the outer rhizosphere and to this extent, it could have been under-estimated.

NEGATIVE CONTRIBUTIONS:

Biological processes sometimes play havoc with management of N in intensive crop production in the Caribbean. The wet season, normally the main cropping season, is characterised by incidence of heavy showers interspersed by less wet periods. These conditions are ideal for alternating periods of nitrification and denitrification, resulting in heavy losses of fertilizer N. Chesney (1967) found that fertilizer N cannot be recovered 6 weeks after application on a bare soil and that 10-95% could even be volatilised after 10 days following apllication depending on soil conditions. To date, recoveries by crop of added N range from 25 percent (Fletcher, 1970) to 50 percent (Ahmad et al, 1982) except when N is added to an established pasture (Ahmad et al, 1967) when the recovery could be higher. Ahmad and Whiteman, (1969), Shand and Ahmad (1974), Weir, 1965, Weir and Davidson, 1968 found that both nitrification inhibitors and slow release fertilizers result in better utilisation of fertilizer N in wet seasons but economic factors have so far excluded the routine use of these materials.

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CONTRIBUTION OF BIOLOGICALLY-FIXED NITROGEN TO FOOD CROP PRODUCTION IN BRAZIL

Key words: Bean Grass-bacteria Forage legume
N_2 fixation Pea Peanut Soybean

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SUMMARY

The increase of soybean production during the 70's based on cultivars bred without nitrogen fertilizer,may represent the best example of the contribution of biological nitrogen fixation (BNF) to food production and the Brazilian economy. With a total production close to fifteen million tonnes, in 1983, this crop alone represented a saving estimated at 900,000 tons of nitrogen fertilizer or 800 million dollars. Research on BNF over the last 20 years has been of major importance for the success of soybean.

Responses of dry beans to nitrogen fertilizer have been erratic, even without inoculation. Recent results showed, that yields three times the country's average can be obtained with certain cultivars with only BNF. Cowpea a major pulse crop grown in the northern and north-eastern part of the country, is commonly grown without nitrogen fertilizer or inoculation. Nodulation seems to be poor in the first plantings on recently cleared land. Peanut has shown good nodulation in most

places and responses to inoculation has not been observed.

Forage legumes species of *Stylosanthes*, *Desmodium*, *Centrosema*, *Macroptilium* etc. are common components of pastures but the assessment of their nitrogen contribution is still sparse.

The native forest legumes have played an important role in maintaining the economy of N in natural ecosystems. Shade leguminous trees also play an important role for the nitrogen economy in cocoa plantations. A recent survey shows 70 new nodulating tree species, many of them useful for agroforestry. There is an increased interest in intercropping, alley-cropping and green manuring with leguminous species. Although green manuring and crop rotation with legumes has been used by farmers, recently there is more research conducted to study its contribution not only for nitrogen economy, soil amelioration and pest control but also as an efficient way to utilize rock phosphates.

Several new N_2 fixing bacteria have been described which associates with grasses and cereals. Rates of fixation up to 40 kg N have been estimated for *Brachiaria decumbens* and *B. humidicola* using the isotope dilution method.

INTRODUCTION

Biological nitrogen fixation (BNF) is recognised as of major importance in Brazil. Today soybean represents the most important export product. The crop relies completely on biological fixed nitrogen. The 180 x 10^6 ha of cerrados (savanna plain, 600-800 m altitude) has the potential to quadruplicate the current grain yield. However, to obtain this application of lime, phosphorus and micronutrients are needed.

Other legumes also contribute to the country's food production and economy such as *Phaseolus* beans, cowpea, peanut, several herbaceous and tree legumes which are used for forage, in agroforestry and as green manure. The first Brazilian export was a non-nodulating forest legume species Pau Brasil (*Caesalpinea echinata*). Although research on BNF including research on nitrogen fixation in grasses received good support from the government the accurate data on contribution of BNF for different crops is still sparse and in most cases is based on assumptions or extrapolations.

Grain legumes

Soybean (*Glycine max* (L.) Merrill) is the most important export crop which benefits from BNF. *Rhizobium* strain selection for soybean started in 1949 (Freire, 1982). Soybean breeding since the 1960's has been directed towards cropping without nitrogen fertilizer. Good results were obtained on breeding and in BNF area for cultivar-*Rhizobium* specificity (Table 1) and for ecological adaptation of both host (cultivars for low latitude) and bacteria strains (strain 29W for cerrados).

Table 1. Nodule dry weight of three soybean cultivars grown in an Oxisol from "cerrado" savanna (Peres & Vidor, 1980).

Rhizobium strain	Soybean cultivars		
	Bragg	Santa Rosa	IAC-2
	(Nodule dry weight.mg/pot)		
Control	43	5	18
SEMIA-532 (RS-Brazil)	168	154	28
CB-1809 (Australia)	151	167	24
965 (Japan)	152	117	112
29W (RJ-Brazil)	285	314	172

The area under grain legume production in 1983 is shown in Table 2. Soybean is the leading crop.

Table 2. Cultivated area and yield of major grain legumes in Brazil in 1983 (Fundação IBGE, 1983).

Crop	Cultivated area	Total yield	Average
	(ha)	(tons)	(kg/ha)
Soybean	8,136,491	14,582,052	1,792
Beans	4,068,872	1,586,993	390
Peanut (with shells)	212,191	284,332	1,340

Assuming a 6% N content in the seeds the 1983 soybean yield of close to 15 million tonnes the cropped without nitrogen fertilizer is estimated to produce 900,000 kg of nitrogen per year. Part of this nitrogen may be derived from the soil organic matter or nitrogen fertilizer applied in previous crop. However symbiosis may provide all the nitrogen required for the soybean crop. (Burris & Hardy, 1975) contained in the 1765 kg ha^{-1} of seeds that were the average yield in 1982. This represent a saving of 800 million dollars of imported fertilizer. The cerrados is rapidly being used for agriculture with soybean as one of the major crops. However, for over 10 years commercial soybean inoculants did not work in this area, until specifically adapted *Rhizobium japonicum* strains were found (Vargas & Suhet, 1980). Adapted strains and several *Rhizobium* sp. (cowpea group) isolates from these soils (Scotti *et al.*, 1980) and strains from newly cleared land from the Amazon which were planted with cowpeas (Döbereiner *et al.*, 1981), were found to be resistant to high streptomycin levels.

Dry beans and cowpea

The yield and area cultivated with beans (Table 2) includes *Phaseolus vulgaris* (dry bean) which is grown from the south of the country up to Bahia and in the highlands in the north and north-east, and *Vigna unguiculata* (cowpea) grown north of Bahia throughout the north-east and in the Amazon region. Average bean yield is less than 500 kg ha^{-1}, and declines over the last few years. Dry bean is a very risky crop. With the exception of same farmers in Rio Grande do Sul, Paraná, Goiás and S. Paulo states, that grow the crop on a large scale with nitrogen fertilizer, most of the dry beans are grown by small holders as a low input crop without inoculation or nitrogen application. Response of dry beans to nitrogen application has been observed in about 50% of the experiments (Franco, 1977; Almeida *et al.*, 1984). High availability of soil nitrogen, presence of other limiting factors, and nodulation with native *Rhizobium phaseoli* may explain the lack of response to nitrogen application. Responses to inoculation are also erratic in Brazil and other parts of Latin America. Lack of response are due to use of cultivars bred with nitrogen application, acidity problems, moisture, stress, etc. Results of experiments conducted on Planosol shows good response of cultivar Carioca to inoculation (Table 3).

Table 3. Response of *Phaseolus vulgaris* to inoculation with *R. phaseoli* and nitrogen application (Duque *et al.*, EMBRAPA/UAPNPBS)(Plant & Soil, accepted).

Bean cultivar	Control		Fertilizer 100 kg N/ha		Inoculated		N_2-fixed[a]
	Nodule weight	Grain yield	Nodule weight	Grain yield	Nodule weight	Grain yield	
	(mg/pl)	(kg/ha)	(mg/pl)	(kg/ha)	(mg/pl)	(kg/ha)	(kg/ha)
Carioca	4	379	10	663	123	991	31.7
Negro Argel	46	494	22	620	155	883	18.4
Venezuela 350	3	378	5	601	39	438	3.6
Rio Tibagi	1	316	29	790	17	583	2.7

[a] Estimated using isotopic $^{15}N_2$ dilution

Six experiments with eight cultivars showed no advantage of nitrogen application (40 kg N ha^{-1}) over inoculation in the Rio de Janeiro Estate (Pesagro, E.E. Campos, personal communication). Good responses to inoculation, have been also reported in the cerrado region (Table 4). In England, Taylor *et al.* (1983) in two years consecutive doubled yield to 1600 kg ha^{-1} with inoculation. Even without inoculation both dry beans and cowpea are found with some pink nodules and since very few crops receive nitrogen fertilizer we can assume that most of the 57.132 kg of nitrogen cropped in 1982 did come from biological nitrogen fixation. The present low average yield cannot be attributed to inability of bean symbioses to provide insufficient nitrogen to the crop grown either as monoculture or in

Table 4. Nodulation and yield of *Phaseolus vulgaris* L. grown in humic soil in the cerrado region (J. R. Peres, A.R. Suhet and M.T. Vargas, EMBRAPA/CPAC, unpublish data).

Treatment	Nodule number per plant[a]	Nitrogenase activity[b] (μmoles C_2H_4 ha/plant)	Grain yield (kg/ha)
Rhizobium strains			
SEMIA 487	109	3.8	984
CO-5	205	1.5	982
CNPAF 150	180	13.0	1.006
CPAC 23	188	13.4	934
Mixture all four	140	7.4	938
Nitrogen control			
100 kg N/ha	0	0	1.434
Control	2	0.9	553

[a] 11 days after germination

[b] 38 days after germination

mixed cropping (Franco & Pessanha, 1984). The use of cultivars bred with nitrogen fertilizer which unable the crop to nodulate well and lack of inoculation may have contributed to the low yield. Cowpea which represents approximately 20% of yield and cultivated area listed under beans in 1983, does not receive nitrogen fertilizer or inoculation with *Rhizobium*.

Peanut

Although peanut (*Arachis hypogea*) is an important source of oil and protein for the country, only few experiments have been done in the States of S. Paulo and Ceará. Though there is diversity in effectiveness of native rhizobia which nodulate peanut cultivars in green-house experiments (Elkan *et al.*, 1981) and good field responses to inoculation have been obtained in India by ICRISAT, 1982 in the above mentioned states (Lopes *et al.*, 1976; Vasconcelos *et al.*, 1977) no response to inoculation was observed because of good nodulation with the native rhizobial strains.

Responses to nitrogen fertilizer are also erratic and most peanuts is mostly grown without or with only very low rates of nitrogen.

Peas

Peas (*Pisum sativum* L.) grown for green pods, are frequently fertilized with high rates of nitrogen, those grown for dry seeds also receive nitrogen fertilization. Field experiments have shown that inoculated plants give yields equivalent to those receiving 100 kg/ha nitrogen (Conceição *et al.* 1981). Good yields have also been obtained from winter season dry peas in the cerrado regions with inoculation (Table 5).

Tree legumes

The leguminosae has provided the finest wood such as *Dalbergia spp.*, *Macherium spp.*, etc., and the first important export timber of *Caesalpinia echinata* (pau Brasil). However, very few tree legumes have been planted extensively in forest plantations. *Acacia decurrens* (Acacia negra) is grown for tannin, production, *Mimosa scabrella* (bracatinga) occurs in natural forest, *Prosopis juliflora* (algaroba) has been introduced on a large scale in the north-east, *Leucaena leucocephala* has been used for forage production and some *Erythrina spp.* are used for shade-trees in cocoa, which can provide sufficient nitrogen for the average cocoa crop (Santana & Cabala-Rosand, 1982).

Table 5. Response of peas to inoculation with *R. leguminosarum* in cerrado region (A.R. Suhet, M.T. Vargas & J.R. Peres, EMBRAPA-CPAC, Brasilia, unpublished results.

Treatments	Nodule number per plant (6 days after emergency	Grain yield (kg dry seeds/ha)
Rhizobium		
VL (CNPA)	8	1,495
EV5 (CPAC)	14	1,701
EV6 (CPAC)	27	1,763
EV335 (IPAGRO)	24	1,745
EV374 (IPAGRO)	9	1,664
EV3007 (IPAGRO)	15	1,375
EV3008 (IPAGRO)	11	1,726
Nitrogen control		
25 kg N/ha	0	1,347
50 "	0	2,027
100 "	0	2,276
200 "	0	1,718
Control	0	1,534

There are other important but underexploited leguminous trees, which are harvested for pulp, charcoal, fire, wood, hard-wood etc. A survey in the north-eastern semi-arid regions of the country (Vasconcelos & Almeida, 1979/80), in the Amazon rain forests (Bradley *et al.*, 1980; Magalhães *et al.* 1982) and in south-east Brazil (Faria *et al.* 1984) revealed 70 new nodulating and potentially useful species (Table 6). The contribution of tree legumes to the economy has not been assessed.

Table 6. Nodulation of native legume trees from north east (Vasconcelos & Almeida, 1979/80), Amazon rain forest (Bradley *et al.* 1980; Magalhães *et al.* 1982) and south east Brazil (Faria *et al.* 1984).

	Sub-families			Total
	Mimosoideae	Papilionoideae	Caesalpinoideae	
Number of species observed	60	75	72	207
Number of species with nodules	51	53	9	113
Number of species found for the first time with nodules	25	37	8	70
Number of genera found for the first time with nodules	2	5	2	9
Number of species found without nodules not reported before	5	15	39	59

Green manure

Green manures have been succefully used, but sporadically by farmers. Recently Research Institutions are giving more attention to this problem.

The most common leguminous green manures in Brazil nodulate well with *Rhizobium* sp. (cowpea group), and show a range of specificity. Table 7 shows data from a cross inoculation experiment, which indicates that mucuna (*Stizolobium aterrinum*) is less specific than five other species. Although inoculation is not practiced for green manures plants show abundant nodulation.

Average yield of several species, over 4 sites for a period of 7 to 13 years have shown high fresh weights from 14.7 tonnes for *Tephrosia candida* to 42.1 tonnes for *Crotalaria paulina* (Miyasaka, 1984). Miyasaka(1984) reviewed the results of several experiments which investigated the effect of crop rotation with legumes and green manures. Economic analyses of several crops in Ribeirão Preto-SP showed, that in rotation with green manures, soybean yield increased by 16% with a saving of 25% in fertilizer costs; cotton yield increased 5% with a saving of 21%; corn yield increased 45% with a saving of 3%, and peanut yield increased 8% with a saving of 7% (Martin *et al.* 1984).

As N_2 fixing plants in general acidify the rhizosphere, this is shown to increase phosphorus uptake from rock phosphate in soybean (Aguillar & van Diest, 1981). Use of legumes that can fix large amounts of nitrogen and acidify the rhizosphere may be an effective way to provide nitrogen and soluble phosphate to the subsequent crop. An experiment was performed to test this hypothesis using mucuna (*Stizolobium aterrinum*) and sunnhemp (*Crotalaria juncea*) in an acid

Table 7. Cross inoculation of 6 legumes used for green manure in Leonard jars (J.R. Peres, A.R. Suhet & M.T. Vargas, EMBRAPA-CPAC, Brasilia, unpublished results.

Rhizobium isolated from	Legume species					
	C. juncea	*C. spectabilis*	*C. cajan*	*C. ensiformis*	*I. hirsuta*	*S. aterrinum*
	(Plant dey weight g/plant)					
Crotalaria juncea	3.8	2.5	3.9	7.0	2.3	8.5
C. spectabilis	3.2	1.9	3.2	3.8	1.0	5.8
Canavalia ensiformis	0.5	0.4	2.6	8.7	0.6	2.9
Cajanus cajan	0.3	0.2	5.4	6.1	0.8	6.0
Stizolobium aterrinum	2.7	1.5	4.0	6.4	0.9	6.8
Indigofera hirsuta	2.5	1.6	4.6	7.5	1.0	8.2

Oxisol. Mucuna accumulated more phosphorus from rock phosphate than sunnhemp. Mucuna also accumulated more nitrogen than sunnhemp with all sources of P (Table 8).

Table 8. Phosphorus uptake by *C. juncea* and *S. aterrinum* (mucuna) grown in an Oxisol ammended with several phosphorus sources. (E.M. Silva *et al.* EMBRAPA/UAPNPBS, Rev. bras. Cienc. Solo-accepted).

Sources of P	Legume species	Total P in the plant (kg/ha)*	Total N in the plant (kg/ha)
Patos rock phosphate	Mucuna	35,8 ab	318 a
Patos rock phosphate	Sunnhemp	15,7 c	151 c
Thermophosphate	Mucuna	37,2 a	353 a
Thermophosphate	Sunnhemp	31,7 b	253

* Number followed by different letters are significantly different at $P \leq 0,05$.

Forage legumes

It is difficult to understand why tropical forage legumes is not more intensively used in Brazil considering, (a) the diversity of native species in unimproved pastures, and (b) Latin America has been a genetic source of forage legumes. Acidity, problems phosphorus and Mo deficiencies (De-Polli *et al.* 1977b) and poor management may explain the failure to maintain 25 to 30% of legumes in intensively grazed pastures. More recently leucaena has been introduced in several places. In the cerrado region with low Ca^{2+} concentration in the lower profile it produces large superficial and lateral roots, plants are susceptible to drought and with lower productivity than observers found in south-east Asia (Hutton, 1983). Several *Stylosanthes* species are found all over the country: however, with intensive cultivation anthracnose is a major problem. Siratro (*Macroptilium atropurpureum*) is very productive with good management and in soil with improved fertility. Several *Centrosema* species have been found very productive in low P and K soils with acidity problems.

Although forage legume are not intensively cultivated in pastures, nitrogen fertilizer is not extensively used. Pastures derive its nitrogen mainly from soil or biological fixation, both in grasses and legumes.

Grasses

Several new N_2 fixing bacteria associated with grasses and cereals have been described (Döbereiner, 1966; Tarrand *et al.* 1978; Barraquio *et al.* 1983; Magalhães *et al.* 1983). Plant responses under field conditions to *Azospirillum* inoculation have been reported from various places (Okon, 1982; Subba Rao, 1981; Vlassak & Reynders, 1979). Although responses were usually accompanied by increase in N incorporation, proof of N_2 fixation has not been shown. Recent estimates by R.M. Boddey & R.L. Victoria (personal communications) using ^{15}N isotopic dilution technique indicates, that 53 kg N/ha per year was fixed in association with *Brachiaria decumbens* and 23 kg/ha per year with *B. humidicola*. ^{15}N dilution experiments also showed incorporation of nitrogen in *Paspalum notatum* (De-Polli *et al.*, 1977a). There is also some indication of N_2 fixation in sugar cane (Ruschel & Vose, 1981). Recent information from our laboratory also indicates large differences between sugar cane genotypes in accumulating nitrogen and in isotopic dilution of ^{15}N.

CONCLUSION

It is impossible to quantify the contribution of biological nitrogen fixation to the economy of Brazil. However, much effort is done to maximize legume symbiosis and N_2 fixation with grasses. Soybean output of nitrogen each year exceeds the total of N fertilizer imported and produced in the country. Brazilian agriculture is thus heavily dependent on biological nitrogen fixation, whether from current activity or from the nitrogen contained in the soil organic matter than was fixed and previously accumulated.

Unfortunately there are still integrated forestry, agriculture-livestock and land use projects in the Amazon jungle (like the Jari florestal project) which includes trees, forrage grasses and grain crops, with no legumes and disregarding completely BNF (Briscoe, 1983).

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NITRIFICATION AND RESPONSES TO <u>RHIZOBIUM</u> INOCULATION IN TROPICAL SAVANNA AS AFFECTED BY LAND PREPARATION.

Key Words: *Centrosema* Nitrification Oxisol Pasture establishment. *Pueraría* Reduced tillage *Rhizobium* inoculation Tropical forage legumes *Trachupogon* savanna

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Nitrate (NO_3) concentration were high, medium and low respectively in an acid infertile Oxisol at Carimagua, Colombia, from 0-1.10 m depth in areas which had either been ploughed and left bare, ploughed and planted, or from undisturbed savanna. Higher rates of NO_3 accumulation were observed in ploughed than undisturbed savanna soild from 0-10 cm depth at 3 sites containing 448, 952 or 1176 ppm total N, and incubated for 12 weeks in pots or undisturbed soil cores. NO_3 accumulation rates in pots increased with time and final concentrations were higher than in cores. More NH_4 accumulated in pots than in cores, in soil from undisturbed savanna than in ploughed soil, and in the soils with higher total N content. Two forage legumes (*Pueraria phaseoloides* and *Centrosema macrocarpum*) were planted with and without *Rhizobium* inoculation either in ploughed soil or with reduced tillage at the same 3 sites mentioned above. Both legumes yielded more N with inoculation than without, and the response to inoculation was greater with reduced tillage than in ploughed soil, es pecially in the soil with highest total N. This implies that N fixation may be inhibited by N mineralization when establishing pure legume stands in ploughed savanna soil.

INTRODUCTION

There are 67.5 million ha of Oxisols and Ultisols in Colombia which constitute 57% of the total area of the country (CIAT, 1977) and are covered by tropical savannas and rainforests. These areas have considerable potential for agricultural development. Although the soils are infertile and acid (pH 4.5), they have good physical structure. Increased agricultural production, especially in the savanna regions, would relieve pressure in the more populated mountain areas where soils are rapidly becoming degraded due to intensive subsistence agriculture (Sanchez and Cochrane, 1980).

Forage legume and grass germplasm is being screened as part of a programme designed to develop legume-based pastures on the acid, infertile soils of tropical South America (CIAT, 1980). Low fertilizer inputs are applied without liming in order to reduce the costs of pasture establishment. Thus the germplasm selected must be tolerant to low fertility and acid conditions. N_2 fixed by the legumes is considered to be an important component of the increased quality of the improved pastures. *Rhizobium* strains for inoculation of the most promising legumes are being selected (Sylvester-Bradley, in press).

Reduced tillage methods have been recommended for pasture establishment, both to reduce costs and to protect the soil from erosion (Spain *et al.*, 1980). However, conventional tillage is also used, and can be successful if care is taken not to over-prepare the soil.

The nitrification process in soil requires a source of NH_4^+ as substrate. Acid and anaerobic conditions are known to inhibit nitrification (Alexander, 1965). However, some nitrifiers maintain activity at low pHs (Walker and Wickramasinghe, 1979).

Nitrification rates in undisturbed grassland soils have often been found to be low, but when they are tilled nitrification may be stimulated to higher levels than in soils which have been under cultivation (Nye and Greenland, 1960; Powlson, 1980).

Mineral N as either NH_4^+ or NO_3^- is known to inhibit and substitute N_2 fixation as a source of N for legume growth. Thus the effect of soil management methods such as tillage on nitrification would be expected to affect N_2 fixation also, depending on whether the changes in rates of nitrification resulted in greater or lesser availability of mineral N for plant growth. It was observed that inoculation and N fertilization responses of tropical forage legumes were masked in pots of disturbed soil from Carimagua, a site considered to be representative of the well-drained savannas of Colombia, whereas in cores of undisturbed soil marked responses to these treatments occurred (Sylvester-Bradley *et al.*, 1983). It is important to determine whether a similar effect occurs in the field and to evaluate the effect of tillage on N mineralization in this soil type, so that establishment methods likely to conserve soil N and increase N yields can be recommended.

In the experiments described here the effect of tillage on NO_3^- in unlimed soil was studied. Having detected an increase in NO_3 accumulation and total mineral N in the soil due to tillage, further studies were carried out to determine whether tillage would mask the response of pasture legumes to *Rhizobium* inoculation.

MATERIALS AND METHODS

1. Ten replicate soil samples were collected in July 1981 (3 months after the beginning of the wet season) from undisturbed savanna, soil ploughed in April 1981 and kept free of plants, and soil ploughed at the same time but which was subsequently

fertilized and planted with the forage legume *Stylosanthes capitata*, at Carimagua, Meta, Colombia (4.5°N, 71.5°W, 150 m elevation, 2000 mm mean annual rainfall). Each sample was taken at 6 depths down to 1.10 m and placed immediately in a polystyrene box with ice. The 10 replicate samples from each depth were bulked and kept frozen till analyzed. NO_3^- was extracted from the humid bulked samples in water and measured colorimetrically as nitrophenol disulphonic yellow colour at 420 mm (Jackson, 1958). Values were then converted to ppm NO_3^--N on a dry weight basis.

2. Three replicate soil samples were collected in July 1983 from 0-10 cm depth at 3 sites at Carimagua with 2 treatments at each site. The 3 sites represented soils with differing total N and sand contents (Rincon: total N 448 ppm; sand 61%; Hato 3: total N 952 ppm; sand 30%; Reserva: total N 1176 ppm, sand 12%), and at each site the soil was collected from under undisturbed savanna and from areas which had been ploughed in April 1983 and kept free of plants. The 5 kg samples were placed in pots and sampled immediately and after 3, 6, 9, and 12 weeks incubation in the greenhouse. Throughout the incubation soil humidity was kept at the initial level by adding rainwater to the pots. At 12 weeks samples were also collected from the original sites in the field. Samples were kept frozen till analyzed. NO_3^- concentration was measured as described above. NH_4^+ was extracted from humid samples in IN KCl and analyzed colorimetrically as a green ammonium salicylate complex buffered at pH 12.8-13.8 at 660 mm on an autoanalyzer.

3. In addition to the samples collected and incubated in pots as described above, 3 replicate cores of soil were collected at the same time from the same sites, by driving 25 cm lengths of 10 cm diameter PVC tubing into the soil. The cores were removed from the soil with a spade, disturbing the soil within them as little as possible. They were incubated for 12 weeks together with the

pots, maintaining initial humidity as above. At 12 weeks samples of 0-10 cm soil were analyzed for NO_3^- and NH_4^+ as above.

4. At the same 3 sites described under 2, two forage legumes (Pueraria phaseoloides CIAT accession No.9900 and Centrosema macrocarpum No.5065) were planted using two land preparation methods in savanna which had recently been burned. The legumes were planted in 25 m long rows 1.5 m apart either in ploughed and disked soil (conventional tillage), or in furrows made without disturbing the savanna between them (reduced tillage treatment). These furrows were made using two tynes 40 cm apart on the foreward bar of a cultivator and a sweep between them on the rear bar. The soil in the furrows was disturbed to approximately 10 cm depth whereas with ploughing it was disturbed to about 20 cm. Each legume was planted either with or without inoculation with Rhizobium strains which had been preselected in soil cores (Sylvester-Bradley et al. 1983). Strains CIAT 2434 for P. phaseoloides and 1780 for C. macrocarpum were applied to seeds as peat-based inoculant at a rate of 50 g inoculant/kg seeds and pelleted with rock phosphate. Fertilizer was applied in the row using the following rates (kg/ha): 22 P, 122 Ca, 33 K, 40 S, 20 Mg, 5 Zn, 2 Cu, 1 B and 0.4 Mo calculated on the basis of 1 m^2/linear m of row, considering that the legume roots would be expected to explore approximately this area. Each experimental plot consisted of two 25 m long rows. Two blocks were planted. Nodulation was evaluated on a relative scale (0 = zero, 1 = scarce, 2 = moderate, 3 = abundant) on 6 plants per plot 10 weeks after planting. No standardization cut was made. Three 2 m long randomly placed subsamples were cut within each plot at 12, 15 and 18 weeks after planting, each cut being in a different place (i.e. rate of growth and not regrowth was measured). Fresh and dry weight of each subsample was determined. The 3 subsamples were then bulked and %N determined by Kjeldahl analysis. Factorial analysis of effects of inoculation, soil type, land preparation and cut on KgN produced/ha was carried out separately for each

legume. Then kg N in tops/ha in tops/ha of the uninoculated legumes was expressed as a percentage of that of the corresponding inoculated legumes within each treatment, and these values were used to analyse the effect of legume, land preparation, soil type and cut on inoculation response.

RESULTS

NO_3^- levels were very low in soil collected from under undisturbed savanna (Figure 1). In ploughed land kept free of plants NO_3^- levels were much higher and increased with depth in the soil. In

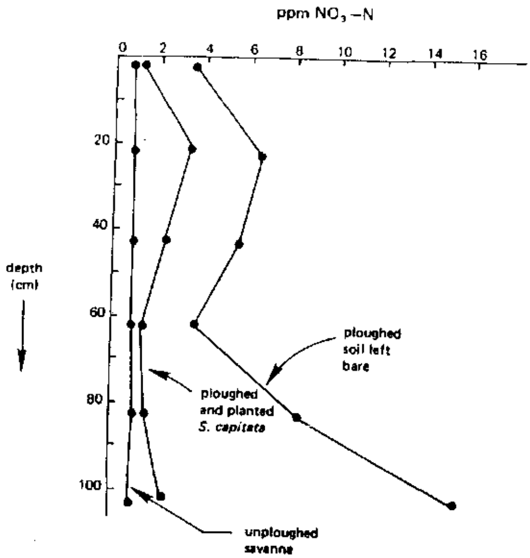

FIGURE 1 Change in NO_3 -N concentrations with depth in Carimagua soil with three different treatments, July, 1981.

ploughed soil planted with S. capitata the NO_3^- levels were higher than under undisturbed savanna, but there was no accumulation of NO_3^- at 1.10 m depth as observed in the ploughed unplanted soil. When surface soil was incubated in pots there was a marked difference in NO_3^- accumulation over time between ploughed and undisturbed soil (Figure 2). In the ploughed soil a fairly consistent rate of NO_3^- accumulation occurred over the first 9 weeks in all three soil types, followed by an increase in rate

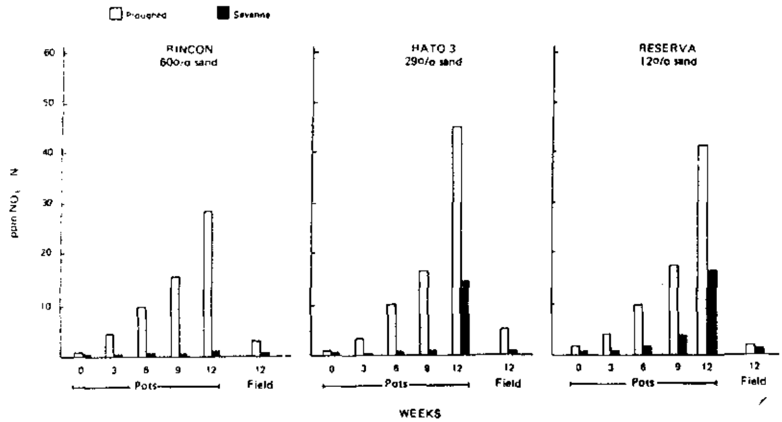

FIGURE 2 NO_3^--N concentrations in 0-10 cm soil from three sites at Carimagua with differing sand and total N contents which had either been ploughed or left undisturbed after different times of incubation in pots, and after the same length of time in the field.

from 9-12 weeks. 30-45 ppm NO_3^--N accumulated by the end of the incubation period. On the other hand NH_4^+-N levels increased over time more rapidly in soil from undisturbed savanna than ploughed soil. Soils with higher total N contents showed higher rates of NH_4^+-N accumulation (Table 1).

When soil was incubated in cores marked differences in rates of NO_3^- accumulation between ploughed and undisturbed soil were observed as in the pots (Table 2), but less NH_4^+ accumulated (c.f. Tables 1 and 2). The highest mineral N increase observed in the cores (30 ppm in ploughed Hato 3 soil) would be equivalent to 3 kg N/ha/week if the same rates of mineralization occurred in the field as in the cores. The NO_3^- concentrations observed in the field after the same incubation time were much lower (Figure 2), which would be expected, since any NO_3^- produced in the field would be subject to leaching during the wet season (April-November).

TABLE 1. Mineral N (ppm dry soil) in 0-10 cm Soil from Three Sites at Carimagua taken from the Field in July 1983 and incubated in Pots for 9 weeks (n = 3). Numbers in Brackets show Change in N Concentration from 0-9 weeks.

		Mean ppm N (change in ppmN)	
Site	Compound	Ploughed	Savanna
Rincon	NO_3^--N	14.99 (+14.42)	0.24 (-0.22)
(61% sand)	NH_4^+-N	4.71 (-3.02)	5.61 (+1.63)
	Sum	19.70 (+11.40)	5.85 (+1.41)
Hato 3	NO_3^--N	16.17 (+15.08)	0.65 (+0.09)
(30% sand)	NH_4^+-N	6.84 (- 1.07)	10.58 (+4.67)
	Sum	23.01 (+14.01)	11.23 (+4.76)
Reserva	NO_3^--N	17.05 (+15.56)	3.56 (+ 2.88)
(12% sand)	NH_4^+-N	7.73 (+2.09)	14.33 (+ 9.15)
	Sum	24.78 (+17.65)	17.89 (+12.03)

When soil from undisturbed savanna was incubated in pots an increase in NO_3^- accumulation rate was observed in Hato 3 and Reserva soil after 9 and 3 weeks respectively (Figure 2). In the cores this effect was not so marked (Table 2).

TABLE 2. Change in mineral N (ppm dry soil) in 0-10 cm Soil from Three Sites at Carimagua taken from the Field in July 1983 and incubated in Cores for 12 weeks (n = 3).

		Mean change in ppm N	
Site	Compound	Ploughed	Savanna
Rincon	NO_3^--N	+20.21	0.00
(61% sand)	NH_4^+-N	- 5.25	-0.04
	Sum	+14.96	-0.04
Hato 3	NO_3^--N	+28.94	+6.04
(30% sand)	NH_4^+-N	+ 2.04	-0.09
	Sum	+30.98	+5.95
Reserva	NO_3^--N	+20.47	+3.41
(12% sand)	NH_4^+-N	- 0.29	-1.29
	Sum	+20.18	+4.79

The results of the experiment to test Rhizobium inoculation response of two forage legumes when established with reduced tillage and in ploughed soil in the same 3 soils studied above are shown in Figures 3 and 4. Both legumes responded significantly to inoculation across site, land preparation and cut (Table 3). The overall increases in N yield due to inoculation were 36% in the case of P. phaseoloides and 118% in the case of C. macrocarpum.

TABLE 3. Factorial Analysis of effects of Inoculation, Site, Land Preparation and Time after Planting on kg N in tops/ha produced by Centrosema macrocarpum No.5065 and Pueraria phaseoloides No.9900 at Carimagua May-August, 1983. Different Letters represent Significant Differences within Vertical Groups (P = 0.05). Legumes were analysed separately.

Treatment	C. macrocarpum	P. phaseoloides
Uninoculated	88.38a	291.68a
Inoculated	192.75 b	396.85 b
Rincon (61% sand)	100.92a	246.36a
Hato 3 (30% sand)	106.29a	326.57ab
Reserva (12% sand)	214.49a	459.88 b
Reduced tillage	113.34a	305.35a
Ploughed	167.79 b	389.19 b
Cut 1 (12 weeks)	90.90a	173.72a
Cut 2 (15 weeks)	138.69 b	285.84 b
Cut 3 (18 weeks)	192.11 c	573.25 c

With conventional and reduced tillage the increases across sites and cuts were 27% and 48% for P. phaseoloides and 69% and 238% for C. macrocarpum, respectively.

Overall N yield was greater in the ploughed treatment than with reduced tillage, and in the less sandy soils.

Analysis of the effect of treatments on inoculation response showed that reduced tillage caused a greater response across sites

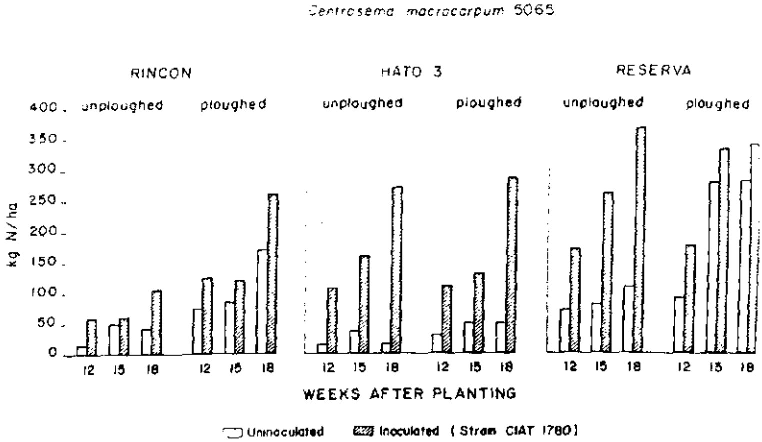

FIGURE 3 Effect of inoculation on N yield of Centrosema macrocarpum No.5065 established with reduced (unploughed) or conventional (ploughed) tillage at 3 sites with different sand and total N contents (Rincon: total N 448 ppm; sand 61%; Hato 3: total N 952 ppm; sand 30%; Reserva: total N 1176 ppm; sand 12%) at Carimagua, 1983.

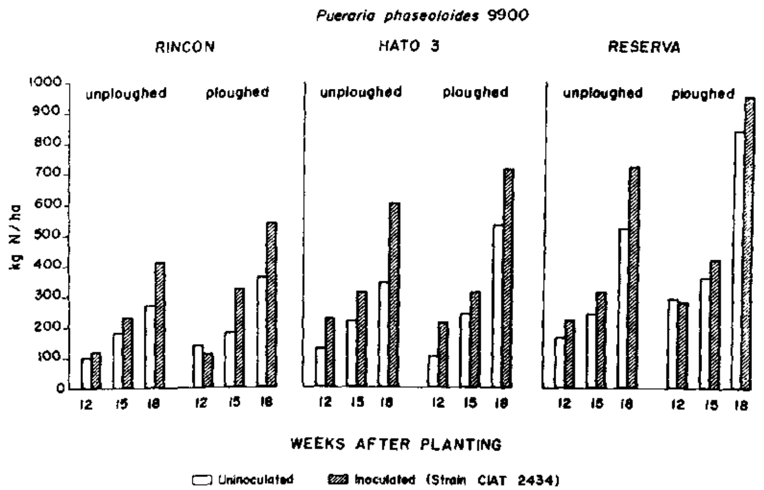

FIGURE 4 Effect of inoculation on N yield of Pueraria phaseoloides No.9900 established with reduced (unploughed) or conventional (ploughed) tillage at 3 sites with different sand and total N contents (Rincon: total N 448 ppm; sand 61%; Hato 3: total N 952 ppm; sand 30%; Reserva: total N 1176 ppm; sand 12%) at Carimagua, 1983.

than in ploughed soil. Comparison between sites showed a greater inoculation response at Hato 3 than the other sites across the other treatments. The response increased over time in the sandiest soil (Rincon). Comparison of the analyses within sites

TABLE 4. Factorial analysis of Inoculation Response (kg N in tops/ha of Uninoculated Treatment expressed as Percentage of Inoculated Treatment) as affected by legume, Land Preparation, Time (cut), and Soil Type at Carimagua, May-August, 1983. Different letters Represent Significant Differences between Groups of Numbers (P = 0.05). n.b. Lower values indicate Greater Inoculation Response.

Treatment	Uninoculated as % of Inoculated			
	Analysis for Individual Sites			Analysis across sites
	Rincon	Hato 3	Reserva	
C. macrocarpum	65.5a	21.6a	53.7a	46.9a
P. phaseoloides	74.8a	63.0 b	82.0 b	73.3 b
Reduced tillage	69.8a	37.4a	54.3a	53.8a
Ploughed	70.6a	47.2a	81.3 b	66.4 b
Cut 1 (12 weeks)	77.6 b	37.2a	68.0a	60.9a
Cut 2 (15 weeks)	72.7ab	51.3a	66.1a	63.4a
Cut 3 (18 weeks)	60.2a	38.3a	69.4a	56.0a
Comparison between sites	70.2 b	42.3a	67.8 b	

shows that the effect of both legume and land preparation on inoculation response was greatest in the least sandy soil (Table 4).

Nodulation evaluations (Figure 5) showed that nodulation increased with inoculation of *C. macrocarpum* and less so with *P. phaseoloides*. No marked effects of land preparation or soil type on nodulation were observed.

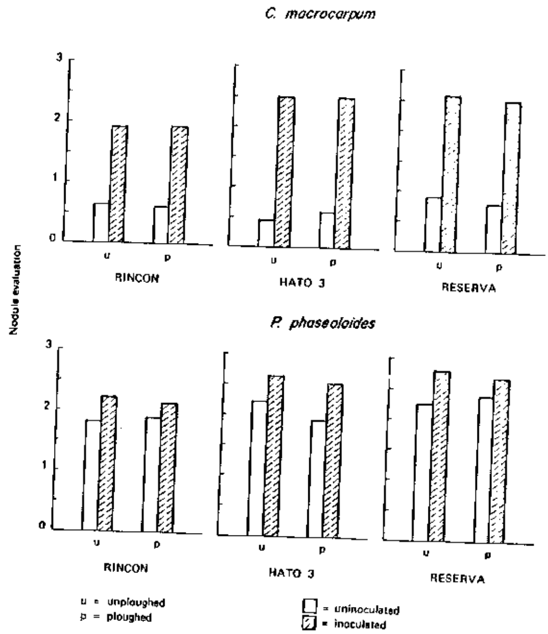

FIGURE 5 Mean nodule evaluations on a relative scale (0 = zero, 1 = scarce, 2 = moderate, 3 = abundant) of 6 plants per plot of Centrosema macrocarpum No.5065 and Pueraria phaseoloides No. 9900 inoculated (strains CIAT 1780 and 2434 respectively) or not inoculated, 10 weeks after planting the experiment shown in Figures 3 and 4.

DISCUSSION

Higher NO_3^- levels under ploughed soil than under undisturbed savanna as shown in Figure 1 could be due either to higher nitrification rates or less efficient uptake of the NO_3^- produced.

The lower initial rates of NO_3^- accumulation in savanna than ploughed soils in pots of soil without plants (Figure 2) show that the lack of NO_3^- observed under savanna cannot to be due solely to NO_3^- uptake by plants. The final NO_3^- concentration after 12 weeks incubation of soil from undisturbed savanna was lower in cores than pots (Figure 1, Table 2), which implies that even in the absence of plants, NO_3^- accumulation is more restricted in undisturbed than disturbed soil. The dominant grass in Carimagua savanna is Trachypogon vestitus (Blydenstein, 1967). Trachypogon plumosus has been shown to produce antibiotic substances (Stiven, 1952). It has been suggested that savanna grasses inhibit nitrification as an N-conserving adaptation (e.g. Rice and Pancholy, 1972). The lag observed before the onset of NO_3^- accumulation in pots of soil from undisturbed savanna could be due to the time taken for such antibiotics to disappear from the soil, to an initially high rate of NO_3^- immobilisation followed by a decline, to the slow build-up of the nitrifying population due to an increase in NH_4^+ availability, or to the effect of more aerobic conditions on the relative activities of nitrifying and denitrifying populations. Whatever the reason, it is implied that less NO_3^- would be available for plant growth in undisturbed than ploughed soil.

The data on NH_4^+ accumulation indicate that incubation of soil in pots stimulates NH_4^+ release whereas in the cores this did not occur. Possibly the humidity in the pots fluctuated more than in the cores resulting in a "Birch effect" (Birch, 1964). Alternatively, the difference may be due to the extra disturbance of the soil in pots which would expose more of the soil organic N to aerobic conditions, resulting in NH_4^+ release. In pots where no NO_3^- was accumulating, higher NH_4^+ levels were observed, which implies that nitrification was restricted, rather than that NO_3^- or NH_4^+ was immobilized. In pots where NO_3^- accumulation was taking place, no NH_4^+ accumulated. Apparently, as soon as the NH_4^+ was produced, it was converted into NO_3^-. Although more NH_4^+ accumulated in pots of soil with higher total N content, this had no marked effect on NO_3^- accumulation, and the overall increase in mineral N due to soil disturbance was not related to the total N content of the soil. Thus the major effect of the treatments on mineral N accumulation observed was that of soil disturbance independent of total N content. If the rates of NO_3^- accumulation observed represent those occurring in the field, the results imply that even without fertilization or liming, after an initial lag, ploughed soil can supply amounts of N which could affect plant growth and N_2 fixation. Deeper soil (10-20 cm) may also mineralize N, in which case the actual amounts released would be higher than those estimated here. If the soil were limed even higher rates might be expected. It is important that when such N is released by ploughing it should not be lost by leaching, but rather taken up by sown plants, or it should be conserved by reduced tillage methods.

The results of the inoculation experiment show that both legumes responded to inoculation. Thus if the lack of nitrification in savanna soil is due to antibiotics, they did not apparently affect these Rhizobium strains, which were selected for their effectivity in cores of savanna soil (Sylvester-Bradley et al., 1983). Ploughing did reduce the inoculation response across sites, but mainly in the soil with highest total N. The less marked effect of tillage at the other sites may have been due to higher leaching rates and restriction of growth caused by lower fertility levels. If abundant mineral N had been available in the conventional tillage treatment, lower nodulation rates would be expected. However, no marked differences in nodulation were observed between soils or land preparation method. Possibly the concentration of mineral N in the soil did not reach sufficient levels to inhibit nodulation, even though it could have been taken up by the plants and inhibited N_2 fixation.

The results show that the effect of disturbing the soil by ploughing was similar to that observed in pots and cores (Sylvester-Bradley et al., 1983), especially in the least sandy soil. Where inoculation responses are decreased by soil disturbance, it is implied that N_2 fixation is inhibited by N mineralization. Possibly by planting grass-legume mixtures, this effect could be minimized. The increased establishment rates which are often observed when using reduced tillage as compared to no-till establishment methods (Spain et al., 1980) may be at least partially due to an increase in N mineralization due to soil disturbance. Possibly the slower growth observed with no-till establishment could be overcome by inoculating appropriate Rhizobium strains.

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LIMING ACID MINERAL SOILS IN INDONESIA AS A PRECONDITION TO INCREASE N-EFFICIENCY.

Key words: Acid soils Crop response Lime requirement

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SUMMARY

Laboratory and greenhouse experiments were carried out to determine lime requirement of Indonesian acid mineral soils, and the effects of liming on soil chemical properties, performance of maize, and nutrient uptake.

The experimental results showed:
(1) Liming to pH (H_2O) of 5.5 was adequate to reduce exch. Al^{3+} to non-toxic levels irrespective of differences in exch. Al^{3+}-content of soils.
(2) Soils with Al-saturation > 30% responded differently to liming at pH < 5.5 than those with Al-saturation < 30%. At pH > 5.5 the response was the same.
(3) pH of 5.5 to a maximum of 6.0 is recommended for assessing LR test.
(4) The best fit regression equation for assessing LR of soils with Al-saturation < 30% are;

LR-pH(H_2O) 5.5 = 1.34 + 0.71 SMP-LR-pH 6.0
LR-pH(H_2O) 6.0 =-0.47 + 0.90 SMP-LR-pH 6.0

(5) The best fit regression equations to assess LR of soils with Al-saturation > 30% are;

LR-pH(H_2O) 5.5 = 5.71 + 0.70 Exch. Al^{3+}
LR-pH(H_2O) 6.0 = 7.53 + 0.85 Exch. Al^{3+}

(6) Uptake of N, P, K, Mg, Zn and Cu are significantly increased with liming.

INTRODUCTION

Acid mineral soils occupy more than 50 percent of the 191 million hectares total land area in Indonesia (Satari and Orvedal, 1968). These soils need to be limed and fertilized when their full production potential is to be realized. However, lime and especially fertilizers are costly inputs.

The major source of acidity of Indonesian Podzolic soils is mainly monomeric trivalent aluminium. In Latosols, acidity is due to pH-dependent sources. Liming will neutralize and eliminate Al toxicity, creates new sites for exchange reactions and renders nutrients more available to plants. Lime recommendation in temperate regions to pH 6.5 is to reduce soil acidity and has no adverse effects (Corey, et al., 1971). However, liming tropical acid soils to pH > 6.4 often results in decreased crop yields (Reeve and Summer, 1971), while liming to near neutrality is unnecessary (Kamprath, 1971; McLean, 1971). McLean (1971) recommends, that liming tropical acid mineral soils should be based on the amount of lime required to inactivate Al^{3+} and to supply essential Ca .

For the Indonesian acid mineral soils, which are relatively low to very low in weatherable minerals, the effect of liming on soil properties, nutrient availability and crop responses need to be studied in order to develop useful lime recommendations for the farmers using a reliable lime requirement test. Some of the results of these investigations are reported in this paper.

EXPERIMENTAL METHODS

Incubation Experiment.

Twenty-eight acid mineral composite soil samples collected from west and central Java, west Sumatra and east Kalimanten, representing a wide range of chemical properties, were used in the incubation experiment. The average and the range of properties of these soils are listed in Table 1.

For this study 1000 g soil ($\leq$ 2 mm) were mixed with different levels of reagent grade $CaCO_3$. Soils were then placed in polythelene bags and watered to 100% FMC. Bags were tied and kept at room temperature.

Table 1. Average and range values of selected properties of the soils used in investigations.

Soil property	average[a/]	range
$pH_{(H_2O)}$, 1:1	4.6	4.0 - 5.4
$pH_{(KCl)}$, 1:1	3.7	3.3 - 4.6
Soil texture,		
sand (%)	8.2	0.3 - 12.3
silt (%)	27.2	7.0 - 48.9
clay (%)	64.6	18.5 - 92.5
C-organic (%)	2.06	0.78 - 4.04
Total N (%)	0.20	0.19 - 0.29
Exch-Cations (me/100 g),		
Na^+	0.14	0.04 - 0.86
K^+	0.21	0.06 - 0.59
Ca^{+2}	2.88	0.45 - 17.16
Mg^{+2}	2.05	0.04 - 10.19
Al^{+3}	5.88	0.06 - 28.82
TAc (me/100 g)	7.15	0.22 - 30.88
Exch-Ac (me/100 g)	11.13	5.87 - 21.46
CEC (me/100 g)	24.73	8.85 - 49.51
ECEC (me/100 g)	12.36	3.46 - 32.58
Base saturation[b/] (%)	18.0	4.3 - 39.9
Base saturation[c/] (%)	52.3	5.2 - 99.0
Al-saturation (%)	38.1	0.2 - 88.5
Ext-Al (me/100 g)	12.83	2.90 - 38.24

a/ Average of 28 soils used
b/ Calculated based on CEC
c/ Calculated based on ECEC

Subsamples were taken at one and 12 months incubation for chemical analysis. The following chemical analysis were carried out: pH (H_2O) and pH (KCl) using 1:1 ratio; soil texture by pipette method (Kilmer and Alexander, 1949); CEC using NH_4 Ac at pH 7.0; ECEC, Org C and total N (Juo, 1979); Total Acidity (TAC) by extr. with 1N KCl using 1:10 ratio; Exch-Acidity (Alexander, 1976) Exch-Al^{3+} (Rainwater and Thatcher, 1960); Extr-Al (Slamet Setyono, 1974); Exch-basis (Chapman and Pratt, 1961). Plant tissue analysis was done using dry ashing (Juo, 1979).

The standard Lime Requirement (LR) test for each soil was calculated by plotting the equilibrium pH against the amount of $CaCO_3$ added. The LR values, expressed in milliequivalent per 100 g soil (me/100 g) was calculated for each soil at pH(H_2O) 5.5 and at pH(H_2O) 6.0. These standard LR tests were used as the reference LR tests and expressed as $CaCO_3$-LR-pH(H_2O) 5.5 and $CaCO_3$-LR-pH(H_2O) 6.0.

The buffer method which was tested against the reference LR test were: (1) the SMP Buffer Method expressed as SMP-LR-pH 6.0 (Shoemaker, et al., 1961); (2) the double SMP Buffer Method expressed as SMP-DB-LR-pH 6.0 (McLean, et al., 1978) and (3) estimation of LR based soil properties by regression analysis.

Data from the one month incubation was used to study the effect of lime on soil chemical properties.

Greenhouse experiment-I

Seven soil samples were used . Six liming levels were compared using as of basis SMP-LR-pH 6.0. The amount of $CaCO_2$ required to bring soil pH(H_2O) to 6.0 was used as the 1.0 SMP-LR-pH 6.0, and the other levels were 0, 0.25, 0.50, 0.75 and 1.25 SMP-LR-pH 6.0. The treated soils (1000 g ovendry) were incubated at 100% FMC in polythelene bags, and kept at room temperature.

After one month incubation, the soil was air dried and ground to pass a 2 mm sieve.

After addition of basal nutrient, the soils were brought to 100% FMC and incubated for additional 10 days prior to cropping.

Maize was used as test crop. The plants were harvested after 35 days after planting, oven dried at 60 ^{0}C for 72 hours, weighed, and grinded to pass a 40 mesh sieve. Plant tissue analysis was done after dry ashing as described by Juo (1979).

Greenhouse experiment-II

The experiment was carried out using wooden boxes lined with black polythelene sheet. Glass windows were also provided at one side of the boxes. The boxes had an upper diameter of 25 cm , and a bottom diameter of 20 cm . The height was 60 cm. Subsoil aggregates were placed in the bottom 20-60 cm, and topsoil aggregates were packed in the surface 0-20 cm. Packing was carried out to give a uniform bulk density Of 1.0. The topsoil received the following factorial treatments, depth of treatment (0-10 and 0-20 cm), and five lime rates (equivalent to 0, 0.25, 0.50, 0.75 and 1.00 SMP-LR-pH 6.0 units).

Following lime application the soils were incubated at 100% FMC, and placed at room temperature for 30 days. The incubated soils were then air dried, and basal nutrient added. An additional 100 mg/kg N was sidedressed 30 days after planting.

The soils used were also selected from the 28 soils, representing two different types of buffering capacity and have Al-saturation higher than 30 percent.

Maize was used as indicator plant. Four plants were planted per pot. Two plants were harvested at 35 DAP, and the remaining harvested at 45 DAP. The harvested plants were oven dried at 60 ^{0}C, and weighed. During the course of the experiment, root growth and development were observed through the glass window. The windows were covered with a black polythelene sheet.

RESULTS AND DISCUSSION

The Effect of Liming on Selected Soil Properties

1. Soil pH. The effect of liming on soil pH varies. Different acid strength or buffering capacities are observed. Soils relatively high in exch-Al , exhibit high buffering capacity below pH (H_2O) 5.5, and soils low in exch-Al exhibit low buffering capacity below pH (H_2O) 5.5. The buffering characteristics is reversed above pH(H_2O) 5.5.

2. Total exchangeable acidity (Exch-Ac). As expected exch-Ac decreases with liming. The negative relationship is either linear or curvilinear and appears to be dependent on exch-Al^{3+} content. Those relatively high in exch-Al^{3+} , showed a curvilinear relationship, consisting of two linear curves where the inflection points are located at pH(H_2O) 5.5 to 6.0.

3. Exchangeable aluminum (Exch-Al^{3+}). Exch-Al^{3+} decreases drastically with increasing soil pH. The negative curvilinear relationship is in line with the evidence reported by many researchers.

4. Effective cation exchange capacity (ECEC). The ECEC of the soils were calculated by summing up the exchangeable bases plus the exch-Al and the exch-H_2O. Liming generally increases ECEC of the soils. But, soils having exch-Al^{3+} beyond 10.0 me Al^{3+}/100 g show a reduction in ECEC with the first two to three lime levels, but show a drastic increase with higher lime levels. This behaviour could be due to precipitation of the newly formed hydroxy-Al-polymers in interlayer position of 2:1 type clay minerals (Hsu and Bates, 1964). The increase in ECEC with further lime increments can be associated with the formation of gibbsite.

5. Aluminum saturation (Al-saturation). Al-saturation was calculated based on ECEC (Sanchez, 1976). The values were related to the corresponding pH values. The curvilinear character of the relationship agrees with those reported by many workers. The relationship is more meaningful than the corresponding exch-Al^{3+}-soil pH relationship, in describing the different rates of Al ions occupying exchange sites at any soil-pH. The higher the exch-Al^{3+} , the higher is the Al-saturation value per unit soil-pH decrease below 5.5. At pH > 5.5 differences were small. In figure 1 is shown the relationship between soil pH and percentage Al^{3+} neutralization with liming. At pH 5.5, 92% of exch-Al^{3+} is neutralized.

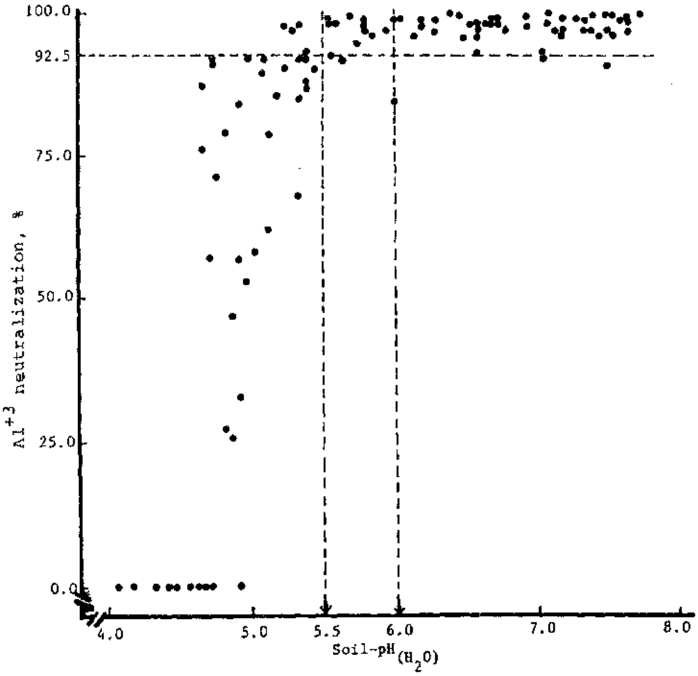

Figure 1 . The Relationship between Soil-pH and Aluminum Neutralization

PREDICTION OF LIME REQUIREMENT (LR)

1. The standard LR test. The amount of lime required to raise soil-pH to 5.5 and 6.0, derived from the pH-lime curve was used as the standard LR test value. These test values at the two different incubation periods are closely related. The 12 months LR-test values are higher than the one month LR values.

2. The SMP-LR-pH 6.0. The SMP-LR-pH 6.0 correlates well with the CaCO -LR tests. Better correlation coefficients are obtained with soils having exch-Al^{3+} < 30% than with soils having exch-Al^{3+} > 30%. The better correlation of SMP-LR test values with the LR test values for acid soils where acidity sources are mainly pH-dependent sources was also reported by Corey et al (1971).

3. The SMP-DB-LR-pH 6.0. The derived values, together with the corresponding standard LR test, and the SMP-LR-test values are presented in table 2. Although the derived LR values are closely related to the CaCO -LR-test values, however, the corresponding SMP-LR-pH 6.0 values correlate better with the standard LR values.

Table 2. The SMP-DB-LR-$pH_{6.0}$, $CaCO_3$-LR-$pH_{(H_2O)6.0}$ and the SMP-LR-$pH_{6.0}$ Test Values

Soil sample	SMP DB LR-$pH_{6.0}$	$CaCO_3$ LR-$pH_{6.0}$	SMP LR-$pH_{6.0}$
	....	(me $CaCO_3$/100 g)	....
1	6.49	7.15	8.20
2	5.03	6.85	9.20
3	7.59	11.92	13.40
5	11.54	9.25	10.40
8	9.53	10.05	11.20
9	2.44	4.50	4.80
10	5.84	7.10	8.30
11	- a/	30.05	25.80
12	-	32.55	26.60
13	3.97	4.95	6.40
14	5.33	5.20	5.40
15	4.48	5.20	7.00
16	7.17	8.65	11.60
17	4.45	3.50	4.60
18	8.73	10.05	12.00
19	6.04	8.20	10.40
20	5.01	6.45	8.80
21	13.88	12.35	13.80
22	-	16.70	21.50
23	6.91	6.50	8.20
24	8.27	11.00	12.40
25	8.59	9.70	11.20
26	-	15.95	22.00
27	-	16.15	23.20
28	-	21.45	22.00

a/ The "d-value" calculated with the original equation given by McLean et al (1978) was negative. Therefore, the LR test value could not be derived.

4. Lime estimation based on soil properties. The selected soil properties possibly affecting the LR of the soils were assumed to be: pH, % OM, % clay, exch-Ac, exch-Al , and ECEC. Keeney and Corey (1963), and Ross et al. (1964) also used these relationships for determining lime requirements of soils. Exchangeable-Al^{3+} has received the greatest attention for determining LR of tropical soils (Kamprath, 1970; Corey et al., 1971; Reeve and Sumner, 1971).

Simple correlation analysis were carried out to study the relationships between selected soil properties with the LR test (Table 3). For soils with exch-Al^{3+} < 1.97 me the greatest contributor to acidity as measured by the LR test is the organic matter content. In the second group with exch-Al^{3+} > 1.97 me, is the greatest contributor to acidity.

Simple correlation coefficients may not accurately predict contributions of each soil parameter, because of interactions among soil properties. Therefore, the relative importance of each soil property in predicting LR is better evaluated by multiple regression analyses. Partial regression coefficients were used to compare the relative contribution of each soil property to the LR of the soils. The level of significance of the dependent variable was evaluated from the corresponding partial F-ratio value.

Table 3. Simple correlation coefficients of selected soil properties with the reference LR tests

Reference LR Test	Soil parameter	Correlation coefficient		
		A[a/]	B[a/]	A + B[a/]
		(n=13)	(n=11)	(n=24)
$CaCO_3$-LR-$pH_{(H_2O)}$6.0	$pH_{(H_2O)}$	-0.145	-0.110	-0.514*
	% OM	0.790**	0.231	0.229
	% Clay	-0.109	0.274	-0.134
	TAc	0.512	0.969**	0.959**
	Exch-Ac	0.714**	0.956**	0.931**
	Exch-Al^{+3}	0.518	0.974**	0.960**
	Nonexch-Al	0.261	0.482	0.503*
	ECEC	-0.151	0.965**	0.692**
$CaCO_3$-LR-$pH_{(H_2O)}$5.5	$pH_{(H_2O)}$	-0.387	-0.139	-0.572*
	% OM	0.700**	0.219	0.194
	% Clay	0.029	0.259	-0.127
	TAc	0.614*	0.973**	0.965**
	Exch-Ac	0.534	0.946**	0.905**
	Exch-Al^{+3}	0.584*	0.971**	0.959**
	Nonexch-Al	0.029	0.473	0.414*
	ECEC	-0.111	0.968**	0.694**

a/ Group A = Soils with exch-Al^{+3} $<$ 1.97 me Al^{+3}/100 g
B = Soils with exch-Al^{+3} between 1.99 to 28.82 me/100 g
A+B = Soils with exch-Al^{+3} between 0.06 to 28.82 me/100 g

When the last variable entered in the regression equation had a partial F-ratio value which was not significant at the 10% probability level, the process of computation was terminated. When the partial regression coefficient of an independent variable is twice that of another variable within the same multiple regression equation, the first variable is then twice as important. These comparisons are presented in Tables 4 and 5.

The results show, that soil properties contributing to LR of the soils in group A are those exhibiting pH-dependent acid characteristics. The exch-Al^{3+} has proved to be the dominant soil property contributing to the LR of the soils having exch-Al^{3+} $>$ 30%.

Table 4. Multiple regression analyses by forwards selection procedure of soil parameters contributing to lime requirement

Soil group	The Reference LR test	Overall Regression F-value	Coeff. Determ. (R^2;%)	Soil parameter (X_i)	Regr. Coeff. (β_i)	Std. Error of Regr. Coeff. (S_{β_i})	Std. coeff. of Regr. (β_i)	Partial F-value ($\beta_i^2/S_{\beta_i}^2$)
A (n=13)	$CaCO_3$-LR-pH$_{(H_2O)}$5.5	10.602**	88.3	X_0=constant	18.9482	-	-	-
				X_2= % OM	2.5091	0.7606	0.932	10.881**
				X_7= ECEC	- 0.3847	0.1070	- 0.585	11.920**
				X_5=Exch-Ac	0.4766	0.1764	0.463	7.300*
				X_1= pH	- 4.1922	1.7904	- 0.556	5.483*
				X_4= T-Ac	- 1.2677	1.1868	- 0.348	1.141 n.s.
B (n=11)	$CaCO_3$-LR-pH$_{(H_2O)}$5.5	65.964**	96.6	X_0=constant	-19.2440	-	-	-
				X_4= T-Ac	0.6820	0.0498	0.996	187.547**
				X_1= pH	5.1306	2.6478	0.159	3.755 a/
				X_2= % OM	0.7920	0.7843	0.082	1.020 n.s.
A+B	$CaCO_3$-LR-pH$_{(H_2O)}$5.5	161.630**	93.9	X_0=constant	2.4797	-	-	-
				X_4= T-Ac	0.7040	0.0400	0.958	309.760**
				X_2= % OM	0.8264	0.4952	0.090	2.785 n.s.

**, *, a/ = Significant at the one, 5, and 10 percent probability level, respectively
n.s = Nonsignificant at the 5 percent probability level

Table 5. Multiple regression analyses by forwards selection procedure of the soil properties contributing to lime requirement

group	LR test	Regression F-value	Determ. (R^2;%)	Soil parameter (X_i)	Regr. coeff. (β_i)	Std. Error of Regr. coeff. (S_{β_i})	Std. coeff. of regr. (β'_i)	Partial F-value ($\beta_i^2/S_{\beta i}^2$)
A (n=13)	$CaCO_3$-LR-pH$_{(H_2O)}$6.0	12.311**	86.0	X_0=constant	-1.3925	-	-	-
				X_2= % OM	2.4575	0.5690	0.731	18.654**
				X_5=Exch-Ac	0.6907	0.2190	0.537	9.947*
				X_7=Nonexch-Al	-0.4122	0.1559	- 0.502	6.991*
				X_8= ECEC	-0.0625	0.0497	- 0.199	1.597 n.s.
B (n=11)	$CaCO_3$-LR-pH$_{(H_2O)}$6.0	105.704**	96.4	X_0=constant	4.4031	-	-	-
				X_6=Exch-Al^{+3}	0.8058	0.0636	0.925	160.524**
				X_7=Nonexch-Al	0.4432	0.2517	0.129	3.101 n.s.
A+B	$CaCO_3$-LR-pH$_{(H_2O)}$6.0	119.967**	96.6	X_0=constant	0.5827	-	-	-
				X_6=Exch-Al^{+3}	0.6747	0.1229	0.718	30.138**
				X_5=Exch-Ac.	0.4995	0.2625	0.257	3.621 a/
				X_2= % OM	0.8697	0.6042	0.082	2.072 n.s.

**, *, a/ = Significant at the one, 5, and 10 percent probability level, respectively
n.s = Nonsignificant at the 5 percent probability level

The best fit regression equations to assess LR of acid mineral soils having Al-saturation < 30% are:

$$LR\text{-}pH(H_2O)\ 5.5 = 1.34 + 0.71\ SMP\text{-}LR\text{-}pH\ 6.0\ (r = 0.960^{**})$$
$$LR\text{-}pH(H_2O)\ 6.0 = -0.47 + 0.90\ SMP\text{-}LR\text{-}pH\ 6.0\ (r = 0.974^{**})$$

The best fit regression equations to assess LR for acid mineral soils having Al-saturation > 30% are:

$$LR\text{-}pH(H_2O)\ 5.5 = 5.71 + 0.70\ Exch\text{-}Al^{3+}\ (r = 0.971^{**})$$
$$LR\text{-}pH(H_2O)\ 6.0 = 7.53 + 0.85\ Exch\text{-}Al^{3+}\ (r = 0.974^{**})$$

Another measure to evaluate the contribution of exch-Al^{3+} to LR of the acid mineral soils is by deviding the exch-Al^{3+} by the corresponding $CaCO_3$-LR-pH 5.5 or 6.0 (Table 6).

Table 6. Contribution of Exchangeable aluminum to Lime Requirement of The Soils Studied

Soil	Exch-Al^{+3}	$CaCO_3$-LR-pH$_{(H_2O)}$ 5.5	$CaCO_3$-LR-pH$_{(H_2O)}$ 6.0	$\left(\frac{Exch-Al^{+3}}{CaCO_3-LR-pH_{5.5}}\right)$	$\left(\frac{Exch-Al^{+3}}{CaCO_3-LR-pH_{6.0}}\right)$
	.... (me/100 g)	......		.... (ratio)	....
A: 14	0.06	1.30	5.20	0.016	0.012
9	0.15	2.40	4.50	0.062	0.033
10	0.41	5.50	7.10	0.075	0.058
23	0.48	4.00	6.50	0.120	0.074
5	0.60	6.50	9.25	0.092	0.065
13	0.70	3.00	4.95	0.233	0.141
20	0.83	4.55	6.45	0.182	0.129
1	0.89	4.55	7.15	0.196	0.124
15	0.92	3.50	5.20	0.263	0.177
17	1.17	2.65	3.50	0.442	0.334
21	1.28	8.40	12.35	0.152	0.104
19	1.37	6.05	8.20	0.226	0.267
8	1.97	6.35	10.05	0.310	0.196
B: 3	1.99	8.85	11.92	0.225	0.167
2	2.18	5.30	6.85	0.411	0.356
24	2.55	8.05	11.00	0.317	0.232
25	2.96	7.15	9.70	0.414	0.305
18	3.18	7.70	10.05	0.413	0.316
22	8.09	14.15	16.70	0.572	0.484
26	11.96	13.70	15.95	0.873	0.750
27	12.51	13.20	16.15	0.948	0.778
28	18.66	16.35	21.45	1.141	0.870
11	24.33	25.00	30.05	0.973	0.810
12	28.82	25.75	32.55	1.119	0.885

For soils in group A, the contribution of exch-Al to the $CaCO_3$-LR test values are 12.4 and 18.2 percent, respectively. On the contrary, the contribution of exch-Al^{3+} to the soils in group B are 54.1 and 67.3 percent, respectively. These results confirm and strengthen the results of the multiple regression analysis discussed previously.

THE EFFECT OF LIMING ON DRY MATTER YIELD.

Dry matter yields of maize in response to lime application are presented in figure 2. The DM yields in the surface soils are higher than on the corresponding subsoils. The limed soils give significantly higher yields. In general, the responses have a culvilinear character with the largest yield response occuring at lower lime levels. At high lime rates, DM yield degression may be due to nutrient imbalance.

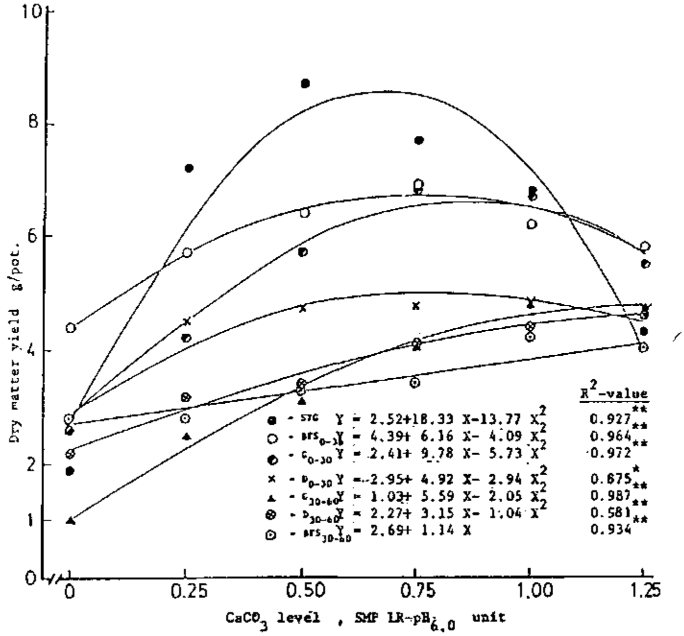

Figure 2. The effect of liming on dry matter yield of maize.
BFS= Brown forest soil, STG= Sitiung, D= Darmaga, G= Gajruk. (0-30 = surface soil, 30-60 = subsoil).

When DM yields are related to the corresponding soil pH changes, the optimum DM yields are achieved on the average at soil-pH(H_2O) 5.3 (Figure 3); the highest DM yields are within soil-pH(H_2O) 5.5 to 6.0, and beyond 6.0, the DM yields tend to decrease on the top-layer soils. The maize plants on the unlimed soils having aluminum saturation > 30% exhibited severe Al-toxicity symptoms.

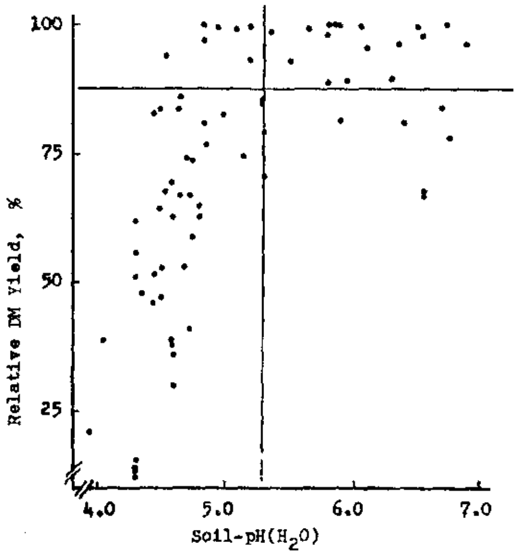

Figure 3. Cate-Nelson plot for soil-pH vs relative yield as affected by liming.

THE EFFECT OF $CaCO_3$ ON NUTRIENT CONCENTRATION IN MAIZE TISSUE, AND NUTRIENT UPTAKE BY MAIZE.

The effect of liming on nutrient concentrations of the maize plants varies between soils. The phosphorus and nitrogen concentrations were below the sufficient range for maize, indicating that the amounts applied as basal fertilizers were not enough.

To better assess the effect of liming on nutrient availability in a short term greenhouse experiment it is best to measure nutrient uptake instead of nutrient concentration. Uptake of major nutrients are significantly increased with liming. The responses are quadratic for the surface soils, and linear for the subsoils. Differences of N-uptake for the soils studied is presented in figure 4. The relationships between liming and N-uptake, except for BFS 30-60, are curvilinear. The maximum N-uptake lies within lime levels equivalent to SMP-LR-pH 6.0 0.50 to 1.0, and 0.75 SMP-LR-pH 6.0 $CaCO_3$ level seems to be the desired amount of liming for optimum N-uptake by maize.

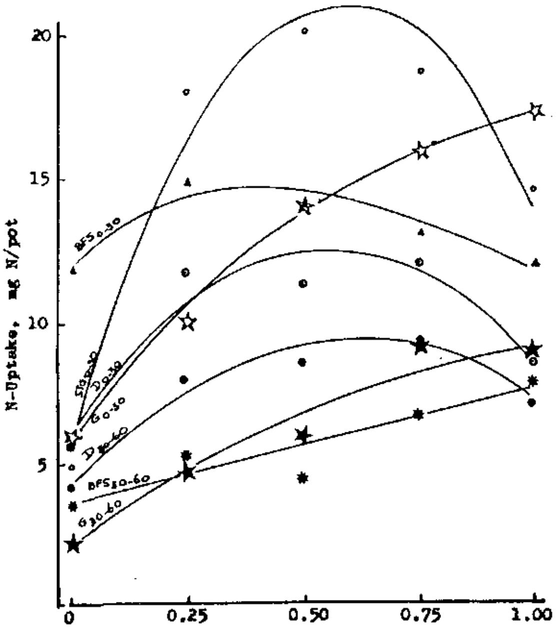

Figure 4. The effect of liming on N-uptake by maize.
BFS= Brown forest soil, STG= Sitiung, D= Darmaga, G= Gajruk. (0-30= surface soil, 30-60 = subsoil).

ROOT GROWTH AND DEVELOPMENT

Root observation showed, that in the unlimed soil roots exhibit severe Al toxicity symptoms. Roots which were able to grow into the unlimed subsoil also exhibit Al toxicity symptoms. It seems, that the Ca movement in the soil was not fast enough to neutralize Al^{3+} in the subsoil, though there should be a differential gradient of Ca^{2+} movement in the unlimed sub-layer as reported by Juo and Ballaux (1977).

The corresponding DM yields of maize, harvested at 35 and 45 days after planting, were significantly higher with liming the 0-20 cm soil layer than with liming the 0-10 cm soil layer. It is therefore advisable to incorporate lime material as deep as possible to promote more root growth.

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THE EFFECT OF MOISTURE STRESS ON THE RESPONSE TO NITROGEN BY MAIZE IN THE HUMID TROPICS OF SURINAME.

Keywords Fertilizer N recommendation Humid tropics Moisture stress Nitrogen recovery Nitrogen utilization Three-quadrant method.

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SUMMARY

From 1977 to 1983 the University of Suriname and the Agricultural University of Wageningen in the Netherlands carried out a joint research programme on the acid low fertility sandy loams of the Zanderij formation in Suriname. The objectives were to identify the limiting factors for the production of annual crops and to design appropriate crop management systems.

One research outcome was that maize responses to N application varied widely from season to season. For closer examination yield response curves were split into the relations between N application and N uptake (recovery), and between N uptake and yield (utilization) according to the three-quadrant method.

A simple model was developed to calculate the number of moisture stress days during the critical period of maize growth from data on rainfall, evapotranspiration and soil moisture storage.

Low responses to N application was due primarily to poor N utilization, which was related to moisture stress. N recovery depended partly on N utilization.

Taking into account the expected number of moisture stress days a year round recommendation scheme for optimum rates of N application was formulated for the region.

INTRODUCTION

General information

Suriname is situated on the northeastern coast of South America and borders on the Atlantic Ocean, Guyana, Brazil and French Guiana. It lies between 2° and 6° north latitude and between 54° and 58° west longitude. Three major physiographic regions are distinguished: the coastal plain, the Zanderij belt and the interior uplands. The Zanderij belt is an east-west running strip, for the major part covered with tropical rainforest. The main agricultural activity is shifting cultivation for subsistence; a rather recent development is the introduction of livestock and oilpalm. The area is sparsely inhabited.

In 1969 and in 1977 two experimental farms, Coebiti and Kabo, respectively, were cleared from rainforest and used for research on pastures, perennial and annual crops. From 1977 to 1983 the University of Suriname and the Agricultural University of Wageningen in the Netherlands carried out a joint multidisciplinary research programme on these farms. The main objectives were to monitor changes taking place in and above the soil when rainforest is replaced by annual crops, to identify the limiting factors for annual crop production and to design appropriate cropping systems for mechanized farming. A full report on this project is in preparation.

Climatic data

According to Köppen's classification, the major part of Suriname has a Tropical Rainforest (Af) climate; that is, all months have on the average more than 60 mm of rainfall. Average annual rainfall is 2200 mm. Distribution is bimodal with a short rainy season from end November till mid January and a long rainy season from mid April to mid August (Fig. 1). The mean daily relative humidity closely follows these seasons, but the correspondence is less pronounced for mean monthly temperature and average number of sunshine hours. Pan evaporation estimates range from 140 mm in December and January to 190 mm in September and October. Average wind speeds are low (1.7 m s^{-1}).

Temperature distribution allows year-round crop growth, but rainfall, especially its distribution and reliability, is a limiting factor for annual crop production.

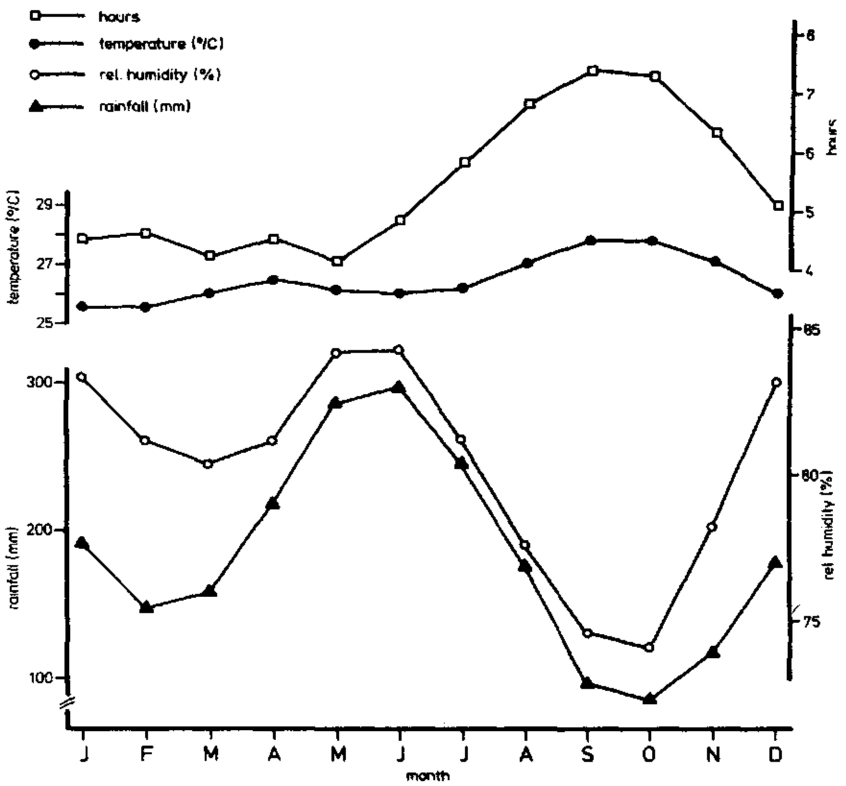

FIG. 1. Average monthly rainfall, relative air humidity, mean temperature and number of sunshine hours (8-18 h) at Zanderij Airport.

Soil conditions

The Zanderij formation consists of several metres of thick sediments, with textures ranging from sand to sandy clay. The area has a level to gently undulating landform, with some steeper slopes along drainage lines. The soils can be distinguished into bleached white sands, brown sands, and brown sandy loams, covering area fractions of 0.4, 0.3 and 0.3 respectively. According to Bennema (1982) the brown sandy loams are Yellow Kaolinitic Oxisols intergrading towards Ultisols. The sandy soils are very poor and not suitable for arable farming. The brown sandy loams are better, but chemically poor (Table 1).

TABLE 1. Means of some chemical and physical properties of brown sandy loams under forest.

Sample depth, cm	0–20	20–40	40–60
Org. C, g kg^{-1}	12	8	4
Org. N, g kg^{-1}	0.8	0.5	0.3
pH-KCl	3.7	3.9	4.1
pH-H_2O	4.2	4.5	4.7
Exch. Ca, mmol(+) kg^{-1}	1.5	0.5	0.3
Mg, mmol(+) kg^{-1}	0.9	0.3	0.3
K , mmol(+) kg^{-1}	0.4	0.3	0.1
Na, mmol(+) kg^{-1}	0.1	0.1	0.1
Al, mmol(+) kg^{-1}	10.2	9.9	7.3
ECEC, mmol(+) kg^{-1}	13.1	11.1	8.1
100 x exch. Al/ECEC	78	89	90
CEC, pH7, mmol(+) kg^{-1}	34	24	18
P-Bray I, mg kg^{-1} P	2	1	1
Porosity, volume fraction	0.50	0.46	0.46
Available moisture, volume fraction	0.11	0.10	0.09
Textural class	loamy sand	sandy loam	sandy clay loam

Following mechanical clearing of the forest soils are often compacted. Maize roots grow hardly deeper than 30 cm. Therefore, the amount of available moisture in the rooting zone is not more than 30 to 35 mm.

The main chemical constraints are acidity and a short supply of primary and secondary nutrients. A large number of trials were set up to determine the optimum lime and fertilizer rates for different crops. This paper deals mainly with results obtained with maize.

RESULTS OF SOIL FERTILITY STUDIES

Liming studies showed that the optimum pH-KCl of the topsoil (0-20 cm) was between 4.2 and 4.6 and the optimum pH-H_2O between 5.0 and 5.6. To reach these values two tons of agricultural lime have to be applied per ha after clearing and supplemented annualy with one ton of lime.

The résponse to N application varied widely as will be discussed below. P application was required. Soil available P improved readily with repeated P application, and after a number of years P fertilization was needed only to compensate for P withdrawal by crops. Studies on K and Mg revealed, that it was virtually impossible to maintain exchangeable K and Mg to values above 1 and 3 mmol(+) kg^{-1}, respectively. Requirements for K and Mg fertilizers depended on yield levels, which in turn depended on liming, N and P application, and weather conditions.

For part of the trials crop components were chemically analysed and the uptake of nutrients by maize was calculated. These data were used to compute the relation between uptake and yield, the recovery of applied fertilizer nutrients, and the supply of nutrients from the soil (Table 2).

TABLE 2. Nutrient uptake (kg) by maize per ton of grain yield, recovery of fertilizer nutrients (%), and amounts of nutrients taken up from the soil alone in kg ha^{-1}.

Parameter	Fert.rate[1)]	N	P	K	Mg
uptake per ton		18-77	2-10	8-72	3-10
recovery	1	30-50	15-25	35-60	0-10
	2	3-20	3- 6	20-30	n.d.[2)]
uptake from soil alone		30-50[3)]	3-10[4)]	10-25	5-10

1) 1 = below, 2 = above optimum rate, see text.

2) n.d. = no data.

3) N uptake depended on soil organic matter content.

4) P uptake depended on available P (P-Bray I) in soil.

The large variation in nutrient uptake per ton (Table 2) was related to the harvest index (ratio of grain yield to total dry matter yield), which was affected by drought, during ripening, pests, diseases, and tillage. Nutrient recovery decreased with application rates above optimum. The nutrient supply from the soil was sufficient for one to two tons of maize. The P supply from the soil in Table 2 is exagerated due to high residual effecting previous P application.

MAIZE RESPONSE TO NITROGEN

Yields

Fig. 2 shows the results of ten trials with maize and one with sorghum. Yields and responses to fertilizer N varied strongly, due to various reasons.

In trial 8 accidental spraying with Gramoxone hampered early growth. Trials 9 and 10 were planted too late and the crop severely suffered from drought. In trials 5, 6 and 7 yields were rather low as a result of waterlogging and erosion runoff after planting. The yield difference in these trials was due to split N (and K and Mg) applications. Usually N, K and Mg were applied in three equal portions: at planting, at 30 and 50 days after planting. This was done also in trial 5, but not in trial 6 where N was split applied in two portions, and in trial 7 where all fertilizers were applied at planting. Split application clearly improved yields and responses to N, up to a rate of 160 kg ha^{-1} N.

Recovery of fertilizer N and utilization of absorbed N

Crops were analysed in trials 3, 5, 6, 7, 10 and 11, so that N uptake could be calculated. In Fig. 3 the relationships between N application, N uptake and yield are visualized in a three-quadrant diagram, according to the procedure introduced by de Wit (1953). The rate-yield curves of Quadrant II are the same as in Fig. 2. These curves are split into rate-uptake (Quadrant IV) and uptake-yield (Quadrant I) curves. In Quadrant IV the slope of a curve represents the recovery of fertilizer N and in Quadrant I the efficiency of N utilization. The line vKvH indicates the yields to be obtained when absorbed N is utilized with maximum efficiency. This requires that no other growth factors than N are yield limiting (van Keulen and van Heemst, 1982).

TABLE 3. Details of the nitrogen trials of Fig. 2 and Fig. 3.

Number	Location	Growth period	Reference
1	Kabo	81.11.19-82.03.30	
2	Coebiti	82.05.12-82.09.04	
3	Coebiti	82.05.12-82.08.31	Slaats and Ukkerman, 1983
4	Coebiti	81.05.11-81.09.02	
5,6,7[1)]	Kabo	80.04.15-80.07.31	Bakema, 1981
8	Coebiti	80.04.18-80.07.30	
9	Coebiti	78.06.01-78.09.29	
10	Coebiti	79.06.21-79.10.08	
11[2)]	Coebiti	81.12.10-82.03.12	Hijkoop, 1983

1) Fertilizers were split applied in three, two and one portions, respectively.

2) Sorghum was sown after kudzu had been ploughed in.

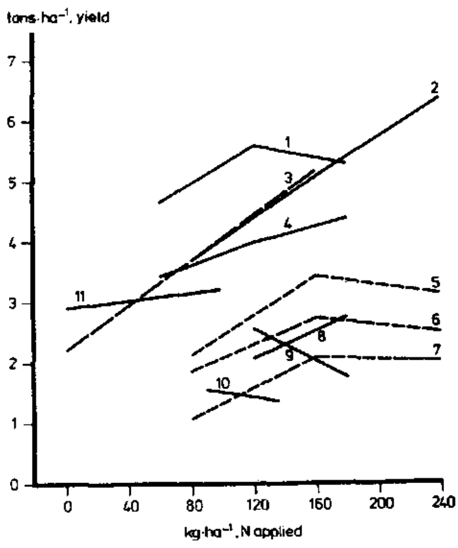

FIG. 2. Response of maize (trials 1-10) and sorghum (trial 11) to fertilizer N.

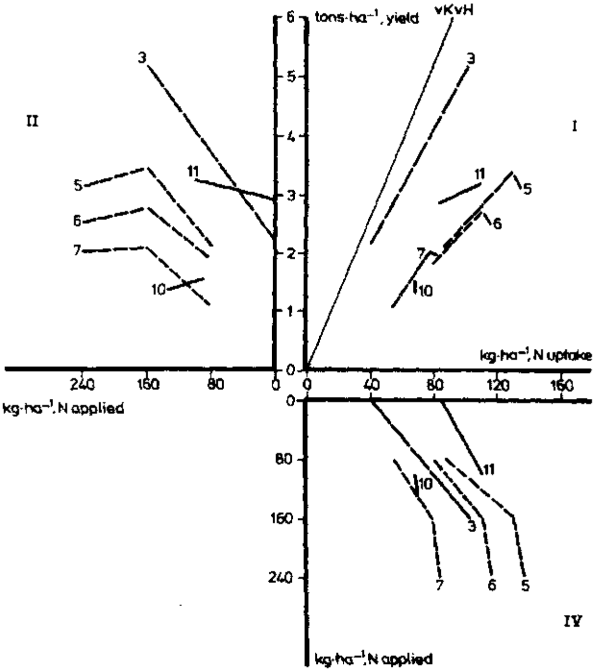

FIG. 3. Three-quadrant diagram for the response of maize (trials 3, 5, 6, 7, 10) and sorghum (nr. 11) to nitrogen; vKvH is the maximum curve of N utilization according to van Keulen and van Heemst (1982).

The high yield and strong response to N in trial 3 was related primarily to a better N utilization and not to a larger N uptake from the soil or a higher fertilizer N recovery than in other trials. Utilization efficiency in trial 3 was near, but others were far below the maximum, which implies that also other growth factors than N supply were limiting.

Sorghum (trial 11) grown after kudzu took about 85 kg ha^{-1} N from the soil with no N application. Mineralization of kudzu was shown to contribute about 50 kg ha^{-1} (Hijkoop, 1983).

Yield differences between trials 5, 6 and 7 were caused mainly by differences in recovery (Quadrant IV), due to the split application methods. When N was applied only at planting (trial 7), recovery was low. Waterlogging after planting certainly contributed to leaching and denitrification, and low yields.

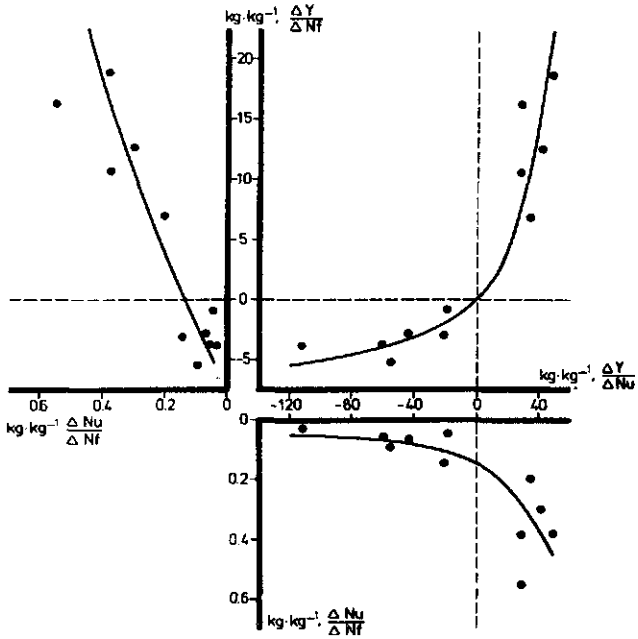

FIG. 4. Three quadrant diagram for the slopes of the rate-yield (ΔY/ΔNf), the uptake yield (ΔY/ΔNu) and the rate-uptake (ΔNu/ΔNf) curves. For explanation, see text.

Where increased application of fertilizer N led to yield depression, recovery was low but positive, but utilization was negative. This shows up clearly in Fig. 4, where the slope of the rate-yield curve (ΔY/ΔNf) is split into the slopes of the uptake-yield (ΔY/ΔNu) and the rate-uptake (ΔNu/ΔNf = recovery) curves. They are related as follows:

$$\Delta Y/\Delta Nf = \Delta Y/\Delta Nu \times \Delta Nu/\Delta Nf$$

(where Y, Nf and Nu are yield, applied fertilizer N and N uptake, respectively, all expressed in kg ha^{-1}).

From the limited data (Fig. 4) it appears that as long as maize positively responded to N application recovery was more than 0.3, and when maize responded negatively recovery was below 0.1. This suggests that the low recovery at high N application rates was due to incapability of the crop to utilize the extra absorbed N, and is therefore not the cause but the result of the yield decline.

MOISTURE STRESS

Calculation of moisture stress days

To quantify the influence of moisture stress, a model was developed to calculate the number of moisture stress days during the critical (drought sensitive) period of maize growth. As critical period was taken the interval from 17 days before until 32 days after silking, i.e., from about 36 until 85 days after planting for the maize variety used. The moisture stress day was defined as a day with 12 or less mm of final available soil moisture. The amount of final available soil moisture was calculated as follows:

Final available soil moisture = initial available soil moisture + effective rainfall - evapotranspiration.

For the model the maximum amount of available soil moisture in the rooting zone was set at 35 mm. Initial available soil moisture was the final available soil moisture of the previous day. If daily rainfall exceeded 10 mm, it was assumed to be distributed over effective rainfall and runoff at a ratio of 80:20. If rainfall was less than 10 mm, effective rainfall was assumed to equal daily rainfall. For evapotranspiration was taken a fraction of 0.8 of the evaporation data as calculated by Lenselink and van der Weert (1973).

$E_0 = 2.59 + 4.58\ n/N$

(where E_0 = daily evaporation in mm and n/N = relative duration of bright sunshine).

If initial available soil moisture was between 0 and 13 mm, evapotranspiration was reduced proportionally to the amount of available soil moisture.

The above starting-points were chosen after several trial and error approaches. The model was tested in a planting-date experiment with bimonthly planting intervals between June 1978 and July 1979. In these trials maize received 120 kg ha^{-1} N. A close linear relationship was found between number of stress days and yields ($r^2 = 0.87$).

Moisture stress and nitrogen

Fig. 2 shows that the N application rates at which yield response changed from positive to negative, varied from 80 to more than 240 kg ha^{-1}. The cause of this wide variation most likely was moisture stress.

For the Coebiti trials the number of stress days during the critical period was calculated using the model described earlier. Fig. 5 shows that stress days clearly depressed yields, the slopes of the curves being steeper with higher N application rates.
For the Kabo trials it was not possible to calculate the number of stress days for lack of meteorological data.

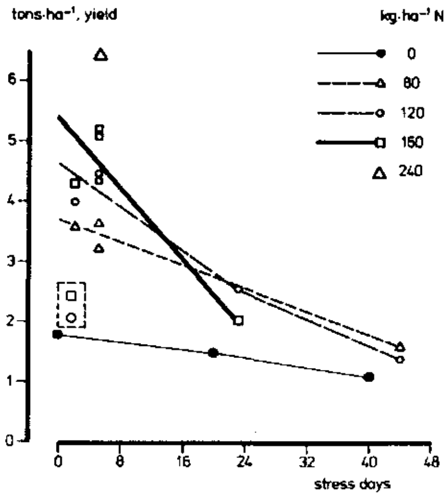

FIG. 5. Maize yields as related to number of stress days during the critical period and to N application rates. Curve for oN was obtained from data from extrapolation in Fig. 2. Data in square are from trial 8, where an accidental spraying with Gramoxone reduced yield.

Based on the relationships shown in Fig. 4 and Fig. 5, a schematized three-quadrant diagram was calculated for 0, 10, 20 and 40 stress days (Fig. 6). It shows that control yields, N utilization, recovery, and optimum N application rates were all negatively affected by moisture stress. The amount of N taken up from the soil alone was estimated at 35 kg ha^{-1}. This value was found by extrapolation and the available data was not sufficient to make a distinction between 0, 10, 20 and 40 stress days.

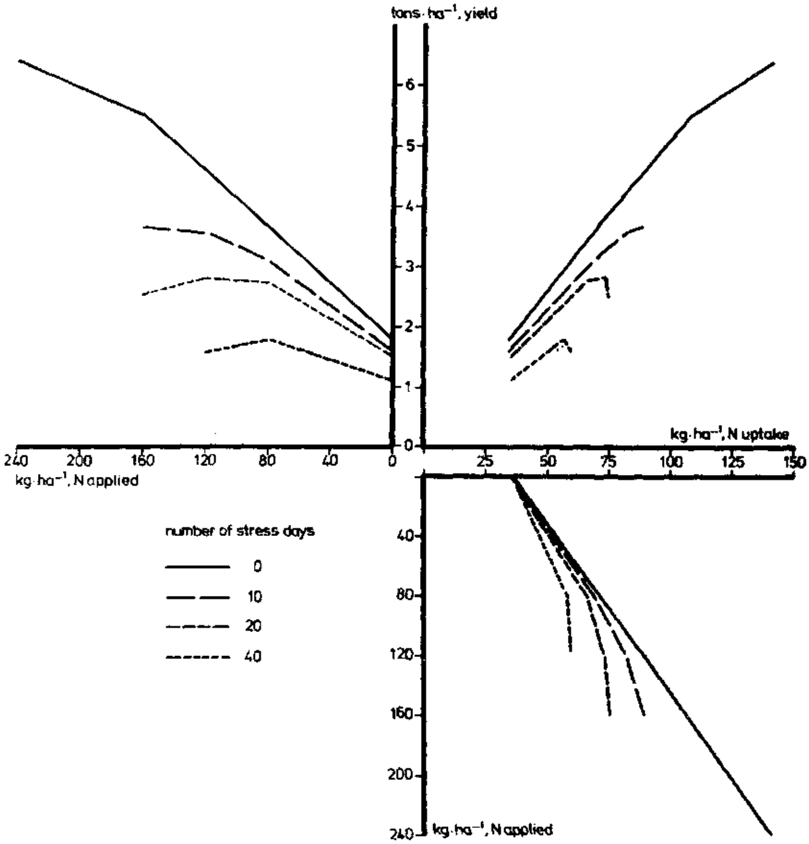

FIG. 6. Schematized relationships between N application, N uptake, and maize yield for 0, 10, 20 and 40 moisture stress days during the critical period.

NITROGEN FERTILIZER RECOMMENDATIONS

The influence of moisture stress on crop response to fertilizer N has far-reaching implication on the profitability of N use and recommendation. The latter should take into account the expected number of stress days.

The price of 1 kg urea-N was about one Suriname guilder (Sf 1,-), while the price of maize fluctuated between Sf 0.25 and Sf 0.40. To be economically advantageous, maize yield increases should exceed 2.5-4 kg per kg urea-N applied.

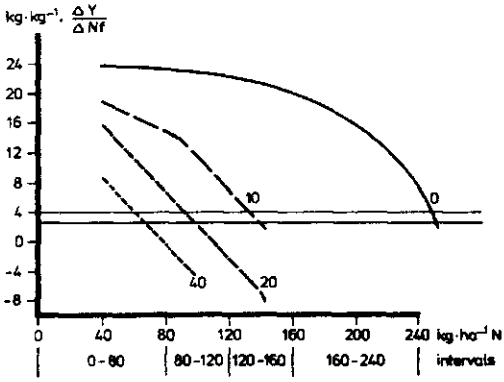

FIG. 7. Slope of the rate-yield curve (ΔY/ΔNf) as related to the level of N application, for 0, 10, 20 and 40 moisture stress days during the critical period.

Yield increases per kg N (ΔY/ΔNf) were calculated from Fig. 6 for application rates of 0-80, 80-120, 120-160 and 160-240 kg ha^{-1} N. The results were plotted versus N application rate for 0, 10, 20 and 40 stress days during the critical period (Fig. 7). The intersections of these curves and the horizontal straights, representing ΔY/ΔNf of 4 and 2.5, indicate approximate optimum N application rates. They were 250, 140, 90 and 60 kg ha^{-1} N for 0, 10, 20 and 40 stress days, respectively.

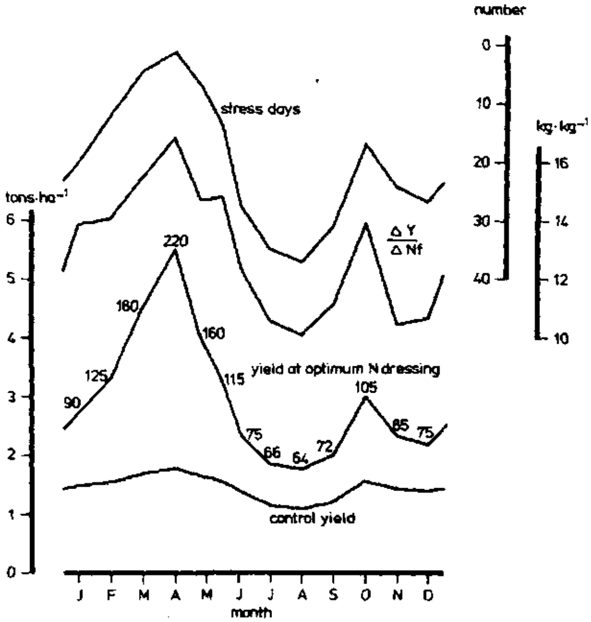

FIG. 8. Number of moisture stress days during critical period of maize planted at the indicated time. Averaged over the years 1977–1982 for Coebiti. Corresponding control yields, yields at optimum N rates (figures refer to optimum N rate in kg ha^{-1} N) and slope of the rate-yield curve ($\Delta Y/\Delta Nf$).

To estimate the best planting time the number of stress days for subsequent planting times were averaged for the years 1977–1982. They are shown in Fig. 8, together with calculated control yield, yield at optimum fertilizer N rates and corresponding $\Delta Y/\Delta Nf$. April appears to be the best time for planting maize in the region.

The number of stress days differed considerably between the years from 1977 to 1982. Table 4 gives the extremes in the number of stress days, optimum N rates and expected yields, for March, April and May plantings.

TABLE 4. Highest (1) and lowest (2) number of stress days during the critical period of maize sown in March to May, as found for Coebiti over the years 1977-1982. Corresponding optimum N application rates (kg ha^{-1}) and related yields.

Period	Stress days		Optimum N rate		Yields, ton ha^{-1}	
	1	2	1	2	1	2
March 8 - March 21	11	0	135	250	3.5	6.5
April 1 - April 28	6	0	170	250	4.3	6.5
April 29- May 12	15	0	110	250	3.1	6.5
May 12 - May 25	21	0	90	250	2.6	6.5

To account for this variation in the number of stress days, it is recommended to plant maize in April and to apply 170 kg ha^{-1} N in two applications (e.g., at planting and 30 days after planting), while a third application (ca. 45 days after planting) might vary from 0 to 80 kg ha^{-1} N, depending on weather conditions.

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OBSERVATIONS ON NITROGEN LEACHING LOSSES IN YAM INTERCROPPING SYSTEM

KEY WORDS: Nitrogen Leaching Ultisol Yam based Systems

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SUMMARY

Observations were made on N leaching losses from three yam intercropping systems (yam/maize, yam/cowpea and yam/sweet potato) compared to sole yam using unreplicated filled-in lysimeters at Umudike in southeastern Nigeria for three years period.

Mean N loss averaged over the three-year period was highest in the sole yam (111 kg N/ha) and least in the yam/cowpea mixture (67 kg N/ha).

Uptake of N by crops was highest in the yam/cowpea mixture and lowest in the sole yam. Yields of yam and component crops followed the same trend as the N uptake.

The results show that among the crops compared cowpea is the best intercrop companion for yam cultivation.

INTRODUCTION

Although loss of nutrients through leaching has been recognized as a major factor limiting crop production in the humid tropics, very few attempts have been made to quantify the magnitude of loss in tropical Africa. A knowledge of drainage losses of N is important not only for an understanding of the changes of soil N in the field but also for a rational approach towards N fertilization. Greenland (1959) described a lysimeter for studying nitrogen balance in tropical soils. Data obtained in one year showed, that N was leached mostly in the form of nitrate and more nitrogen was lost under maize crop than under legume or bare fallow. Wild (1972) studied the leaching of nitrate at Samaru in Northern Nigeria and obtained nitrate leaching rate of 0.3 - 0.7 cm/cm of rainfall. He observed that leaching of nitrate added to the surface as fertilizer was more rapid than the native soil nitrate. Jones (1975) estimated the rate of leaching of native nitrate at Samaru to be 0.2 - 0.3 cm/cm of rainfall and the upper limit for fertilizer nitrate at 0.5 cm/cm of rainfall. This supports the findings of Wild (1972) that fertilizer nitrate is more easily leached than native nitrate. In a laboratory study using undisturbed soil cores from Onne, nitrate, accompanied by Al^{3+} and Ca^{2+} leached readily through the kaolinitic Ultisol profile (IITA, 1979).

The acid sands are the dominant soil group in eastern Nigeria (Obihara, 1961). They are deep, well drained, non-gravelly and coarse sands with kaolinitic as the dominant clay mineral. In view of these soil characteristics and the high rainfall in the region, leaching losses of nutrients are likely to be high.

Njoku et al. (1983), found that 20% and 43% of fertilizer nitrogen applied to cassava/maize intercrop were recovered in the leachate, mostly as nitrate during the first and second cropping years. The results reported here are part of on-going studies on drainage and nutrient losses in an acid sand Ultisol in the rainforest zone of Nigeria. This paper presents the leaching losses and uptake of fertilizer N in yam-based crop mixtures.

MATERIALS AND METHODS

The Lysimeters:

Four tank-type filled-in lysimeters were constructed in 1967 at the Research Station, Umudike (05^0 29'N, 07^0 33'E, mean annual rainfall 2159 mm) on a sandy loam Ultisol. Each lysimeter measured 2 m x 3 m with a depth of 1.2 m. Tests carried out over the years indicated that the lysimeters had attained a high degree of settlement. They were cropped to cassava/maize for two years prior to the study. Some properties of the soil before cropping in 1981 and 1983 are shown in table 1.

Table 1. Some properties of the lysimeter soil before cropping in 1981 and 1983.

Lysimeter	Year	Texture			pH		Org C	Total N	Extr. P	Exch. cations	
		Clay	Silt	Sand	H_2O	KCL	(%)	(%)	(mg/kg)	K	Ca+ Mg
		-------%--------								(meq/100g)	
1	1981	21	3	76	5.5	4.7	1.41	0.15	61	0.15	3.02
	1983	-	-	-	5.7	4.4	2.00	0.18	105	0.17	2.56
2	1981	22	3	75	5.6	4.6	1.46	0.14	40	0.18	2.36
	1983	-	-	-	5.6	4.4	2.40	0.20	80	0.15	2.08
3	1981	21	3	75	5.4	4.6	1.53	0.14	17	0.15	3.00
	1983	-	-	-	5.5	4.3	2.20	0.16	62	0.09	1.68
4	1981	21	3	76	5.3	4.5	1.58	0.14	43	0.11	3.78
	1983	-	-	-	5.3	4.7	2.00	0.15	84	0.08	2.88

Treatments:

In 1981 5 t/ha farmyard manure (FYM) containing 79.5 kg N dry weight basis, was applied to each lysimeter. Six seed yams of D. rotundata, CV obiaoturugo were planted in each lysimeter. One lysimeter was interplanted with maize (FARZ 34), another with cowpea (CV Ife Brown) and the third with sweet potato (CV TIS 2421) while the 4th lysimeter had only yam. A fertilizer mixture giving the following fertilizer rate of 30 kg N, 26 Kg P, 90 Kg K, 10 kg Mg and 5 kg Zn/ha, was applied to each lysimeter 2 weeks after planting the crops. Nitrogen was top-dressed with 30 kg N/ha calcium ammonium nitrate 4 weeks later. Cropping was repeated in 1982 and 1983 without further application of FYM. In 1983, nitrogen rate was increased to 120 kg/ha and no P was applied. Trials were unreplicated.

Percolate water from each lysimeter was collected in a receptor tank and sampled weekly. Nitrogen content in samples were analysed by the method of Bremner (1965).

At harvest crop yield and total dry matter were determined. Nitrogen in plant samples were determined by the method of Nelson and Sommers (1973). Statistical analysis of data were carried out with years as replicates.

RESULTS AND DISCUSSION

The mean monthly rainfall and percolation averaged over the crop mixtures are shown in figure 1.

Percolation water usually started to drain into the receptor tanks when about 350 mm of rain had fallen. Percolation was not much influenced by the cropping system. Percolation was highest in sole yam, which was 9% more than in yam/ cowpea mixture which was the lowest. Borth rainfall and percolation attained their peak values in July and September.

Mean monthly loss of nitrogen follows the same pattern as the rainfall and percolation. Mean annual drainage loss of N was 83.5 kg/ha of which 60 kg (71.8 %) was leached between June and September. The cumulative N losses in relation to percolation under the different crop mixtures are shown in figure 2. N losses under the various crop mixtures were similar up to June when about 400 mm of water had percolated. With heavier rains in July, more N was leached under the sole yam crop than from the crop mixtures. About 111 kg N/ha was leached under sole yam while only 67 kg N/ha was leached under yam/cowpea crop mixture. The corresponding figures for yam/maize and yam/sweet potato were similar, being 78 kg N/ha.

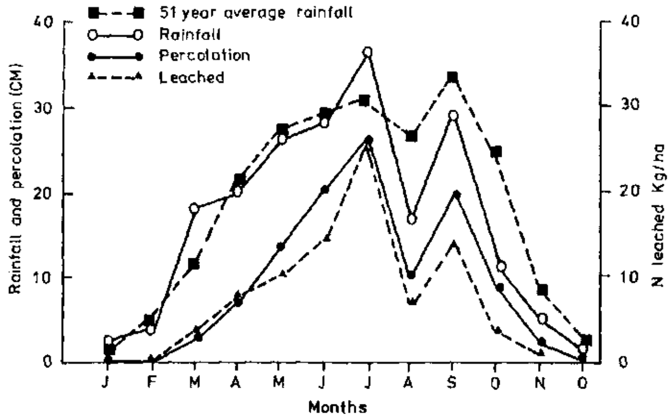

Fig. 1. Mean monthly percolation as related to precipitation and N loss.

Crops Yield and N uptake:

Although yam tuber yields from the various crop mixtures were not statistically different, the yield from the yam/cowpea mixture was higher than that of sole yam crop by 25 %. Intercropping with maize and sweet potato caused a yield epression of 46.8 and 22.2 % respectively of the yam crop. The yields of the other crops, especially the sweet potato, were moderate for mixed cropped systems.

Table 2. Mean yield of crops calculated over three years period as affected by crop mixtures.

Crop Mixture	Yam	Maize	Cowpea	Sweet Potato
		Yield (kg/ha)		
Sole yam	3549	-	-	-
Yam/maize	1887	1358	-	-
Yam Cowpea	4438	-	1278	-
Yam/sweet potato	2762	-	-	6273
S.E.	± 613.3			

Total N uptake by the crops was highest with the yam/cowpea intercrop and lowest with sole yam, (table 3). Taking into account the N contained in the FYM, the uptake of N as percentage of total N applied was 11.6, 28.2, 40.5 and 48.8 % respectively for sole yam, yam/maize, yam/sweet potato and yam/cowpea. Maize, cowpea and sweet potato removed 80.3, 75.6 and 80.1 % of the total uptake by yam/maize, yam/cowpea and yam/sweet potato respectively.

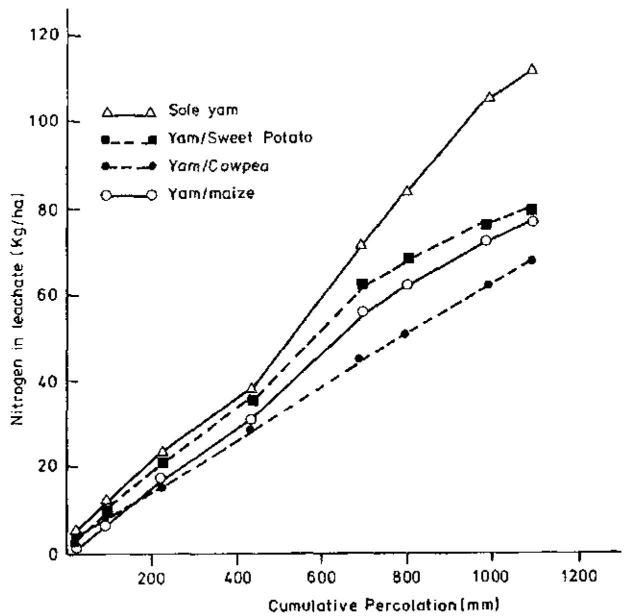

Fig. 2. Cumulative N losses in relation to percolation under different crop mixtures.

Table 3. Mean nitrogen uptake per crop calculated over three years perio

Crop Mixture	Yam	Companion crop	Total
	(kg N/ha)		
Sole yam	12.4	-	12.4
Yam/maize	5.9	24.1	30.0
Yam/cowpea	12.7	39.3	52.0
Yam/sweet potato	8.6	34.6	43.2
S.E.	± 1.8		

As highest rainfall and percolation were recorded between June and September (55.8 % of the mean annual rainfall and 69.4 % of the mean annual percolation) and September, leaching losses of mineral N applied to crops during this period is likely to be loss by leaching. Leaching loss can, therefore, be reduced if fertilizer is applied not later than mid-May and the N split so that a second dose is applied in August. The time of N application should, however, take into cognisance the period of maximum demand by the crop. It was in recognition of this fact that Sobulo (1972) suggested mid-May as the best time for application of fertilizer to yam planted in December through February.

The finding that more N was leached under yam/maize than under yam/cowpea confirms the results of Greenland (1959) which showed that more N was leached under maize crop than under legume or bare fallow. Cowpea forms a better ground cover than maize and hence reduces direct impact of rain drops on the soil.

The results obtained in this study confirm the advantages, highlighted by Okigbo (1977), of interplanting root crops with other crops. Such a cropping system not only reduces leaching losses of nutrients but it also ensures higher toal crops yield and higher net returns.

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EFFECT OF NITROGEN SOURCES ON CROP YIELD AND SOIL PROPERTIES IN THE SAVANNA

Key words: Acidification Calcium cyanamide Exchangeable bases Leaching Nitrogen efficiency Residual effects Savanna Sulphur-coated urea

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SUMMARY

Experiments on highly water-soluble nitrogen fertilizer sources in the savanna zone of Nigeria have been mostly limited to ammonium sulphate, urea and calcium ammonium nitrate. The results show that they all have nearly the same efficiency with respect to crop yield. The delayed release nitrogen fertilizers tested gave slightly lower grain yields than calcium ammonium nitrate when applied to relatively short season ($<$ 120 days) crop such as maize but showed greater promise for long season (150-180 days) crops like cotton and sorghum.

Residual effects of the various nitrogen (both soluble and delayed release) sources as measured by the yield of subsequent maize crops are very low. Continuous application of N, irrespective of source, results in the acidification of the soil. This effect is most pronounced with ammonium sulphate and the effect is greater in the Southern Guinea than in the Northern Guinea savanna zone.

The efficiency of highly soluble N sources may be increased by split application in the Southern Guinea and Sudan zones. The mixing of urea with calcium cyanamide at a ratio of 10 : 1 retards the nitrification of urea and therefore offers some promise in increasing its efficiency.

INTRODUCTION

The savanna zone of Nigeria extends from latitude 6^0 21'- 14^0 N and from longitude 2^0 44'- 14^0 42' East of Greenwich. On the basis of soil groups, the zone may be divided into four broad categories. In the southern part are the deep, freely-drained sandy loams derived from Cretaceous sandstones and lying within the Southern Guinea vegetation zone (Keay 1959) with a mean annual rainfall of 1,100 - 1250 mm confined to a single season of about 8 months (March - September). These soils are described as ferrallitic tropical by D'Hoore (1964) and classified as ferrasols by the FAO (Dudal 1968) or ultisol in the USDA system (Harpstead 1973). North of the ferrallitics lie the ferruginous soils which are situated mainly in the Northern Guinea savanna vegetation belt with a mean annual rainfall of about 1000 mm spread over a 5-month period (May - September). About 50% of the rain falls in July and August. These soils comprise nearly 43% of the savanna region (Klinkenberg and Higgins 1968). They have been classified as Alfisols by Harpstead (1973). The third group of soils are the inceptisols (Harpstead 1973) or brown and reddish brown soils using the legend of D'Hoore (1964). They lie in the Sudan savanna zone with a mean annual rainfall between 500 and 700 mm. About 60% of the rain falls in July and August. The last major distinct group are the Vertisols with swelling clays. They are mostly confined to the north-eastern portion of the country.

The savanna zone is the major grain belt in Nigeria. Most of the fertilizers used in Nigeria are consumed in this zone. The straight nitrogen sources which are used here are calcium ammonium nitrate (CAN), ammonium sulphate (AS) and urea while the major compound fertilizers are 20-10-0, 20-10-0, 20-20-0, 25-10-0 and 15-15-15 (NPK). In spite of the fact that a high percentage of the N-source used (38% of total consumption in 1981) is in the form of compounds, there is practically no report of their effect on crop or soil. This paper examines the effect of nitrogen sources from straight fertilizers on crop yields and soil properties in the major savanna soils, excluding the Vertisols. Table 1 gives some of the properties of representative profiles.

Table 1. Selected properties of representative profile.

Soil	Kadawa			Samaru			Mokwa		
Depth (cm)	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60
Particle Size (%)									
2.0-0.2 mm	5.5	4.5	4.7	15.4	14.5	11.0	68.0	57.5	55.0
0.2-0.02 mm	85.8	82.5	78.7	64.0	52.0	41.4	17.6	22.5	15.5
0.02-0.002 mm	4.3	3.7	3.3	7.4	7.5	7.2	3.4	4.6	3.5
0.002 mm	4.4	9.3	13.3	13.2	26.0	40.4	11.0	15.4	26.0
Organic C (%)	0.27	0.18	-	0.45	0.32	-	0.55	0.43	-
pH ($CaCl_2$)	5.90	6.05	5.73	5.12	5.10	5.25	5.55	5.60	5.45
Effective CEC (meq/100g)	6.0	6.1	6.7	4.0	4.5	5.5	1.8	1.4	1.6

EFFECT OF NITROGEN SOURCES ON CROP YIELDS

A considerable number of trials has been carried out to compare the effects of different nitrogen sources on crop yields. Jones (1974) summarized the results of trials conducted from 1964-66 on the effects of AS, CAN, urea, calcium nitrate and sodium nitrate on the yields of maize, sorghum, millet and yams. Less than 20% of the trials gave significant yield differences between sources and the average crop yield from any one source rarely deviated by more than 5% from the mean of all sources (Table 2). However, in other series of trials from 1970-72, conducted in 18 locations, CAN gave higher yield of maize than urea and AS.

Table 2. Effect of N-source on crop yields (Jones, 1974).

N-Source	Crop yield as percentages of mean yields off all sources			
	Maize	Sorghum	Millet	Yam
AS	104.4	96.2	102.1	100.8
Urea	95.4	98.9	98.6	107.3
CAN	99.2	100.7	101.1	105.7
Calcium nitrate	100.5	99.5	100.9	94.0
Sodium nitrate	100.4	104.7	97.2	92.1
No. of trials	19	12	8	4
Trials with significant differences	7	0	0	1

Table 3. Effect of N-source on maize yield (Jones, 1973).

N-Source	Maize yield (kg/ha)	% Increase over control
Control	1181	0
AS	2138	81
Urea	2180	85
CAN	2380	102

In a study involving different N sources and rates Jones (1974) reported a drastic fall in maize yield at high rates of AS (Table 4). Within 3 years maize yield from AS plots decreased by 56 and 25% respectively at Samaru and Mokwa with annual application of 280 kg N/ha. Yields from urea were also depressed but not as much as by AS. However at N rates normally recommended for maximum yield there were no significant differences between sources. Balasubramanian and Singh (1982) conducted a maize-wheat rotation study at Kadawa using urea and CAN and N rates ranging from 0 to 180 kg N/ha and found that urea gave significantly higher yields than CAN in one out of four seasons. They concluded that urea is equally effective as CAN for maize and wheat in semi-arid savanna soils. The above conclusion appears valid for most of the soils of the savanna zone when these N sources are applied at optimum rates to relatively short season ($<$ 120 days) crops. The Vertisols of the Lake Chad basin are possible exceptions, but some studies need to be done in this regard.

Table 4. Effect of N-source and rates (kg/ha) on maize yield (kg/ha) at Samaru and Mokwa (Jones, 1974).

N-Source	1970		1972	
	140	280	140	280
Samaru				
AS	3612	3597	2636	1570
Urea	3656	2607	3362	2318
CAN	3307	3804	3687	3812
Mokwa				
AS	3433	3298	3043	2486
Urea	3157	3336	2939	2845
CAN	2712	3204	2543	3100

Few trials have been carried out on delayed release nitrogen sources. In a lysimeter experiment at Samaru Nnadi (1975) reported that CAN gave higher yields of maize than urea and sulphur-coated urea (SCU-30) with 30% dissolution rate in 7 days. However there was not much difference between SCU and urea. In field trials, Nnadi and Abed (1983a) compared two types of SCU having 11 and 30% dissolution rates in 7 days with CAN using cotton and sorghum as test crops. They found that at low N rates of application (30-40 kg N/ha), SCU-11 was more effective than SCU-30 and CAN (Table 5). In another experiment at Kadawa applications of 60 kg N as calcium cyanamide and 120 kg N/ha as urea or CAN did not result in significantly different yields of wheat (Nnadi unpublished). These results indicate that at low N rates delayed release fertilizers might be more effective than highly water-soluble N fertilizer, especially on relatively long season (> 150 days) crops.

Table 5. Comparative effects of sulphur-coated urea and calcium ammonium nitrate on crops (Nnadi & Abed, 1983b).

Source of N	levels of N applied	Yield (t/ha) Sorghum	Cotton
No N	0	1.17	0.78
CAN	1	1.76	0.83
	2	2.48	0.94
	3	2.41	0.91
SCU - 11	1	2.20	0.93
	2	2.04	0.91
	3	1.84	1.06
SCU - 30	1	1.96	0.87
	2	2.21	1.04
	3	2.17	1.11
	SE	0.10	0.10

EFFECT OF N SOURCES ON SOIL PROPERTIES

Savanna soils are chemically fragile. Most of them have very low clay and organic matter contents and dominated by kaolinitic clay. As a result most of these soils have very low cation exchange capacities and are poorly buffered. Inappropriate use of fertilizer, both type and rate, can result in rapid soil degradation. Bache (1965) and Bache and Heathcote (1969) reported that fourteen annual applications of AS at the rate of 22 kg N/ha lowered soil pH at Samaru to 3.53 compared to 4.56 in the control plot. Amounts of exchangeable Al and Mn were markedly increased (Table 6). Similar results as in Table 7 have been obtained at Kano (Institute for Agricultural Research 1980).

Table 6. Effect of ammonium sulphate on soil pH and exchangeable cations (Bache & Heathcote, 1969).

Rate of N (kg/ha)	pH (water)	pH ($CaCl$)	Exchangeable Cations Al	Mn	Ca	Mg	K
			M x 10		-----meq/100g-------		
0	5.95	4.56	0.07	0.10	1.03	0.44	0.16
12.5	5.61	4.24	0.29	0.19	0.93	0.39	0.17
25.0	5.36	3.98	0.78	0.14	0.83	0.36	0.17

Table 7. Effect of ammonium sulphate on soil acidity and exchangeable cations at Kano, Nigeria (Institute for Agricultural Research, 1980).

N Rate (kg/ha)	pH	Exch. Acidity	Ca	Mg	K
		meq/100g			
0	4.65	0.067	1.204	0.197	0.132
62.5	4.38	0.161	1.110	0.150	0.108
135	4.23	0.177	1.203	0.141	0.098
SE (+)		0.032	NS	0.015	0.007

Jones (1976a) reported a drastic reduction in soil pH at Samaru and Mokwa when 280 kg N/ha as AS were applied for only 3 years (Table 8). Depletion of Ca and Mg in the profile was found.

Balasubramanian and Singh (1982) found no differences in soil pH between CAN and urea after 2 years of irrigated wheat at Kadawa but high N rates, irrespective of the source depressed soil pH by 0.56 units. Similarly Nnadi and Abed (1983b) found no difference between CAN and SCU with respect to their acidification effect after 2 years of cropping, but the application of 120 kg N/ha per annum from soluble and delayed release sources resulted in decrease of 0.2-0.3 pH units relative to the control in the sandier soils at Mokwa and Kadawa. These results show that acidification of savanna soils is likely to occur with continous application of N fertilizers irrespective of the source though it is more rapid with AS.

Table 8. Effect of nitrogen sources and rates on soil pH (0.01M $CaCl_2$) (Jones, 1976a).

Soil dept (cm)	Rate of N (kg/ha)	initial pH	N - Source AS	Urea	CAN
				Samaru	
5	0	4.47	5.75	5.62	5.72
	140		4.59	5.32	5.30
	280		3.87	5.38	5.58
20	0	4.42	4.39	4.53	4.64
	140		4.56	4.57	4.51
	280		3.76	4.69	4.95
35	0	4.49	4.49	4.80	4.63
	140		4.62	4.73	4.65
	280		4.56	4.75	4.79
				Mokwa	
5	0	5.42	6.30	6.11	6.08
	140		5.11	6.20	6.02
	280		4.90	5.96	5.57
20	0	5.59	5.52	5.52	5.93
	140		4.83	5.57	5.24
	280		4.17	5.02	4.58
35	0	5.36	5.26	5.14	5.53
	140		4.75	5.56	5.28
	280		4.14	4.64	4.40

RESIDUAL SOIL NITROGEN AND N SOURCES

The amount of nitrogen left in the rooting zone from previous fertilizer N application is generally quite low, irrespective of the nitrogen source. Nnadi and Abed (1983b) found that the residual N from CAN and SCU did not differ significantly at any of the locations in the study (Table 9). The apparant residual N values were less than 5 mg N/kg after 2 years of N application and cropping. Biological evaluation of residual N obtained by growing maize showed that very little N from previous fertilizations is available to a subsequent crop (Table 10).

Table 9. Residual soil nitrogen (mg N/kg) After 2 years of cropping (Mean of three locations) (Nnadi and Abed, (1983b).

Cumulative fertilizer applied kg N/ha	CAN	N - Source SCU - 11	SCU - 30
		0 - 15 cm	
0	9.4	9.4	9.4
70	10.2	12.7	10.7
140	11.5	14.1	12.5
210	10.9	12.2	11.1
Means	10.5	12.1	10.9
		15 - 30 cm	
0	10.1	10.1	10.1
70	11.6	13.9	10.6
140	12.5	15.0	12.0
210	12.0	13.0	12.3
Means	11.6	13.0	11.3

Table 10. Maize yield as affected by previous application of nitrogen fertilizers (Nnadi and Abed, (1983b).

N fertilizer source	Maize Yield (kg/ha) Kadawa	Mokwa
Control	383	186
SCU - 11	397	158
SCU - 30	477	148
CAN	242	102

Split nitrogen applications are generally recommended for maize, wheat, sorghum and cotton (Balasubramanian et al., 1979). The advantage to be gained by split N application varies within the savanna zone.

Jones (1973) did not obtain any advantage in maize yield at Samaru from split N application over unsplit application at the rate of 112 kg N/ha (Table 11). Only at an extremely high rate was any benefit due to splitting observed. For the Ferruginous soils in the Northern Guinea savanna, leaching of N is unlikely to pose any problem for early-planted maize (Jones 1975; Nnadi and Stockinger 1975). Comparative studies on the effect of splitting of different N sources are few. Balasubramanian et al (1978) reported significant differences in maize yield by splitting urea but not CAN. This might have been due to seedling damage by urea. Generally, responses to splitting N in the Northern Guinea savanna are sporadic.

Table 11. Effect of Split N Application on Maize Yield at Samaru. (Jones, (1973).

Treatment No	Fraction of fertilizer applied			Maize Yield (kg/ha)
	In seed bed	3,5 weeks after sowing	7 weeks after sowing	
A	1	-	-	4855
B	-	1	-	4657
C	-	-	1	4343
D	1,5	1,5	-	4840
E	-	1,5	1,5	4962

At Kadawa in the Sudan zone, Balasubramanian and Singh (1982) found no advantage by splitting urea or CAN for either rainfed maize or irrigated wheat and concluded that leaching might not be a problem in this soil.

Generally, if planting is done early, leaching losses of N will be quite small, but if planting is delayed there is some advantage in split N application (Jones 1973).

It is quite a different condition in the Southern savanna. Lombin and Ogunlela (1979) obtained a significant response to split application of N to cotton on the soils derived from sedimentary sandstones. Jones (1976b) calculated that the leaching of nitrate from fertilizer nitrogen at Mokwa could be 4-5 times the rate at samaru. The work of Jones (1976a) indicates that since AS, CAN and urea acidified the subsoil at Mokwa, leaching of N is quite rapid and therefore split application would be advantageous.

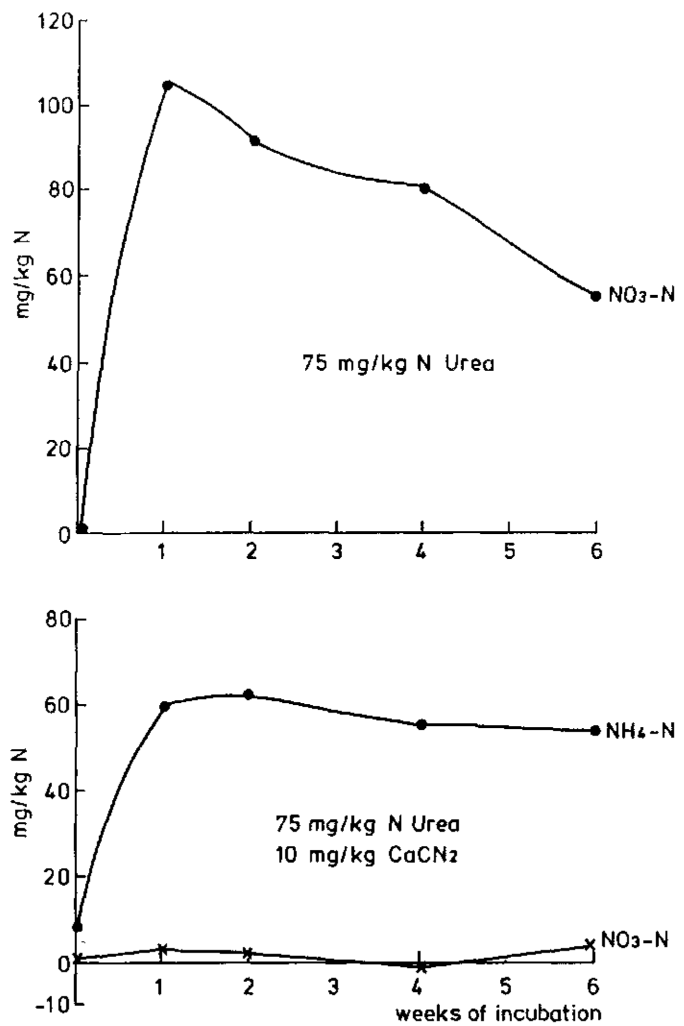

Figure 1. Ammonification and Nitrification of Urea in Samaru Savanna Soil as Affected by Calcium Cyanamide.

While leaching might not be a serious problem in the Sudan and Northern Guinea savanna zones, denitrification could lead to N losses. The rainfall pattern is such that 50-60% of the rain falls in the months of July and August. Under this condition the soil is saturated and often waterlogged for many days, thus creating a suitable environment for denitrification. The use of slow-release nitrogen fertilizer could, therefore, be an advantage. Preliminary investigations show that a mixture of urea and calcium cyanamide at a ratio of 10:1 will delay nitrification (Fig. 1). Since urea is becoming more widely used, such a mixture could result in increased N efficiency while decreasing seedling damage.

CONCLUSIONS

Results from experiments in the savanna zone of Nigeria show:

(1) That all the highly water-soluble N sources (AS, urea, CAN) which are in common use have practically the same effects on crop yield.

(2) Delayed release fertilizers may be useful for relatively long season crops like cotton and sorghum.

(3) Acidification of these poorly buffered soils occurs with all N sources in use but AS accelerates the process much more than other sources.

(4) Acidification eventually leads to lower crop yields. Liming of such soils will become inevitable.

(5) Nitrogen formulations that give lower nitrification rates can supply the plant with adequate N by the ammonification process, and could lead to greater N efficiency use and decreased acidification.

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NITROGEN AND PHOSPHORUS RESPONSES AND YIELD TRENDS FOR CONTINUOUS MAIZE GROWN UNDER CONSERVATION TILLAGE IN THE LOWLAND TROPICS.

Key words: Farmer recommendations Long-term experiments
Maize Nitrogen responses On-farm research Phosphorus responses
Residual effects Yield trends

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SUMMARY

A nitrogen x phosphorus fertilizer experiment was conducted continuously on maize for 13 crop cycles in the Gulf Coast area of the State of Veracruz, Mexico. The soil was a heavy Vertisol and annual average rainfall was about 1,250 mm. The experiment was conducted using conservation tillage.

During the initial crop cycles no response to either nutrient were observed. After a few crop cycles a nitrogen response was evident followed in later cycles by a phosphorus response. After about 8 cycles an interaction between the two nutrients became apparent. Yields have been maintained at the higher levels of nitrogen and phosphorus fertilization used in the experiment. The trends for the various treatment combinations will be discussed from the standpoint of the results farmers might expect from the adoption of the various fertilization practices represented in the experiment.

No severe weed, disease or insect problems arose from the continuous use of a conservation tillage management system involving herbicides and mulch for maize production over a six-year period.

This research was conducted as a part of the CIMMYT maize production research training program. It was concluded that some long-term experiments of this nature are advisable in on-farm research programs where the treatments have residual effects in succeeding cycles.

INTRODUCTION

There is general agreement that agronomic experiments, conducted with the primary goal of formulating recommendations for farmers, are most appropriately conducted in farmer's fields. For the past 12 years CIMMYT has been training young agronomists from the developing world in the skills required for conducting on-farm production research experiments (Palmer et al., 1980). Experiment station conditions frequently differ drastically from the conditions faced by farmers, so that recommendations derived from the results of experiment station research have often been rejected as unsuitable by farmers (Perrin and Winkelmann, 1976; Aklilu, 1980). In no area is this more apparent than in the area of soil fertility and fertilizer use. Experiment station fertility management is often much different than farmer fertility management even where the soils are the same. Therefore, fertility experiments must be carried out in the fields of the target group of farmers for which a recommendation is to be formulated. As part of the CIMMYT training program in maize production research, fertility experiments were conducted in farmer's fields in the Gulf Coast area of Northern Veracruz, Mexico, starting in 1972. These experiments involved nitrogen and phosphate as variables and the experiments were established on new sites in each crop cycle. Frequently, responses to nitrogen and phosphorus were slight or non-existent even though farmers' maize yields averaged 1000-1500 kg/ha and crops appeared to be deficient in nitrogen at least.

The soils of the area are heavy Vertisols, very difficult to till mechanically. The predominant rotation is maize-maize. Even though two rainfed crops of maize are possible (mean annual rainfall is about 1,250 mm), many farmers do not crop the land twice a year. After moisture supply, weeds have been identified as the primary yield-limiting factor for maize in the area. Yields are generally doubled or tripled by effective weed control with no additional fertility, no change of variety, etc. So, when fertility experiments under effective weed control were conducted on fields where a farmer had been harvesting one maize crop per year at a production level of about 1000 kg/ha, no or small responses to nitrogen or phosphorus were obtained in the first experimental crop cycle at a yield level of about 3000 kg/ha. The recommendation from such experiments would be that nitrogen and phosphorus fertilizers were not economic. So, in 1977, it was decided to conduct a continuous nitrogen by phosphorus experiment in a representative location to investigate the longer-term effects on yield trends of growing maize, two cycles per year, under a range of fertility treatments. In a sense, each treatment would give an indication of the longer-term results a farmer would obtain if he adopted any one of the fertility management levels included in the experiment. Experiments on tillage and weed control in the same area had, by 1977, resulted in the development of an effective zero tillage system for maize (Palmer et al., 1983). So, it was decided to conduct the continuous fertility experiment under conservation tillage management.

MATERIALS AND METHODS

A continuous fertility experiment was initiated in the state of Veracruz, Mexico, in December 1977 on flat land, where the soil was a vertisol. The initial winter cycle 1977/78 will be designated as the 1978A cropping cycle (harvested in April 1978). The following summer cycle (rainy season) will be designated as the 1978B cropping cycle, etc. The same experiment was planted on the site every cropping cycle until 1984A when the experiment was terminated (13 cropping cycles). The crops were carried through to harvest and data were obtained in all but one cycle (1980B when the crop was lost due to drought). During the initial 8 cycles the maize variety used was Tuxpeno-1 (drought-tolerant selection). In 1982A this was replaced by Poza Rica 7822 for the remaining crop cycles. These two varieties are well adapted to the area with very similar agronomic characteristics and yield potential.

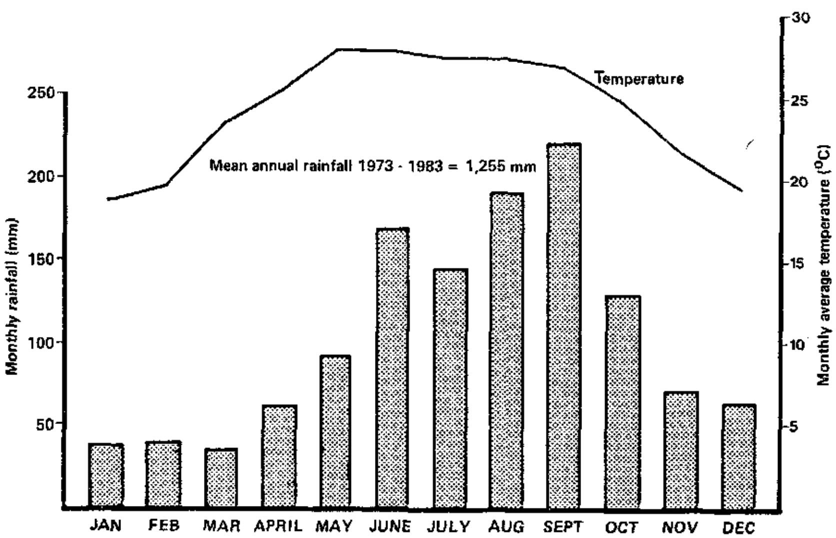

Fig. 1. Monthly Average Rainfall and Monthly Average Temperatures for the CIMMYT Experiment Station, Poza Rica, Veracruz, Mexico for the Period 1973-1983.

The plant population was 50,000 plants per hectare (80 cm between rows, 50 cm between hills and 2 plants/hill). Seed was treated with a Furudan/Arasan mixture, and 4 seeds were planted per hill and thinned to 2 plants/hill at the 5-leaf stage. Further granular insecticide applications were made in the whorl to control fall army worm (Spodoptera sp.), as necessary.

A randomized complete block design was used with two replications. The treatments were applied to the same plots in all cycles. Plot size was six rows five meters long. The two central rows were harvested but the end hills were discarded as border. The treatment design was an A x B factorial with 4 levels of applied nitrogen (0, 50, 100 and 150 kg N/ha) and 3 levels of phosphorus (0, 40 and 80 kg P_2O_5/ha). The nitrogen was applied as ammonium sulfate and the phosphorus as triple superphosphate. The fertilizers were mixed and applied broadcast on a row-by-row basis immediately after planting. Previous experiments in the area utilizing conservation tillage had shown no advantage of splitting the fertilizer application nor any advantage due to fertilizer placement.

Management of the crop was by a conservation tillage system; no tillage was performed on the field throughout the experiment and the crop residues were cut each cyle to form a mulch (with the exception of the end of the 1979A cycle when the farmer burned the mulch). Seeding was performed with the planting stick used in the area. Weed control was achieved by the application of 360 ml Paraquat/ha (as 2 l Gramoxone/ha) and 1 kg Atrazine (as 2 kg Gesaprim-50/ha) applied immediately after planting in 400 l water/ha each cylce. No severe weed, disease or insect problems arose from the continuous use of a conservation tillage management system involving herbicides and mulch for maize over the six-year period.

The experiment was located near the city of Poza Rica in the northern part of the State of Veracruz, Mexico (latitude 21°N and altitude less than 100 m). The location was flat, and the soil was a vertisol with a pH of 8. Rainfall in the area averages about 1,250 mm per year. Monthly average rainfall data and monthly average temperatures for the CIMMYT experiment station near Poza Rica are presented in Figure 1, and the rainfall data for the actual crop cycles in this study are presented in Table 1. Clearly the months of June-October constitute the rainy (B) season in this location (Fig. 1). However, temperatures are much lower during the dry (A) season so that the lower rain fall is used more efficiently. The data in Table 1 illustrate the variability in rainfall during both the A or B cropping cycles. Not only is there considerable variation in total rainfall receipts during both the A or B cycles, but the distribution is also highly variable. As a result, crops can suffer from droughts or waterlogging for extended periods in either the wet or dry seasons. For example, drought caused the loss of the experiment during the 1980B cycle while waterlogging (and the resulting denitrification) severely decreased yields in the 1981A cycle. In general, yields are higher in the dry (A) season than in the wet (B) season (Figure 2).

Table 1. Total Rainfall Recorded at the Poza Rica Experiment Station for the Cropping Cycles 1978A to 1984A.

Year	Total Rainfall per Cycle (mm) A	B
1978	121	629
1979	261	605
1980	157	535
1981	862	715
1982	302	619
1983	98	492
1984	114	-
Mean	274	599

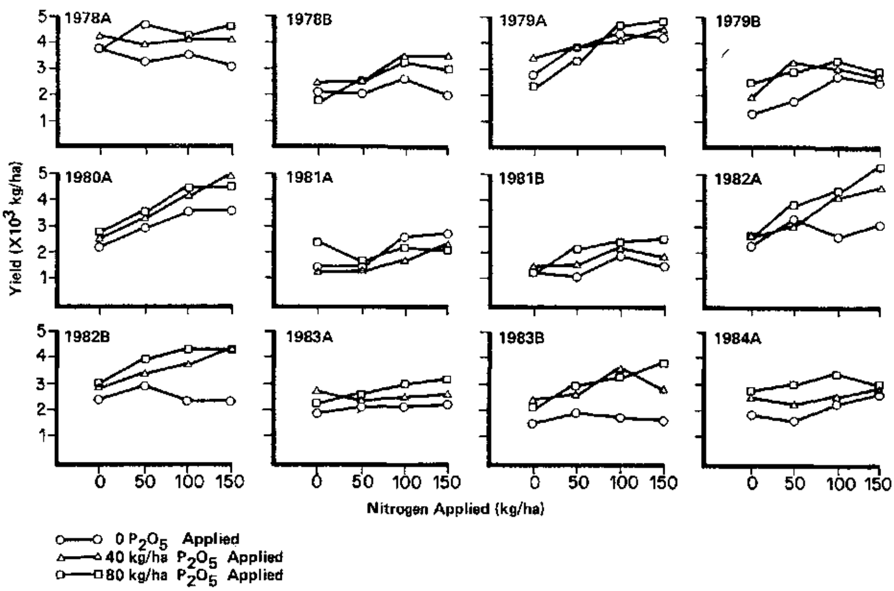

Fig. 2. Yield Responses of Maize to N and P over 12 Crop Cycles of a Continuous Fertility Experiment Conducted in the State of Veracruz, Mexico.

RESULTS

The yield data for the 12 harvested cycles are presented in Figure 2. The superiority of yields in the dry season is clear particularly in the first 5 years. As a result, responses to N and P are more readily seen in these cycles. If we look at the first five A cycle graphs in Figure 2, we can see no response to N or P in 1978A; a clear N response but no P response in 1979A; a more marked N response and a clear P response in 1980A; a clear N and P response in 1982A and a graphical indication of an N x P interaction even though it was not significant in the analysis of variance.

Since the N x P interaction for yield was not significant in any of the crop cycles of the experiment, the mean nitrogen responses across P levels for each crop cycle are presented in Figure 3 and the mean phosphorus responses across N levels for each cycle are presented in Figure 4. The asterisks by the cycle letters indicate the significance level for the N or P response in that cycle in Figures 3 or 4, respectively.

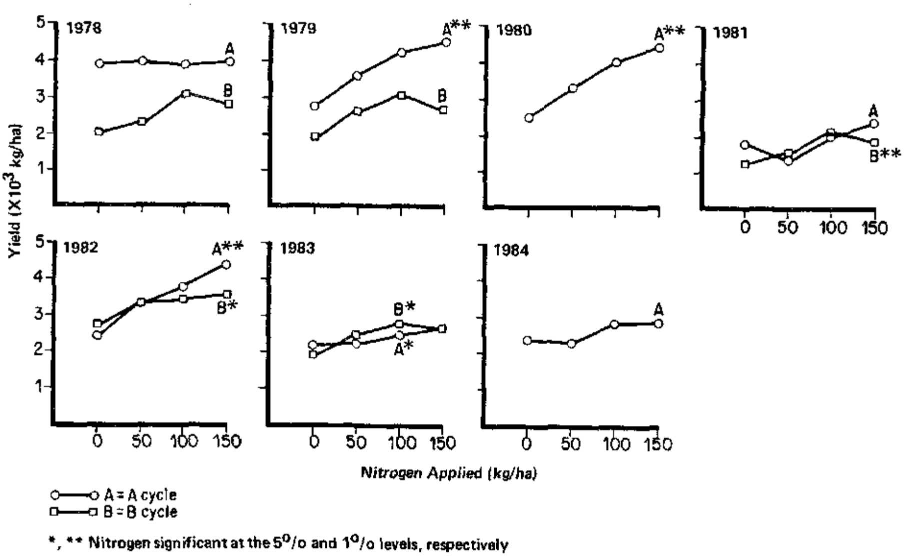

Fig. 3. Mean Yield Responses of Maize to N (over 3 levels of P) in 12 Crop Cycles of a Continuous Fertility Experiment Conducted in the State of Veracruz, Mexico.

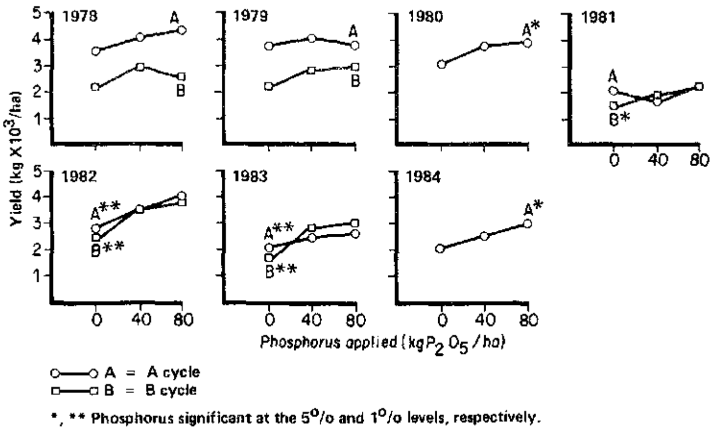

Fig. 4. Mean Yield Responses of Maize to P (over 4 levels of N) in 12 Crop Cycles of a Continuous Fertility Experiment Conducted in the State of Veracruz, Mexico.

Nitrogen responses developed before phosphorus responses especially in the higher yielding A cycles. Phosphorus responses developed in the later cycles even when the yield levels were depressed due to drought and/or waterlogging.

The relative yields (presented as the percentage of the mean yield for the experiment in each particular cycle) for each N or P level are presented for all the cycles of the experiment in Figure 5. While the trends in relative yield levels over time for the nutrient levels of N and P_2O_5 are evident from Figure 5, these are much clearer in Figure 6 in which only data for the A cycles of 1978, 1979, 1980 and 1982 are shown. These were the A cycles where yields were not severely limited by either drought and/or waterlogging.

For plots receiving no nitrogen, yields declined rapidly to a low level relative to the mean over the first 5 years of the trial. Plots receiving 50 kg N/ha maintained a yield level at about the mean yield for each cycle. The yields of plots receiving 100 or 150 kg N/ha tended to be maintained above the mean yield for each cycle.

Similarly, in plots receiving no phosphorus, yields declined to a level below the mean. This decline was slower than that seen for the plots receiving no nitrogen. The yield of plots receiving 40 kg P_2O_5/ha was maintained at about the mean for each cycle, while that for plots receiving 80 kg P_2O_5/ha was maintained above the mean (Figures 5 and 6).

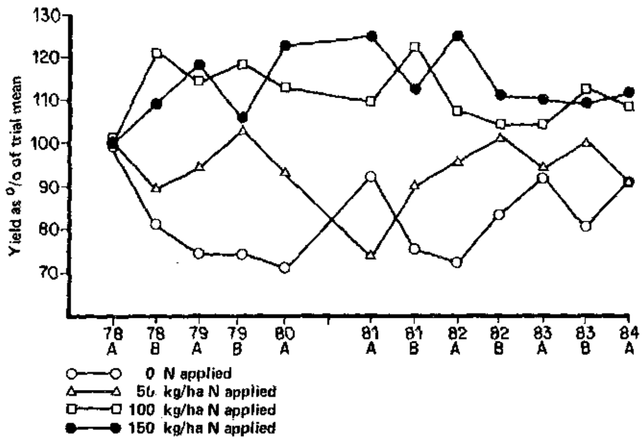

Fig. 5. Relative Yields (as a percentage of the mean yield of the experiment for each particular crop cycle) over Time for the 4 Levels of N and 3 Levels of P in a Continuous Fertility Experiment Conducted in the State of Veracruz, Mexico.

DISCUSSION

The yield data for the various cropping cycles clearly demonstrate that at the beginning of the experiment there was no response to nitrogen or phosphorus fertilizers, and yield was at a relatively high level across all treatments. After a few (3) cropping cycles, a response to nitrogen was clearly evident but there was no response to phosphorus. After 5 cycles, a phosphorus response was shown in addition to nitrogen. After further crop cycles, an N x P inter action was suggested. Therefore, we see clearly that in this area, on the heavy

Vertisols in the valley bottoms, the traditional cropping system does not deplete the natural fertility. With the adoption of efficient weed control practices, high yields van be obtained initially without the application of nitrogen and phosphorus.

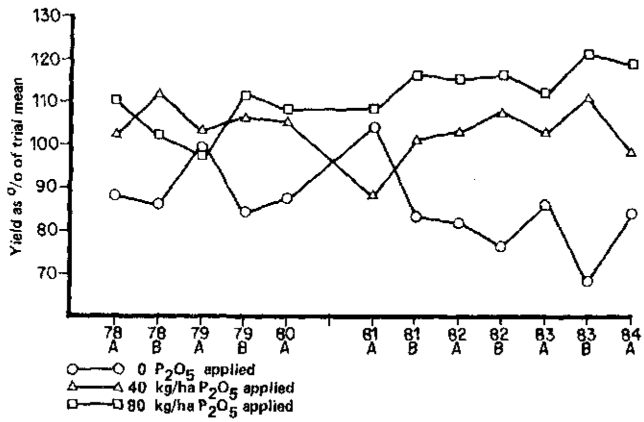

Fig. 6. Relative Yields (as a percentage of the mean yield of the experiment for each particular crop cycle) over Time for the 4 Levels of N and 3 Levels of P in Four Dry (A) Seasons when Drought and Waterlogging were not Severely Limiting.

However, with intensification of the cropping system, by growing two crops per year with substantially higher yields with good weed control, the fertility of the soil was depleted in a few cycles, first for nitrogen, then for phosphorus.

Many adoption studies are made on the degree to which recommendations are adopted by farmers. It is rare to find studies of the consequences of adoption of a particular recommendation by farmers. This type of long-term study provides information, in this case, on the consequences (in terms of yield trends) of adoption of various levels of nitrogen and phosphorus application.

The curves of relative yields over time shown in Figure 6 show what a farmer could expect to happen to yield if he adopted consistently a particular nutrient level and effective weed control practices. However, what is of more interest is the sequence of fertilizers he should adopt so that he adds sufficient but not excess fertilizer after his adoption of good weed control practices. Clearly, he would be wasting resources by applying nitrogen and phosphorus initially. Later, he needs to add nitrogen but not phosphorus. In still later cycles, he needs to add nitrogen and phosphorus due to independent responses to the two nutrients. Still later, he would probably need to consider the interaction between the nutrients in picking his application rates.

The data presented here support the notion that it is not always sufficient to conduct on-farm research for only one cycle at all locations, particularly with variables that have residual effects. If adoption of a recommended fertilizer application rate, for example, will have a residual effect over time, then the recommendation itself may change over time. This effect can only be observed by conducting long-term experiments at the same locations. Hence, it is recommended that a few on-farm research sites be included in the program for a number of cropping seasons when variables of this type (fertilizer application, residual herbicides, etc.) are involved. This could be especially important where the treatments in the experiment have differential effects on erosion, for example. These effects may be seen only by applying the same treatments for a number of crop cycles.

In the example presented here, it can be seen that the initial responses and the pattern of the responses over time will vary according to the soil type and previous cropping history. In this case, we are dealing with a highly fertile soil (albeit difficult to manage) that had been poorly managed especially in terms of weed control practices, that had been cropped once per year at low yield levels, so that initially, nitrogen and phosphorus fertility levels were not limiting production. Hence, nitrogen and phosphorus fertilization was not initially profitable. However, after a few crop cycles at improved management levels (variety, density, weed control, two crops per year), nitrogen application became profitable. In addition, phosphorus application became profitable a few cycles later. All the data for this experiment have been subjected to economic analysis utilizing partial budget analysis (Perrin et al., 1976). In Mexico, government subsidies make fertilizer a very inexpensive commodity in relation to the price of maize. It takes only 1.3 kg of maize to pay for 1 kg of nitrogen and 1.7 kf og maize to pay for 1 kg of P_2O_5. So, by the normal yardsticks of economic analysis, relatively small responses to fertilizers are considered to be economic. In other countries, where it takes 4-16 kg of maize to buy 1 kg of nitrogen (Byerlee and Sain, 1984), profitability requires much larger responses to nitrogen. However, simply carrying out economic analysis on a cycle-by-cycle basis is not adequate in this case. More important are the yield trends and carryover effects. These are not easy to analyze economically. For example, a decision has to be made on the appropriate prices to use especially for forecasting future recommendations. Should one use the prices that were current while the experiment was being conducted, or those current at the end, when a recommendation is being formulated?

This type of long-term fertilizer trial will be required where new lands are being colonized and natural fertility may be high initially. Similarly, such experiments are necessary in slash-and-burn agriculture after a fallow. Otherwise, experiments conducted for one cycle at each location may well lead to misleading recommendations. This will become increasingly important as population pressures mount in many areas, and there is a need to change from shifting agriculture to a more settled farming system.

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NITROGEN BALANCE IN SOME TROPICAL AGROSYSTEMS

KEY WORDS: Agrosystems N-balance Biological fixation Compost Crop residues
Fertiliser losses Manure Tropical soils

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SUMMARY

Investigations by IRAT's soil scientists at national research Institutions in West Africa involves various aspects of fertiliser and soil nitrogen balances under cultivation.

Special attention is given to the respective contributions of soil-derived, fertiliser-derived and symbiotically fixed nitrogen to the total nitrogen requirement of crops at different stages of their development.

Residue recycling is also studied, involving investigations on farmer's practices, straw incorporation and conversion to compost and manure.

Research on soil nitrogen mainly concerns nitrogen movements, drainage losses and contribution of fertiliser nitrogen and crop residues.

Further investigations are needed to manure N losses to the atmosphere in run-off and erosion, in order to enable drawing up complete N-balances.

INTRODUCTION

A first appraisal in 1974 on the work of IRAT agronomists on nitrogen and organic matter emphasised the following:

- the need for a sound knowledge on the day to day crop N requirements,
- the value of incorporating crop residues, and
- the advantages of including legumes in crop rotations.

Since then, research on various plants and cropping systems have been conducted at several sites as follows:

- on groudnut-millet and maize-soyabeans in Senegal,
- on sorghum-cotton in North Cameroons and in Burkina Faso, and
- on maize-rice-cotton and maize monoculture in the Ivory Coast.

The methods of study and the work undertaken varied according to the amount of means available and the research priorities of the national institutions (ISRA in Senegal, IVRAZ in Burkina Faso, IRAF in the Cameroons, and IDESSA in the Ivory Coast). The production economics which envisages the systematic recycling of straw and the routine use of other crop residues has been given major emphasis.
Isotopic labelling, using N15 was used, whenever it was useful to distinguish between several nitrogen sources. For the N15 work assistance was received from AIEA and other laboratories, particularly from the radioagronomy service of the Cadarache Nuclear Centre, and the Soil Biochemistry Institute in Braunschweig-Volkenrode. For research on N fixation, the Orstom soil biology laboratory at Dakar has given valuable assistance. The soil chemistry and mass spectrometry laboratories of Gerdat at Montpellier, have also given continuous analytical and documentary support to the programme.

Research results on the various aspects of the nitrogen cycle (fig. 1), are schematically grouped into two main themes:

- **Plant nitrogen uptake**, which depend on plant needs in relation to nitrogen supply from soil, fertilisers and symbiotic fixation.
- **Soil nitrogen changes**, as estimated from nitrogen movements, mineralisation of organic nitrogen, losses, and additions from fertilisers and organic residues.

Finally, inconsistencies relating to the less well known aspects of the overall cycle are revealed when results related to the study of nitrogen balances under cultivation are put together.

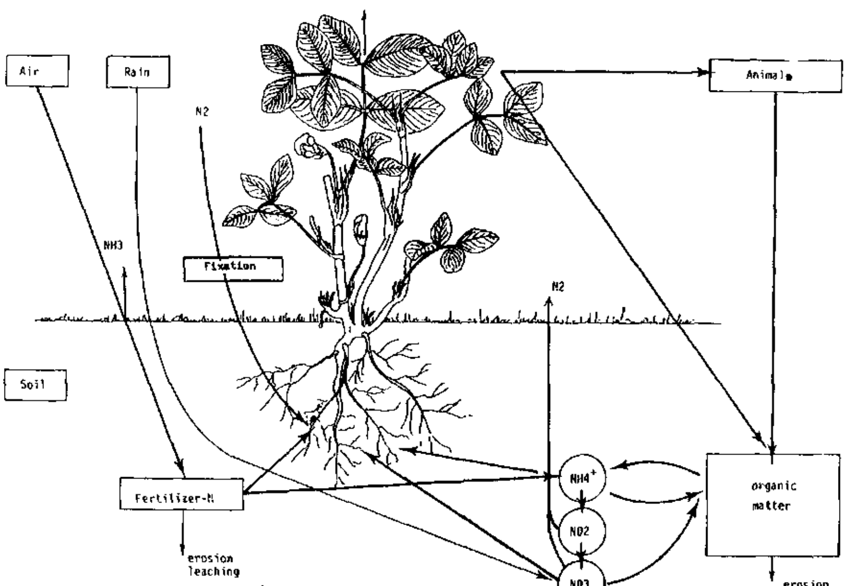

Figure 1. The nitrogen cycle.

I. THE NITROGEN NUTRITION OF PLANTS

1.1. Nitrogen uptake

Determination of nitrogen contained in plants at harvest enables estimation of the overall nitrogen balance between additions and removals and to calculate apparent fertiliser use coefficients. To determine periods of high nitrogen demand, study on nitrogen uptake fluctiations during the entire growing season was required. Two important phenomena have been revealed by these studies:

a. **Differences in uptake rates** between traditional and high yielding varieties of cereals (Table 1).

Table 1. Crop yield and Nitrogen uptake.

Crop (variety)	Yields (kg/ha)	N uptake (kg/ha)	N content of grains (%)	Maximum daily uptake (kg/ha)
Millet (local variety) SEFA, (Senegal)	3130	132	34	2.4
Sorghum (var. S29), SARIA (Burkina Faso)	3100	155	50	4.0
Upland rice (63-83), SEFA (Senegal)	3370	83	50	2.1
Rice (Taichung No. 1), SEFA (Senegal)	4240	74	68	3.5
Maize (ZM 10), SEFA (Senegal)	5440	138	71	5.0

Traditional varieties are long-stemmed with low grain-straw ratio and are late maturing. Their growth is slow which allows nitrogen to be taken up gradually. The daily needs are low enough so that soil supplied nitrogen is often sufficient. On the other hand, they make poor use of applied fertilisers (excessive straw production, lodging, etc.). Improved varieties in contrast have high requirements during periods of rapid growth and make efficient use of nitrogenous fertilisers.

b. **The effects of moisture stress on the lowering of nitrogen levels** in the aerial parts of the plant.

This effect is frequently noted in cereals as they mature, particularly in millet (Siband, 1981), sorghum (Gigou, in preparation) and upland rice (Chabalier, 1976). The fall in nitrogen levels in the aerial plant parts at harvest can reach 40% of the observed maximum at flowering.

Decreases can also occur during the growing period: Siband (1981) gives a spectacular example of this seen on millet in Senegal when a dry period occurred at the end of tillering (Fig. 2).

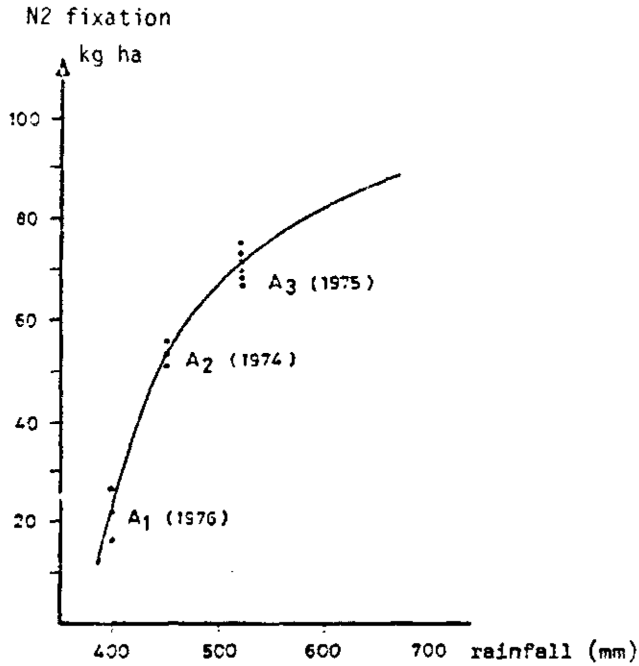

Fig. 2. Effect of 2 dry periods on N content of above ground parts of Millet (var. Souna III) in Senegal (after Siband 1981).

Wetselaar & Farquhar reviewed this subject in 1980 and believe that these losses can occur as soon as the quantities of nitrogen moving from vegetative to reproductive parts are greater than the amounts needed by the latter.

Various mechanisms have been envisaged to explain these "losses" which are distinctly higher than those which can be attributed to losses in vegetative material (leaf fall, etc.), such as:

- transfer soil-wards and storage in roots or excretion (with the possibility of denitrification in the rhizosphere),
- leaching by rain water, and
- gaseous losses from leaves.

It is difficult to evaluate the relative importance of these suggested mechanisms. These losses can probably be reducted by modifying the nitrogen fertilisation method, by choosing varieties less susceptible to these losses, or by changing certain cultural practices. Chabalier and Posner (1978) for example obtained the same grain yield with lower nitrogen uptake during vegetative stages by lowering plant densities.

1.2. Biological nitrogen fixation

Biological nitrogen fixation in groundnuts and soybeans have been extensively studied, particularly in Senegal in collaboration with ORSTOM and INRA, and with the help of IAEA.

Results of non symbiotic N fixation with cereals so far have been disappointing. Ganry (1983) found only a few kg/ha fixed in the rhizosphere of so-called "fixing" sorghum varieties (IRAT, Annual report for 1983, in preparation).

With flooded rice N fixation appear to be higher, especially for grey lower-slope soils in Casamance (Wetselaar and Ganry, 1982), but its control in intensive rice production has not yet been achieved.

Table 2. Effect of inoculation on N_2 fixation of groundnut, in 1975 with normal rainfall and in 1976 with severe drought (Ganry, 1980).

Year	Treatments	N uptake kg/ha		
		total	derived from N_2 fixation	derived from soil
1975	without inoculation	103	67	33
	with inoculation	118	84	32
1976	without inoculation	77	16	57
	with inoculation	77	26	49

Table 3. Effect of inoculation and fertiliser treatment on soybean yield N fixation and N-uptake from soil, and fertiliser in the aerial plant parts (Ganry and Wey, to be published).

Year	Treatment	Yield	N derived from		
		(kg/ha)	atmosphere	soil	fertiliser
		--------	--------(kg/ha)--------		
1973	without inoculation	2015	0	95	5
	with inoculation	2315	55	40	5
1980	17N + I	1280	55	42	3
	120N	1150	0	72	32
	17N + $22P_2O_5$ + I	1600	26	70	4

I = inoculation
N = nitrogen fertiliser
P = phosphate fertiliser

With groundnuts or soybeans, nitrogen fixation in Senegal often reaches 50/70 kg/ha and supplies 60-70% of plant nitrogen needs (Tables 2 and 3). However, this fixation is very susceptible to a number of limiting factors, including aluminium toxicity (Pieri, 1974), tillage (Wey and Obaton, 1978; Ganry, 1980), nematodes (Meyer, et al., 1982), phosphorus availability, etc., but above all drought considerably reduces fixation (Fig. 3). Symbiotic fixation can be reduced without the plant suffering physiologically, the nitrogen then coming from the soil.

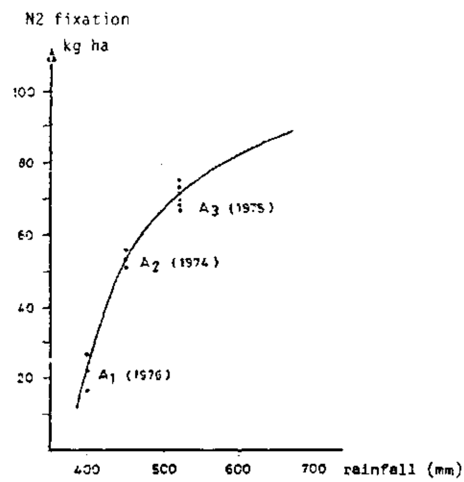

Fig. 3. Effect of rainfall on N_2 fixation by groundnut in Senegal (Wetselaar and Ganry, 1982).

Inoculation is necessary in a soybeancrop because of the absence of **Rhizobium japonicum** from numerous soils (Table 3). A small-scale fermentor, and inoculation techniques have been developed (Wey et al., 1982; Wey, 1983). In Senegal, where seed inoculation has resulted in poor germination, the soil is inoculated using an inoculum distributor on the seed drill (Wey, in preparation).

Groundnut inoculation can increase N fixation, but has no clear effect on yields (Table 2).

Legumes grown under suitable conditions can fix considerable quantities of nitrogen, but this nitrogen is exported in seeds and, particularly, in stems, and the effect of these crops on the improvement of soil nitrogen levels should not be over-estimated.

1.3. Plant use of fertiliser nitrogen

As a result of N15 studies, plant use of fertiliser nitrogen is now better known. Studies were done on cereals using urea or sulphate of ammonia. Most experiments combine fertiliser applications with residue restitution (incorporation of straw, compost or animal manures).

Studies of this type have been carried out in the Ivory Coast, on upland rice at Bouakê and on maize at Bouakê and Gagnoa (Chabalier, 1976; Chabalier and Pichot, 1978), in north Cameroons on sorghum (Gigou and Dubernard, 1978), and in Senegal on millet (Ganry and Guiraud, 1978). These field experiments, often supplemented by lysimeter studies, give remarkably uniform results; about 40-45% of the applied fertiliser nitrogen is found in the above-ground plant parts at harvest, and higher amounts may be found at flowering, when application rate and timing of application are well chosen.

Excessive applications lead to lower levels of utilisation, often 25-30%. Split application has given variable results. As a general rule, split applications become necessary as rainfall and levels of application increase.

Crops in succeeding years continu to utilize initial fertiliser application 4-5% in the second year, and 2-3% in subsequent years.

- One third of plant nitrogen is derived from fertiliser with normal rates of application. The soil supplies 2/3 of the nitrogen as immobilised nitrogen stimulates mineralisation.
- incorporation of straw, compost or farmyard manure lower use of fertiliser nitrogen (Table 4) without lowering the total nitrogen supply to plants. In the presence of organic matter, immobilisation and mineralisation are accelerated.
- the response of cereals to low rates of N application is about 20 kg of grain per kg of nitrogen applied, and increase linearly for most varieties up to 50-100 kg. Insufficient or irregular rains can reduce these responses.

Table 4. Utilisation of fertiliser nitrogen by Souna III millet in a dry year at Bambey, Senegal (Ganry and Guiraud, 1974, unpublished).

Treatment		Yield dry grain (kg/ha)	Amount of N (kg/ha)		True utilisation coefficient (%)	
			grain	total	grain	total
60N	without compost*	2300	59.4	111.7	21.2	39.2
	with compost	2100	58.2	96.2	17.6	36.4
120N	without compost	1900	57.2	96.3	12.7	27.6
	with compost	2200	61.2	138.5	11.1	27.6

* compost applied at 10 t/ha of dry matter. Nitrogen half broadcast at bolting and half at tasseling.

1.4. Crop residue recycling

The need to recycle

At harvest, one third of sometimes even one half of the nitrogen is in the crop residues (stalks, leaves, etc.). These residues are therefore a source of nitrogen which must be carefully managed. They also contribute to the maintenance of soil organic levels, which provide the soil nitrogen reserves and which often have a tendency to fall rapidly.

In addition, residue recycling supplies P, K, Ca and Mg and also slows down the lowering of pH; these effects appear to be most important (Pieri, 1983; Pichot et al., 1976; Velly and Longueval, 1976).

The management of crop residues at harvest form an important source for soil fertility, nitrogen and other nutrients.

Amounts available

Not all the harvested residues are available for recycling, part is used for construction, animal feed or fuel particularly in areas where firewood is scarce, such as in the Mossi plateau in Burkina Faso (Sedogo, 1981).

Stems of groundnuts and cowpeas are used for animal feed in the Soudano-Sahelian region, and are therefore essential parts of the harvest.

Investigations in various parts of Senegal (Allard et al., 1983) have shown that availability is very limited in the northern part of the country, where animal feeding in the dry season is a problem. Crop residues are more available in the wetter areas (Table 5).

Residues can be recycled by burning, direct incorporation, conversion by animals to manure or by aerobic or anaerobic composting, or can be used as mulch.

With burning virtually all the nitrogen is lost. Nitrogen recycling in mulch is little studied by IRAT scientists. The results of numerous studies on incorporation, animal conversion and composting are summarized below.

Straw incorporation

Following incorporation of the straw in the soil, major transformations of mineral nitrogen and "nitrogen hunger" are expected, but this was not generally observed, except in special cases, involving heavy applications of straw with very low nitrogen content and without nitrogen fertiliser application (Gigou, 1982; Sedogo, 1981).

With straw applications of 3-5 t/ha, equivalent to normal harvests and particularly with repeated applications, the effects on yields are modest and generally positive (Chabalier, 1976; Chabalier and Pichot, 1978). The favourable effects become more marked with incorporation for many years (Table 6), although this effect is not due to nitrogen alone. Chabalier (1976) estimates, that nitrogen contribution from straw can reach 15 kg N/ha.

A toxicity problem due to phenolic compounds present in millet and sorghum straw which affect germination has been reported in Senegal (Burgos-Leon et al., 1980; Ganry et al., 1978b). It occurs only in sandy soils, and is short-lived in a moist soil.

Straw incorporation despite its advantages poses a practical problem. It is very difficult to incorporate straw with animal traction. It therefore requires mechanisation.

Table 5. Current use of crop residue in three areas of Senegal (Allard et.al.).

	North central groundnut basin	South central Sine - Saloum	South Casamance
Average rainfall (mm)	500 - 700	800 - 1000	1000 - 1500
Years of observation	1978 / 1979	1979	1980
Amounts of straw, produced by the main crops (tons/ha)			
Groundnut tops	0.5-1.0 / 0.7-1.2	0.7-1.7	0.2-0.8
Millet stover	1.0-2.0 / 0.7-1.7	1.4-3.0	0.8-4.0
Maize stover	-	-	1.5-5.0
Sorghum stover	-	-	1.0-2.7
Rice straw	-	-	0.1-0.9
Current usage and surpluses			
Groundnut			
Proportion collected	100%	100%	100%
Use	animals	animals - sale	animals - sale
Surplus	0	0	0
Pearl millet			
Proportion collected	50 - 100%	10 - 15%	< 10%
Use	animal - domestic consumption	domestic consumption	domestic consumption
Surplus	0	1 - 2.5 t/ha	1 - 2.5 t/ha
Sorghum and maize			
Proportion collected	-	-	< 10%
Use	-	-	domestic consumption
Surplus	-	-	maize 1-4 t/ha sorghum 0.8-2.5 t/ha

Table 6. The effect of repeated straw incorporation (5 t/ha/year) and nitrogen (N1: 60 kg N for rice, 100 kg N for maize) on yields of upland rice, maize and yams in the central Ivory Coast on gravelly ferrallitic soils (Chabalier, unpublished).

Treatment Yields of grains or tuber, t/ha

Nitrogen	straw	1969 rice	1970 maize	1971 rice	1972 maize	1973 rice	1974 maize	1975 rice	1976 maize	1977 rice	1978 maize	1979 rice	1980 maize
N0	without	1.06	3.1	1.85	3.6	1.06	3.20	1.70	4.68	1.89	4.27	12.1	1.75
	with	1.04	2.9	1.86	3.5	1.43	4.00	2.00	5.25	2.24	4.47	16.6	2.65
N60	without	1.07	3.2	2.48	5.8	1.16	4.80	2.00	5.32	2.04	4.63	14.6	3.78
	with	0.91	3.5	2.56	5.9	1.42	5.20	2.50	6.22	2.27	4.76	16.5	4.13

Conversion by animals

Conversion of crop residues by animals is traditionally practiced by nomadic tribes in the dry season. This utilisation is important and gave given rise to contracts between cultivators and pastoralists. However, no quantitative information on its effects on soil fertility is available.

The manure produced in kraals where sedentary herds are kept, often called "poudrette", is a mixture of droppings and soil with a variable composition and is often of limited agricultural value (Table 7). Very little information is available on this product (Pieri, 1983) although it is widely used in some regions (e.g. San and Segou in Mali).

Table 7. Comparative effect of anaerobic compost and manure on millet yields in Senegal (Allard et al., 1981).

Treatment	Yields of Souna III millet	
	cobs kg/ha	stems and leaves kg/ha
without organic amendments	1800	4900
with 3 t/ha of manurel	1900	5200
with 3 t/ha of anaerobic compost	2200	5800

It is possible to produce good stable manure with less soil in it, mixed with vegetative material. Ganry and Guiraud (1978) have shown the value of incorporating the manure in reducing nitrogen losses and slowing down organic matter mineralisation.

The importance of manure in maintaining soil fertility is demonstrated by the results of the long term experiment of Saria, carried out since 1960, which shows the superiority of the manure treatments (fig. 4).

Composting

Two composting techniques have been studied:

- aerobic or semi-aerobic composting which involves the production of additional manure from straw (chopped or uncut) with addition of small amount of animal amount
- anaerobic or methane producing composting method which produces biogas.

Numerous trials have used aerobic compost as a substitute for animal manure which was not available in sufficient quantities. This technique does not appear to be practical under farmers conditions.

Sufficient time should be allowed for aerobic composting. Results of studies in Senegal with chopped millet straw showed a loss of 25-50% of the initial nitrogen content during in the first 60 days (despite a relative enrichment of the compost in nitrogen due to the more rapid loss of carbon). Afterwards the nitrogen content increased by N2 fixation to levels equal or slightly higher than the initial level after about 150 days. As the compost is naturally well supplied with N-fixing micro-organisms, inoculation does not result in any noteworthy improvement (Ganry et al., 1979; Ganry and Bertheau, 1980).

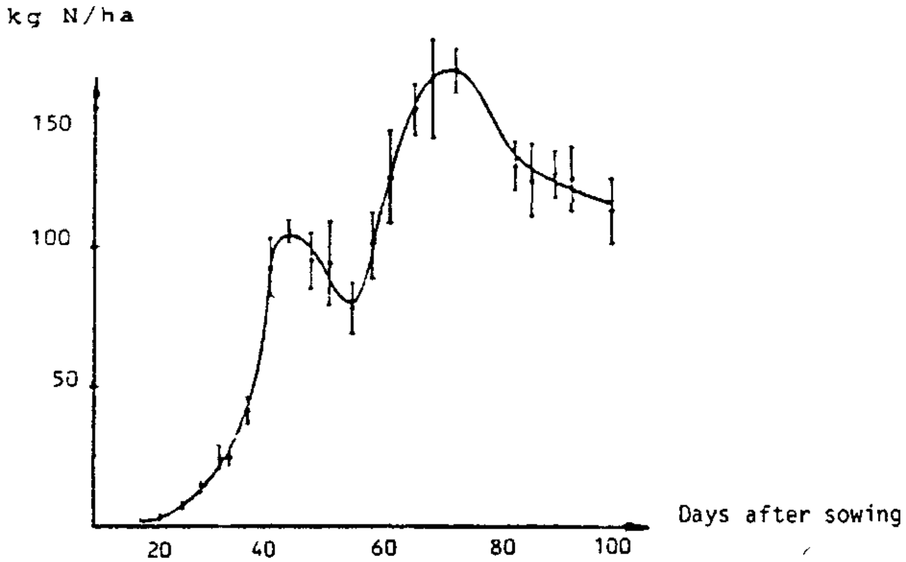

Fig. 4. Sorghum yield in long term experiment in Saria (Burkina Faso) with different treatments (T : Control, fm : low rate of mineral fertilizer, FM : high rate of mineral fertilizer, EV : green manure, fm + r : fm + crop residues ploughed in, FMO : fm + 5 t/ha/year farmyard manure, FMO : FM + 20 t/ha/year farmyard manure). (Pichot et al., 1981).

It is therefore advisable to allow composting for at least 150 days with chopped straw and for longer period with whole straw.

For several years there is a renewed interest to link composting with biogas production, due the high fertiliser prices and need for energy production.

Anaerobic composting modifies the straw only to a very small extent (Table 8). Although in laboratory experiments addition of compost and straw tends to immobilise nitrogen (fig. 5), this phenomenon is not evident in field trials (Table 9).

Addition of compost has a favourable effect in long term trials particularly on poor soils. At Gagnoa, in Ivory Coast on a fertile soil it was only after four years of cultivation that addition of compost had a noticeable effect on crop yield (Table 10), though it subsequently became very important.

Table 8. Composition of aerobic and anaerobic compost as compared with that of sorghum straw and cattle manure (Sedogo, 1981).

Raw sorghum	Anaerobic straw	Aerobic compost	Cattle compost	manure
Carbon (%)	39.4	42.2	32.5	21.7
Total N (%)	4.23	5.19	7.62	14.74
C/N	93	81	43	15

Table 9. Comparative effects on sorghum yields at Saria, Burkina Faso, of aerobic and anaerobic compost, sorghum straw and manure (Sedogo, 1981).

Treatments	Sorghum yields, kg/ha	
	without nitrogen application	with 60 kg N as urea
without organic application	1831	2796
10 t/ha sorghum straw	1652	3427
10 t/ha manure	2409	3591
10 t/ha aerobic compost	2505	3688
10 t/ha anaerobic compost	2304	3601

Table 10. Influence of compost (10 t/ha/year, dry matter) and/of nitrogen applications on the yield of first season (March-June) maize at Gagnoa, southern Ivory Coast.

Treatment		Maize grain yields (t/ha)										
Nitrogen	Compost	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
N0	without	4.75	6.42	5.60	4.05	3.20	1.52	1.00	2.64	2.11	1.69	2.09
	with	4.96	6.30	5.70	5.41	4.04	3.20	4.20	5.59	3.43	4.71	5.28
N60	without	4.70	6.46	5.20	5.10	3.79	3.07	2.50	3.84	3.78	3.82	4.37
	with	5.37	7.37	6.10	5.14	4.93	4.91	5.70	5.38	4.54	6.18	6.33
N160	without	5.03	7.38	5.60	4.22	4.43	4.83	5.20	5.21	5.34	5.88	6.10
	with	4.17	6.92	5.70	5.99	4.77	6.17	6.30	5.46	5.71	5.90	6.69

Uniform annual fertiliser application: 100 kg P_2O_5, 150 kg K_2O plus 100 kg/ha dolomitic limestone.

Compost application: 10 t/ha of dry matter equivalent to about 170 kg N.

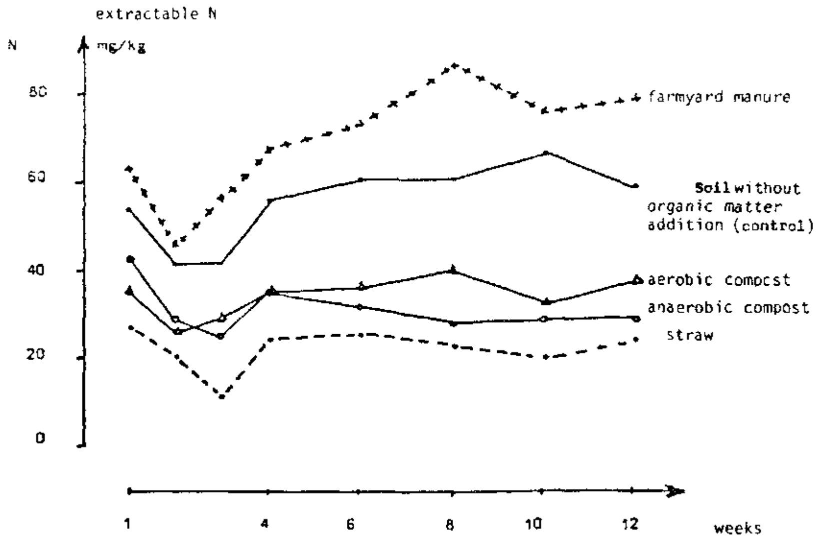

Fig. 5. Extractable N content of soil during incubation with different organic amendments (addition of 350 mg Carbon/100g soil with 50 ppm Nitrogen-fertiliser) (Sedogo 1981).

II. SOIL NITROGEN CHANGES

2.1. Mineral nitrogen status

Investigation on soil nitrogen transformations during the cropping season was undertaken to understand the effects of split nitrogen application. Measurements of KCl extractable nitrate and ammonium were made for several years in Senegal, the island of Réunion, Niger, the Ivory Coast, the Cameroons and Mali. The results brought to light certain aspects which differ from temperate region.

(1) Soil moisture is the main factor affecting nitrogen production, while temperature is never a limiting factor (except of high altitudes), and
(2) in very acid soils nitrification does take place, however large amounts of ammonium nitrogen are often found.

For regions with monomodal rainfall and a long dry season, Gigou (1982) described the changes in mineral nitrogen status for a full annual cycle in four phases.

(a) At the beginning of the wet season the reactivation of microbial activity, involves the mineralisation of nitrogen contained in the easily decomposable organic compounds, but also the utilisation of this mineral nitrogen by microorganisms when easily mineralisable carbon is abundant. Soil N levels will rise rapidly (with a mineralisation flush) if the plant residues in the soil are rich in nitrogen (as when the preceding crop is a legume or a green manure) or decline when the plant residues low in nitrogen are present following maize or sorghum. During this first phase, nitrification is generally active and downward movements can be important.

(b) During the period of regular rains soil mineral nitrogen levels are very low due to plant uptake, low mineralisation rate and often immobilisation (Ganry & Wey, in preparation). Nitrification has virtually stopped.

(c) At the end of the rainy season and the beginning of the dry season, net mineralisation occurs again, particularly if the soil is cultivated. Nitrification occurs as long as the soil is moist, but when the soil has dried up ammonium nitrogen may build up. Crops such as cotton which complete their cycle in this period, will take up nitrogen and dry up the soil more rapidly leaving only very low levels of mineral nitrogen in the soil.

During the dry season, nitrogen levels change very little.

This description involves a considerably modification of previously held ideas, on nitrogen evolution at the beginning of the rains, which does not always involve a flush of mineral nitrogen. It raises questions on nitrogen nutrition during the rainy period when there is hardly any mineral soil nitrogen, ammonification is very low and nitrification has stopped, but plants grow rapidly and take up large amounts of nitrogen. This poses an unresolved problem.

The investigations also should several important aspects of nitrogen uptake:

- in general plants prefer NO_3, but can use NH_4. Rice even prefers NH_4 (Chabalier, 1976). In contrast, millet needs a little nitrate at flowering without which the heads do not form well.
- nitrification in the rhizosphere has been noted for millet by Siband (1981), who described a variety lacking this characteristic, which has low nitrate content even though containing large amounts of NH_4.
- uptake of nitrogen in soluble organic forms. Velly et al. (1980) found in KCl extracts used to measure NH_4 and NO_3 considerable amounts of organic nitrogen. Using N15 they were able to verify that in pot experiments plants use all the KCl extractable forms. Pichot et al. (1981) also found good correlation in long term field trial between KCl extractable nitrogen and sorghum yield.

Mineral nitrogen determinations could be used to determine the crop fertiliser nitrogen needs. Encouraging results were obtained in North Cameroon with nitrate determinations at the beginning of the rainy season, a period of active nitrification (Gigou, 1982) for producting N requirement. In other conditions it would perhaps be better to use total KCl extractable nitrogen.

2.2. Evolution of organic nitrogen forms under cultivation

Measurement of "mineralisable" nitrogen by bacteriological incubation has been employed, to show fertility differences due to soil treatments (Chabalier, 1976; Velly and Logueval, 1976). A more detailed approach has been tried by fractionating organic nitrogen by acid hydrolysis (6N HCl). In long term trials, it was possible to observe:

- an increase in the ratio of hydrolysable and distillable N / total N as the mineralisation capacity of the soil decrease.
- a decrease in non-hydrolisable nitrogen in soils not receiving organic residues.

2.3. Nitrogen losses

Losses from erosion, runoff and leaching

Orstom has made numerous measurements on N losses from erosion and runoff. Roose (1981) for example gives loss values under maize of 5 kg/ha at Adiopodoumé and 11 kg/ha at Korhogo.

Leaching losses concern essentially nitrates, and possibly urea, immediately after application. They have been studied in lysimeters or by soil solution sampling in association with water movement studies. Chabalier (1984) found a good agreement between results obtained by the two methods despite problems of heterogeneity (Pieri, 1983).

In the humid region losses can be considerable (Roose, 1981) but these results can not be extrapolated to other areas. In Soudano-Sahelian regions, even on very sandy soils, losses are limited due to the low volume of drainage water, dense crop root development and above all by low nitrate levels in the rainy season. N losses average 5-15 kg/ha at Bambey, and are higher under groundnuts than millet (Pieri, 1983).

In the humid zone at Bouaké and Gagnoa, losses are much higher (Table 11) with very little direct loss of fertiliser nitrogen.

Table 11. Results of lysimeter studies at Bouaké and Gagnoa on fertiliser-N losses under cultivation (Chabalier, 1978).

Location	Bouaké		Gagnoa	
Year	1973	1974	1973	1974
Crop	Upland rice	Maize-cotton	Maize-maize	Maize-maize
Rainfall/drainage (mm)	960/350	1213/340	1500/500	1340/380
Fertiliser (kg N/ha)		60 120	160 320	100+100
100+100				
Total N loss (kg/ha)	56 71	57 99	120	160
Loss of fertilizer N applied in 1973 (kg/ha)	1 6	1.8 3.6	4	6
Rate of removal	0.35 cm/mm percolating water		percolating water	0.50 cm/mm

Losses due to NH_3 volatilisation

These losses occur at basic pH levels. They can also occur in acid soils with surface application of urea to a soil with low moisture content, since NH_4OH formation raises the pH of the soil close to the urea granules. In a sandy soil, Ganry (1983) lost up to 45% of urea applied in this way. Incorporation of urea in the soil is used to prevent such losses.

2.4. Incorporation of fertilisers nitrogen in soil nitrogen

Nitrogen applied as urea is rapidly hydrolised to NH_4. Ammonium nitrogen from fertilisers mixes with the mineral nitrogen of the soil and follows the normal evolution, i.e. nitrification, absorption by the plant and immobilisation. Nitrates, little used in tropical agriculture will mix with soil nitrates in a similar way.

Fertiliser nitrogen generally remains as mineral soil nitrogen for 1-2 months, but the speed of transformation is variable. Chabalier (1976) noted a slow immobilisation after the first application and a rapid transformation following the second application, which was compensated by high rate of mineralisation of soil nitrogen. Gigou (1982) noted major differences in the Cameroons related to rainfall. About half of the fertiliser nitrogen is commonly incorporated as soil organic nitrogen. The preference of micro organisms for NH_4 immobilisation has been confirmed by Chabalier (in preparation), who found that 60% and 28% of nitrogen supplied by urea and calcium nitrate respectively was immobilised. Recently immobilised nitrogen remains in a form easily utilised by plants (Oliver et al., 1978). Thus, incorporation of fertiliser nitrogen into soil nitrogen is an important phenomenon which removes the applied nitrogen from the risk of loss without preventing its use by plants. This very favourable effect must be carefully analysed: as is observed in the Ivory Coast, it provokes a high rate of mineralisation of soil nitrogen, which might be lost.

This source of organic nitrogen is ephemeral, as regular application of fertiliser nitrogen does not much increase organic levels.

2.5. Soil incorporation of organic residues

When a soil is cultivated, its organic matter content tends to decline rapidly initially and then decrease slowly (Siband, 1974). Applications of farmyard manure or compost always have marked effects on soil organic matter levels as compared to the control. However, the effect varies, application of 10 tons/ha/year of compost is not enough to maintain organic levels at Gagnoa. On the other hand, it is enough for Maroua (Gigou, 1982) or for Bambey, and application of groundnut shells, composted or not, can even raise soil organic level (Feller et al., 1981-82).

Combined application of both straw and nitrogen has a very marked effect on soil organic matter levels in pot experiments (Guiraud et al., 1980; Oliver et al., 1978; Pichot & Egoumenides, 1981). This effect was also found in the field in high altitude tropical conditions (Velly & Longueval, 1976) and in rice fields (Traore, 1974). However, this effect has not been found in the field at low altitude. Application of 10 tons/ha of straw annually or every second year has no measurable effect on soil organic matter levels. This result, confirmed by numerous trials involving rain-fed crops, seems organic matter (Gigou, 1982). There are however a few exceptions involving very poor soils (Pichot et al., 1974). Acid hydrolysis has shown, that compost or farmyard manure increases mainly the hydrolysable but non distillable fraction (Sedogo, 1981). Feller et al. (1981-82), preferred to use a granulometric fractionation of the organic matter for sandy soil showing, that it is the free < 2 mm organic matter which provides short term storage.

III. NITROGEN BALANCES

A seperate knowledge of each of individual changes does not provide an indication of the total change. For this reason, whenever possible a nitrogen balance is worked out, incorporating all the variations measured. In theory, these calculations should allow us to determine modifications in the forms stored, e.g. organic nitrogen levels. However, the different components are known only with low degree of accuracy. Best known are those related to fertiliser use by plants (total uptake, crop exports, use of fertiliser derived nitrogen, symbiotic fixation, and returns in residues). Other components, although measurable, are often little known or not determined:

- leaching losses, whose estimation is often very approximate (except in lysimeter studies).
- erosion losses, which vary greatly according to site and which can hardly be measured in a nitrogen trial. It is better to limit losses by tight erosion control measures, which were not always applied in established trials.
- additions in rainfall which do not vary greatly (5-10 kg/ha/year). These can often be ignored.

Other components not known are:

- free fixation or fixation in the rhizosphere, often negligible.
- losses to the atmosphere among which only NH_3 volatilisation can be measured. Biological or chemical denitrification in the soil and losses from leaves can not be measured easily, and their order of magnitude is not known, though they are not always negligible.

One cannot calculate, on the basis of these imprecise facts, an exact nitrogen balance, on the other hand, comparison of calculated changes with those actually observed can be used to estimate errors in our calculations.

Long term trials lend themselves well to make estimates of N balances but the lack of certainly regarding variations in soil nitrogen storage levels is great, even with very good analyses (0.01% N represents 25 kg/ha N to a depth of 20 cm). Deep ploughing is also a source of error in as much as it changes the distribution of soil nitrogen.

The following three examples illustrate the different uses of nitrogen balances:

- Measurement of balances for fertiliser derived nitrogen applied to lysimeters using N15 (Table 12). In lysimeters, leaching losses are known and there is no erosion. The non recovered portion corresponds to the nitrogen retained in the lower horizons and to that lost to the atmosphere.
- Measurement of nitrogen balance under a millet-groundnut rotation in Senegal. The calculated deficit (160 and 140 kg) was subsequently compared with changes in stored nitrogen as estimated by analysis (120 kg in 4 years). The close agreement supports the results.
- Measurement of nitrogen balance for 5 years at Sanguere in northern Cameroons. The change in stored nitrogen in the 0-40 cm layer is markedly different from the balance of inputs and exports. This difference, or deficit, gives an indication of losses.

TABLE 12. Balance sheet (kh/ha) for fertiliser nitrogen applied to rice in lysimeters at Bouaké (Chabalier, 1978).

	Rates of nitrogen applied	
	60 N	120 N
Used by: year		
rice (1st season)	16	28
maize (2nd year, 1st season)	3.6	7.2
cotton (2nd year, 2nd season)	0.5	0.7
	20.1	35.9
leaching loss	2.8	9.6
immobilisation (in the soil)	24.5	38.4
total recovered	47.4	83.9

CONCLUSIONS

During the last 20 years the use of N15 has increased our knowledge of the fate of fertiliser nitrogen in tropical agrosystems, and has allowed us to quantify symbiotic fixation. Our understanding of transformations occurring in the soil nitrogen cycle has improved considerably. Two aspects still lack information nl.: (1) losses of nitrogen to the atmosphere, and (2) mechanisms envolved in plant nitrogen nutrition during the rainy period.

The results of long term trials show the importance of crop residues, manure or compost, in the maintenance of soil fertility. They have also shown how difficult it is to maintain high levels of organic matter. These results suggest a better utilisation of organic residues, the more so where chemical fertilisers are little used.

Composting, at a country wide scale (urban and industrial residues) or at the farm or even the plot level, should be profitable.

Finally, to achieve efficient agricultural use of nitrogen it is necessary to take into account the whole cropping system, and the following stems are particularly important: (1) energy production (establishment and management of firewood plantations, biogas...), (2) use of organic residues (animal feed, energy, soil improvement, collection problems, etc.), (3) reduction of leaching losses (early sowing, cereal-legume associations, green manures), (4) estimation and reduction of losses to the atmosphere (particularly denitrification and losses from leaves), (5) erosion control, in which there is a renewal of interest, and (6) finally the introduction of new legumes (for example, forage legumes), which can reduce fertiliser needs but may raise problems of integration into farming systems.

It should be strongly emphasised that the establishment of intensive production systems in which nitrogen and organic matter levels would remain stable remains a major research objective for African agriculture.

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NITROGEN MANAGEMENT IN ALLEY CROPPING SYSTEMS

KEY WORDS : Crop response Green manure Nitrogen yield
Woody legumes.

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SUMMARY

Although nitrogen is known to be a very important element for increasing food crop production in the tropics, use of fertilizer nitrogen is limited in many areas of the tropics due to high cost and lack of availability. Hence the need to find technically feasible and viable alternative nitrogen sources for the resource poor farmers, in order to reduce dependency on commercial fertilizer nitrogen. There is a great deal of interest in recent years to use woody leguminous species as potential nitrogen source due to their high nitrogen fixing capacity. Woody legumes grown in hedgerows can be succesfully intercropped with food crops in alley cropping systems. Regular prunings of the woody legumes produce large quantities of green manure for the companion food crops. Leucaena leucocephala and Gliricidia sepium grown in 4 m spaced hedgerows on an Alfisol can produce over 200 and 100 kg N/ha/year with five prunings respectively.

Use of woody legumes in alley cropping with food crops need therefore be recommended for adaptation by farmers in the tropics as a low input but stable method of food farming.

INTRODUCTION

Nitrogen is an important nutrient in crop production. For the last three decades fertilizers have contributed significantly in expanding the global food production. Increasing use of nitrogen fertilizer during 1950 to 1974 for example resulted in doubling cereal grain production during that period (Hardy, 1975). In order to meet the ever increasing food requirement to feed the ever-increasing population in the tropics, it can therefore be expected that nitrogen will assume a more important role in food production in this region in the future.

In the traditional system, farmers mainly rely on a long fallow period to regenerate the fertility of the land exhausted during the cropping period. The bush fallow- crop production rotation is known to be ecologically a stable system where a long fallow period is feasible. When the fallow period becomes too short as observed in areas with high population densities, either fertilizers have to be used or soil improving species have to be included in the production system. High fertilizer costs, particularly that of nitrogen fertilizer (most energy intensive for production) and lack of availibility in many developing countries (Mudahar and Hignett, 1982) will limit their use by many traditional farmers. In addition low activity clay Alfisols and related soils widely distributed in the tropics are also known to be prone to soil acidification with continuous usage of high rates of fertilizer nitrogen (Bache, 1965; Bache and Heathcote, 1969). Thus the need to find technically feasible and economically viable alternative nitrogen sources in order to reduce dependency on commercial fertilizers. This can be done by either inclusion of leguminous species in intercropping or by rotation in the production system. This has led in recent years to an increased global interest in utilizing woody species as source of green manure and also to provide fuel for the energy starved rural and urban areas in the tropics (Brewbaker et al., 1982; Dommergues, 1982a; Kang et al., 1981b; NAS, 1979; NAS, 1980; Rachie, 1983; Roskoski et al., 1982; Nair, 1984). In order to make use of the many benefits that can be obtained from inclusions of woody species in crop production system, Kang et al., (1981b) has developed the alley cropping system. Observations made thus far have shown good promise for the use of alley cropping as a low input, stable and more productive alternative to the traditional bush fallow system.

FIGURE 1. Alley cropping maize with Leucaena leucocephala. Hedgerows spaced 4m. apart.

INTERCROPPING WITH WOODY SPECIES AND ALLEY CROPPING

Intercropping of woody species with crops in various forms which is also called agroforestry is widely practiced by traditional farmers in the tropics (CATIE, 1979; Huxley, 1983; McDonald, 1982). This old practice which is practiced for various reasons, despite its potentials is still a much neglected area of research and needs a lot of quantification to improve its productivity (Budowski, 1982). There is substantial evidence to show that intercropping can result in higher productivity, better control of environment and safeguard against unfavorable conditions. Rachie (1983) also indicated that proper inclusion of woody species in cropping systems can offer many advantages at little or no expense.

Judicious use of woody legumes for example can aid in recycling of plant nutrients and water from deep soil layers and provide mulch and green manure that will contribute biologically fixed nitrogen to the companion crop. Partial shading aids in weed suppression and provides favourable conditions for acitivities of micro- macro- organisms and in addition also aid in soil conservation, provides browse, human food staking material and firewood (Douglas, 1972; Bishop, 1978; Kang et al., 1984; Prussner, 1983; Rachie, 1983; Sumberg, 1984; Wilson and Akapa, 1981).

Results of recent intercropping studies of food crops with woody leguminous species have shown high compatibility of certain species such as Leucaena leucocephala with food crops (Kang et al., 1985; Guevarra, et al., 1978; Rachie, 1983; Redhead et al., 1983). Intercropping with leucaena has either only a slight effect on maize yield (Rachie, 1983) or improved maize yield (Guevarra, 1976). Kang et al., (1985) also showed that leucaena extracts moisture from deeper soil layers than maize.

In alley cropping systems (Kang et al., 1981b; Wilson and Kang, 1981), food crops are grown in alleys formed by hedgerows of trees and shrubs (Figure 1). The hedgerows are cut back and periodically pruned during cropping to prevent shading and reduce competition. When there are no crops, the hedge rows are allowed to grow freely to cover the land. Trees and shrubs grown in the hedgerows still provide the basic advantages of inclusions of trees and shrubs in the bush fallow system. The alley cropping has an additional advantage over the traditional bush fallow system, as it allows the cropping and fallow phases to be brought together and made concurrent on the same land. This cropping system will allow cropping for an extended period without reversing the land to bush fallow; this can reduce the amount of land required for agricultural production.

LEGUMINOUS GREEN MANURE TREES AND SHRUBS

The majority of the tropical legumes are woody perennials many of which are nitrogen fixing (Brewbaker et al, 1982). For their international network trials Brewbaker et al., (1982) listed over ten species as good green manure sources a.o. *Acacia* and *Albizia* spp., *Calliandra callothyrsus*, *Gliricidia sepium*, *Leucaena diversifolia*, *Leucaena leucocephala*, *Mimosa scabrella* and *Sesbania grandifolia*. A great deal of variability exists in the potential of woody leguminous species and cultivars to fix nitrogen (Dommergues, 1982a; Roskoski, 1982). Table 1 gives a rough estimate of N_2-fixed by woody legumes as compared to herbaceous species and N_2-accumulation in young developing forest.

Table 1. Estimates of N fixed by selected woody and herbaceous legumes in the tropics.

Species	N fixed (kg/ha/yr)	References
Woody species		
Leucaena leucocephala	500-600	Guevarra et al., 1978
Acacia mearnsii	200	Orchard and Darby, 1956
Herbaceous species		Nutman, 1976
Chick-peas	103	
Clover	45-673	
Cowpeas	73-354	
Groundnut	72-124	
Guar	41-220	
Lentil	88-114	
Lucerne	56-463	
Clycine	145-208	
Pigeonpea	168-208	
Soybeans	55-168	
Tropical forest	100	Greenland and Nye, 1979

Among the woody species, Leucaena leucocephala shows high amount of N*-fixation. Harvested every three months and grown with favourable year round conditions in Hawaii, Guevarra et al., (1978) reported high values of N_2- fixation for Leucaena leucocephala from 500 to 600 kg N/ha/year. Grown as forage in areas with 1000 mm rainfall in Australia nine months old Leucaena leucocephala can fix 575 kg n/ha (Hutton and Bonner, 1960). Because of its high potential as nitrogen and firewood sources, leucaena is therefore also the most studied among the woody legumes (IDRC, 1983; NAS, 1977 and Oakes, 1968). Another good producer of green manure is Acacia mearnsii which is widely adapted and has been introduced to many parts of the tropics, including east Africa (NAS, 1980).

Due to its fast growth, leucaena can produce large amounts of green manure during a short period. Rachie (1983) reported, that four months old leucaena grown at a population of 50,000 plants/ha at Cali, Columbia can yield a total of 172 kg N/ha in the tops (leaves and branches).

Table 2. Nitrogen yield of four woody species alley cropped with food crops and grown on Egbeda sandy loam (Oxic Palustalf) in southern Nigeria (B.T. Kang, unpublished).

Treatment		Acioa barterii	Alchornea cordifolia	Gliricidia sepium	Leucaena leucocephala	Mean
		--------------------(Kg N/ha/yr)--------------------				
2m spacing	F_1	41.4	87.3	165.0	244.6	134.6
	F_2	35.6	100.2	153.0	255.2	136.2
4m spacing	F_1	19.1	71.7	127.0	215.4	108.3
	F_2	18.6	78.3	114.7	217.0	107.2
Mean		28.7	84.3	140.0	233.1	

LSD.05 Between species mean 27.2; Between treatments mean 12.1; Between treatments within same species 24.2; Between treatments for different species 34.3.

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* Spacing between hedgerows; Fertilizer applied to associated maize crop at following rates, F_1 = 45-20-20; and F_2 = 90-40-40 kg/ha of NPK.

Loppings of woody legumes in alley cropping also produce high nitrogen yield (Table 2). Leucaena leucocephala and Gliricidia sepium as expected have higher nitrogen yield than the non legumes Alchornea cordifolia (Euphorbiaceae) and Acioa barterii (Rosaceae), which are widely grown in traditional fallows in tropical Africa. High nitrogen yield is obtained with closer spacing of the hedgerows (Table 2). Data from long term alley cropping trials carried out on an Apomu loamy sand at Ibadan, Nigeria, over a six years period also show that leucaena hedgerows can withstand repeated prunings and still copice well (Kang et al., 1985). In this study, with five annual prunings yearly, leucaena hedgerows spaced 4 m apart produces over 160 kg N/ha/year. Use of woody legumes in alley cropping have a distinct advantage over the use of herbaceous legumes in rotation systems as the hedgerows remain productive for a longer period.

Pathak and Patel (1982) showed, that the amount of biomass and thus N- yield production of leucaena depends on pruning height. Cutting the plants between 15 to 30 cm produces twice as much shoot than pruning the plants at ground level. Recent observations at Ibadan, Nigeria show, that N- yield of prunings of leucaena hedgerows planted at 2 m interrow spacing and alley cropped with maize is significantly affected by prunings height and frequency (Table 3). Higher pruning height and less frequent pruning result in higher N- yield of the hedgerows in alley cropping system. Rachie (1983) indicated, that prunings stimulates regrowth and nitrogen fixation in leucaena and other legumes. Roskoski et al., (1982) in a field study with Inga junicuil in Mexico also reported marked increases in nitrogen fixation following defoliation and with new leaf production.

Table 3. Effect of height and frequency of prunings of Leucaena leucocephala hedgerows on N- yield of loppings (leaves and young branches), (B. Duguma, unpublished data).

Pruning height (cm)	Pruning frequency Monthly	Bi-monthly	Mean
	-----(kg	N/ha)-----	
25	37	58	48
50	45	69	57
75	51	91	71
100	57	88	72
150	57	100	79
Mean	49	81	

LSD.05 Between pruning height mean, 16
Between pruning frequency means, 11
Between pruning frequencies for same pruning height, 23
Between pruning frequencies for different pruning heights

Although most woody legumes suitable for green manuring do well on the less acid soils, there is a need to breed and select species and varieties that will perform well on acid soils. Some promising results were mentioned by Hutton (1983) on the breeding and selection of leucaena for acid soils. It should also be mentioned as stressed by Benge (1983) that woody legumes as any other trees require proper nutrition to maximize production and sustained yield.

GREEN MANURING AND NITROGEN REQUIREMENT IN ALLEY CROPPING SYSTEM

Green Manuring

Use of loppings from leguminous trees and shrubs as green manure is a very old practice. Loppings of *Sesbania grandiflora* e.g. are commonly used as green manure source in rice production in Asia. Farmers in the savanna region of West Africa have utilized the litterfall under the canopy from *Acacia albida* as nitrogen source for peanuts and millets (Dancette and Poulain, 1969; Felker, 1978). Dommergues (1982b) indicated that the benefit from *Acacia albida* is not due to N_2 fixation but due to concentration of soil nutrients from deeper soil horizons and accumulation of wind blown organic residues near the trunk. However, Felker (1978) mentioned, that improved crop yield under the canopy is due to N_2 fixation.

Despite the increase in recent years in using loppings of woody leguminous species as green manure in crop production, information from field trials is still limited. Prussner (1983) quoted results from the Philippines, showing that the green manuring value of leucaena for maize and rice equals to application of respectively 90-40-40 and 80-30-30 kg/ha of NPK. Bottenberg (1981) reported a yield increase of rice by 89.3 percent with application of 8 tons of leucaena leaves which is equivalent to 69 kg N/ha.

Pathak and Patel (1983) showed in a field trial with cereal fodder at Yanshi, India, that application of 50 kg N/ha only increased yield of the first cutting by 36%. However, following 2 years of leucaena plantation, the fodder yields were increased both in the first and second cuttings for a total of 234%. Guevarra (1976) in intercropping studies in Hawaii observed a large increase in maize grain yield with application of leucaena prunings. Maize yield in control plots averaged 1.9 tons/ha, while application of leucaena prunings (half incorporated prior to planting and half as side- dressing) equivalent to 150 kg N/ha increased yield to 6.6 tons/ha. Kang et al., (1981a) also observed significant increases in maize grain yield with application of leucaena prunings. Addition of 10 tons of prunings (equivalent to about 100 kg N/ha) incorporated at planting, increased maize grain yield from 1.3 tons/ha to 3.2 tons/ha (Table 4). Application of 100 kg N/ha of fertilizer nitrogen (applied in two split dosages) gave about similar maize yield as 10 tons of prunings.

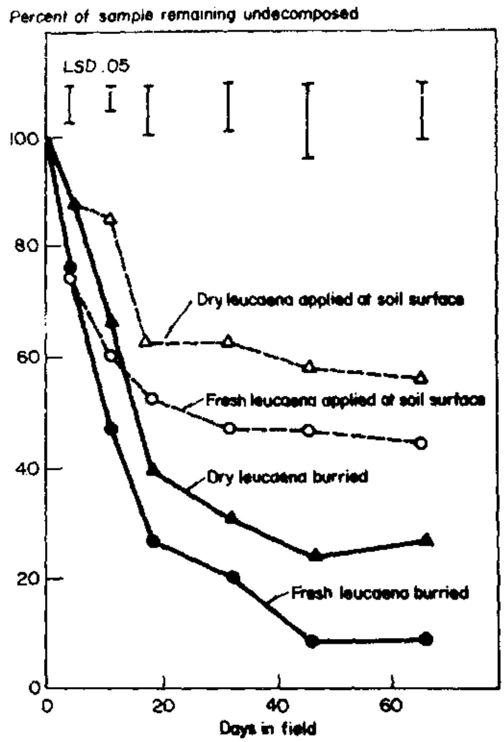

FIGURE 2. Decomposition of fresh and dry leucaena prunings applied as mulch or buried in soil with time (Read, 1982).

Effect of Placement of Green Manure

Loppings from leguminous trees and shrubs because of their relatively narrow carbon-nitrogen ratio are good sources of easily decomposable vegetational material. Investigations carried out at Ibadan also showed rapid decomposition of leucaena leaves as compared to maize stover (Figure 2). Buried in the soil, fresh and dried leucaena leaves have half lives of about 10 and 15 days respectively. Surface application of the leucaena leaves as mulch delayed decomposition. Applied as mulch the half life of fresh leucaena leaves increased to about 20 days. Despite the slower decomposition of dried leucaena leaves, Read (1982) in field studies could not find any differences in maize yield from application of fresh as opposed to dried material. Dried material has an advantage as it is less bulky and thus easier to handle.

Table 4. Effect of method of application of leucaena prunings and inorganic nitrogen of maize grain yield (Kang et al., 1981a).

Leucaena rate tons/ha	N rate kg N/ha	Incorporated	Mulch	Mean
		(kg/ha)		
0	0	1283	1740	1511
	50	2093	2218	2155
	100	3315	3138	3226
5	0	2313	2013	2163
	50	3035	2300	2668
	100	3453	3028	3240
10	0	3213	1855	2534
	50	2578	2338	2458
	100	3068	3023	3046
Mean		2705	2406	

LSD.05 Between methods of leucaena placement, 688
Between treatment (leucaena and inorganic N rates), 709
Between treatment within leucaena placement method, 1002
Between treatments in different leucaena placement methods, 1146

Because of the faster decomposition of leuceana prunings when incorporated in the soil, its direct manurial effect is therefore better when buried in the soil (Kang et al., 1981a). Data shown in Table 4 shows higher maize yield with incorporation of leucaena prunings as compared to mulching. Results of investigations carried out in Hawaii (C.L.I., Everson, personal communication) also showed higher maize grain yield from incorporation of the prunings as compared to surface application. Results of recent studies using Gliricidia sepium prunings also showed higher maize grain yield with incorporation or banding of the prunings than by broadcast application (Table 5).

Table 5. Effect of placement of gliricidia prunings on grain and stover yields of maize grown on Apomu loamy sand (Psammentic Usthorthent), (Kang, B.T., unpublished data).

Treatment*	Placement method	Grain Yield	Stover yield
		(Kg/ha)	
Control		1039	1586
Gliricidia prunings	broadcast	1732	2375
Gliricidia prunings	band/mulch	1803	2750
Gliricidia prunings	band/incorporated	2269	3042
LSD.05		527	816

* Gliricidia applied at rate of 10 tons/green material/ha.

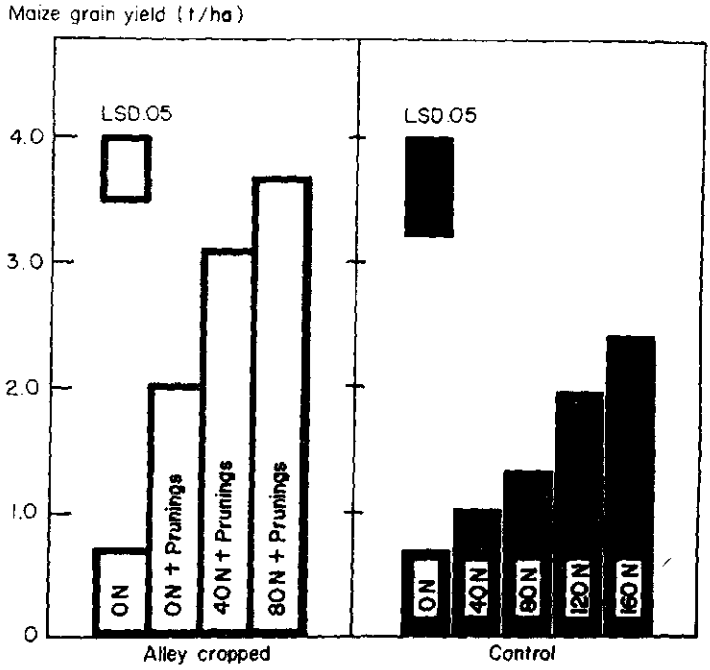

FIGURE 3. Grain yield of maize variety TZPB grown on Psammentic ustorthent as affected by nitrogen application and six years of alley cropping.

Nitrogen Requirements in Alley Cropping

Although high nitrogen yield can be obtained from prunings of hedgerows of woody legumes such as leucaena and gliricidia in alley cropping (Table 2), on low fertility soil application of supplemental nitrogen may still be required for obtaining optimum yield (Kang et al., 1981b). This may in part be attributed to lower efficiency of nitrogen from the prunings as was also reported by Guevarra (1976), who observed that the direct benefit from nitrogen added with the prunings to the immediate maize crop is about 36 percent. Several factors can be attributed to this lower efficiency such as: (1) delayed release, (2) application of prunings as mulch is less effective (Table 3), (3) possible volatilisation loss of nitrogen, and (4) sometimes timely pruning is done mainly to reduce shading rather than to supply nutrients to the companion crop.

Despite the low efficiency of the nitrogen from leucaena prunings, it still contributes a significant portion of the crop requirement (Kang et al., 1981b). Results of six years observation on a low fertility loamy sand at Ibadan showed that grain yield of maize alley cropped with leucaena can be maintained at 2.0 tons/ha with addition of leucaena prunings (with no application of fertilizer nitrogen).

Maize yield in the control plot (without application of leucaena prunings) declined to a low level of about 500 kg/ha during this period. In this study the maize plants in the control plots that grow adjacent to the leucaena hedgerows showed better growth compared to those growing in the middle of the alleys. This is mainly due to nitrogen contribution from the leaf litter in areas adjacent to the hedgerows.

Large increases in yield of sorghum grown in a shallow vertisol were observed with addition of Leucaena prunings with or without alley cropping and nitrogen application in Solanpur (Singh, R.P. and Das, S.K., personal communications). Addition of only leucaena prunings in alley cropping increased sorghum yield from 475 to 931 kg/ha.

Use of prunings of woody legumes in alley cropping system besides serving as nitrogen source also has several additional advantages: (1) to recycle other nutrients contained in the prunings and (2) help to build up soil organic level and nutrient status (Kang et al., 1985). Addition of nitrogen in the form of prunings unlike chemical fertilizer sources also has no effect on soil acidity.

The overall improvement in soil productivity and its effect on maize grain yield in long term alley cropping with leucaena is shown in Figure 3. Higher yield was obtained with the alley cropped maize as compared to yield of maize in the control treatment even with application of high nitrogen rates.

Recent observations by Ngambeki (1983) also showed, that income from alley cropped maize was more than double that of the control. In his study the nitrogen fertilizer required for optimum maize yield was reduced by more than half with alley cropping.

Despite the very promising results obtained in utilizing prunings of woody legumes in alley cropping systems, research in the area is still in its infancy. Further investigations need to be carried out to better evaluate N contribution of a wide variety of leguminous species and cultivars particularly those performing well in acid soils, and there is also a need to look into better management practices that can increase efficiency of nitrogen utilization from the prunings.

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NITROGEN UPTAKE OF MAIZE IN LIVE MULCH SYSTEMS

Key words: Arachis repens Centrosema pubescens
N contribution Psophocarpus palustris.

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SUMMARY

Two field trials were carried out at the International Institute of Tropical Agriculture, Abadan, Nigeria to evaluate the nitrogen (N) contribution of Psophocarpus palustris, Centrosema pubescens and Arachis repens grown as live mulch. N yields were assessed at maize harvest. Live mulches contained between 89 and 161 kg N/ha, and were not affected by N fertilization and weeding. In newly established field, the N content of maize was about the same with 0 and 120 kg N/ha and was the lowest in the centrosema plots. The negative N contribution of the cover crop observed in this trial indicates N competition between the live mulch and the maize crop. In the field cropped for six seasons, N uptake by maize was lowest in the unfertilized and unweeded plots with no cover crop. Live mulch contributed N to maize crop. In the absence of N application, with continuous cropping, higher maize yields could be sustained in live mulch systems with P. palustris and C. pubescens. P. palustris showed the highest N contribution averaging 30.7 kg N/ha, representing < 30% of the mulch N content. A. repens in unweeded plots contributed the least N.

INTRODUCTION

The direct planting of food crops such as maize into a low-growing cover crop without tillage has been termed live mulch system (Akobundu, 1980). This practice can be viewed as an attractive alternative to the traditional bush fallow system because it smothers weeds and incorporates the soil conservation features of organic mulch.

Experiments in which several types of ground covers were compared with no-till and conventional tillage systems indicated, that weed infestation was lowest and did not significantly affect maize yield in plots with Centrosema pubescens and Psophocarpus palustris (IITA, 1980-1983, Lal et al. 1979). Weed yield in conventional till plots was at least eight times more than that of the unweeded centrosema and psophocarpus plots. The live mulch was also found to protect soil against erosion and runoff, and to maintain better soil structure, lower soil temperature during early crop development, and higher moisture infiltration capacity and retention. Earthworm activities were considerably more in live mulch plots, resulting in favourable soil environment for plant root growth. Akobundu (1980) also observed, that maize yields, after five seasons of continuous cropping without N fertilizer, were superior in live mulch plots of psophocarpus and centrosema (2 t/ha) to yields in either the no-tillage (0.8 t/ha) or conventional tillage (1.0 t/ha) plots. Maize in the live mulch plots showed little or no response to N fertilizer, whereas in the no-tillage systems higher maize yields were recorded with the application of $\geq$ 60 kg N/ha. These data led to the assumption that leguminous live mulches, living in symbioses with Rhizobium, contributed additional N to the maize crop. An experiment was therefore set up to evaluate the N contribution from P. palustris, C. pubescens and A. repens in live mulch systems.

MATERIALS AND METHODS

The study was conducted at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, in two separate fields under no-tillage system. Experiment 1 was newly established. The experimental design was a split plot with four replications. There were three main plots: control without cover crop, Psophocarpus palustris, and Centrosema pubescens. Nitrogen fertilizer rates (0 and 120 kg N/ha) were the subplots. The field was hand-weeded regularly. Experiment 2 was a plot that had been cropped continuously for six seasons. A split split plot design with three replications was used. The following land management systems were the main plots: control without cover crop, and P. palustris, C. pubescens, and A. repens as live mulches. Subplots were N fertilizer rates (0 and 120 kg N/ha) and sub-subplots consisted of regular weeding and no weeding. All plots received a basal application of P as single superphosphate and K as muriate of potash at 60 kg/ha each. Maize TZE4 was sown at spacing of 25 cm x 75 cm, 3-5 days after strips had been opened in the mulch with paraquat at a rate of 0.48 kg a.i./ha. The climbing tendency of the cover crops was reduced by spraying the plants with a growth retardant, CGA 47283 (Ciba Geigy), applied at a rate of 2 kg a.i./ha at 3 weeks after sowing maize. At harvest, maize N content was determined on plants collected from the two middle rows, and biomass production of the respective live mulches was assessed by means of sampling a 0.5 m x 1.0 m quadrat. Four samples were collected in each plot. Roots were harvested to a depth of 15 cm. N content in both live mulches and maize samples was determined by micro-Kjeldahl digestion and analyzed with a Technicon Autoanalyzer.

Table 1. Plant N content and maize* grain yield in a newly established field, as affected by N fertilization and live mulch (LM).

Treatments	Total N LM	Total N Maize	N contribution by LM to maize (kg/ha)	Maize grain yield
No N fertilizer				
No live mulch	0	34	0	1120
Centrosema	95	9	-25	960
Psophocarpus	114	20	-14	880
120 kg N/ha				
No live mulch	0	38	0	1400
Centrosema	116	16	-22	960
Psophocarpus	109	27	-11	920
LSD (5%) for the same fertilizer treatment	57	15	18	240
LSD (5%) for different fertilizer treatments	64	14	18	300

* Values were calculated for a maize population of 40,000 plants/ha

RESULTS AND DISCUSSION

The top dry weights of the cover crops were similar in all the plots and averaged 4 t/ha. Root dry weight ranged from 0,4 to 2.65 t/ha. *A. repens* produced 1.5 and 3 times more roots in weedfree and unweeded plots respectively than *P. palustris* or *C. pubescens*. In both experiments, live mulches contained between 89 and 161 kg N/ha at maize harvest (Table 1 and 2). Arachis gave higher N yield than psophocarpus and centrosema. In our experimental conditions, dry matter production and N content of psophocarpus, centrosema and arachis were not significantly affected by N application (120 kg N/ha), indicating that the N requirements of these cover crops were taken care by themselves.

In the newly established field (Experiment 1), the N uptake by maize was about the same for the 0 and 120 kg N/ha treatments and was the lowest in centrosema plots (Table 1). The N contribution of the cover crops was calculated as the difference between the N content of maize in live mulch plots and its N content in plots without live mulch. N contribution in Experiment 1 was negative, indicating that the cover crops in this trial competed with maize for N. Earlier observations revealed that *P. palustris* and *C. pubescens* nodulated poorly at IITA and that their symbiotic N fixation was further reduced by the growth retardant CGA 47283 (IITA, 1982-1983). It was therefore concluded that these cover crops utilized soil N more efficiently than the cereal did. Maize N yield at harvest was about 5% of the total N in the live mulch. Maize grain yields were generally poor in the live mulch plots.

Table 2: Effect of N fertilization and live mulch (LM) on plant N content and maize* grain yield in a long-term mulch plot.

Treatments	LM	Maize	N contribution by LM to maize (kg/ha)	Maize grain yield
Weedfree, no N fertilizer				
No live mulch	0	60	0	600
Centrosema	99	39	-21	1200
Psophocarpus	105	63	3	1320
Arachis	161	37	-23	640
Weed free, 120 kg N /ha				
No live mulch	0	82	0	1600
Centrosema	130	68	-14	1440
Psophocarpus	89	109	27	1560
Arachis	134	105	23	1560
Unweeded, no N fertilizer				
No live mulch	0	16	0	1480
Centrosema	117	76	60	1680
Psophocarpus	134	60	44	1240
Arachis	156	29	13	680
Unweeded, 120 kg N/ha				
No live mulch	0	49	0	320
Centrosema	121	84	35	1840
Psophocarpus	103	98	49	1400
Arachis	111	40	-9	1000
LSD (5%) for the same fertilizer and weed treatment	69	33	28	560
LSD (5%) for different fertilizer levels and the same weed treatment	78	38	28	840

* Values were calculated for a maize population of 40,000 plants/ha

In Experiment 2, maize N content was lowest in unweeded plots without live mulch and N fertilizer application (Table 2). Ineffective weed control under arachis (IITA, 1982) resulted in low N uptake by maize in unweeded plots having this legume as live mulch. The N contribution of psophocarpus was relatively high, averaging 30.7 kg N/ha. This represents however only a small fraction of the live mulch

N. there was no significant correlation between maize yield and N contribution of the live mulches, but maize yields were generally lower in arachis and no live mulch plots.

The positive N contribution of the cover crops in the field cropped for six seasons (Experiment 2) probably was from legume litter and earthworm casts accumulated under the live mulch. Legume litter was difficult to evaluate because much of it was trapped in the top soil. Live mulch plots had more earthworm casts in the long-term field (Experiment 2) than in the newly established trial (Experiment 1) (personal observation), and these casts contained 0.40% N. Data from several field experiments also show no evidence of significant transfer of N from a growing legume to companion crops (Agboola and Fayemi, 1972; Shelton and Humphreys, 1975; Henzell and Vallis, 1977), only when organic N has been accumulated under the legume after some years (App *et al*. 1980).

CONCLUSIONS

The live mulch system, the direct planting of a food crop through a low-growing leguminous cover crop, has potential in tropical agriculture. In a newly established plot, the cover crop minimizes the need for weeding, prevents soil erosion, and stimulates soil biological activity (Akobundu, 1980). However, N and grain yields of the food crop may be less in these plots as a result of competition for nutrients between the legume and the non-legume. After some years of establishment, besides the advantageous features mentioned above, the organic N accumulated under the cover crop may improve N and grain yields of the food crop. At this stage, the live mulch will minimize the requirement for commercial N fertilizer necessary for sustained food crop production. The performance of live mulch species as source of N is different in the system; *P. palustris* was the best of three in our trials. Screening for a wider range of legumes is needed to identify species with high nitrogen fixing ability and little or no competition with the food crop.

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NITROGEN MANAGEMENT IN MULTIPLE CROPPING SYSTEMS

Key words: Intercropping Leguminous cover crops Apparent N-recovery 15N-Recovery Rotation.

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SUMMARY

A field trial was carried out on Ultisols at Onne in Eastern Nigeria. The experimental area had over 12 years of bush fallow and was hand cleared and burnt before cropping. Five N rates (0, 45, 90, 135 and 180 kg N/ha) and four cropping systems were tested using a split plot design with four replications.

Part of the first three years results is reported in this paper. Maize and cassava yields were highest following land clearing. In the first year maize whether monocropped or intercropped with cassava showed significant response to N application. The first year cassava showed significant tuber yield reduction with N application. Yield of intercropped maize was lower. With continuous cropping maize yield can be sustained at lower than the original yield level with N- application. Cowpeas, mucuna and stylosanthes grown in rotation benefit the succeeding maize crop.

Apparent N- recovery by the maize crop was low ranging from 27% to 42% depending on the N- rate applied. Although cassava showed negative apparent N- recovery, 15-N recovery data showed significant N- uptake by the cassava crop. Intercropping with cassava considerably increased fertilizer-N uptake by the intercrop system.

INTRODUCTION

Multiple cropping has been practiced by farmers in the tropics for centuries. In the course of time, specific multiple cropping systems have developed in different regions that are closely adapted to the prevailing ecological and socio-economic conditions, which fit the operational limits imposed by the farmer's knowledge and command over resources (MacArthur, 1976). Although improvement in farming methods and changes in socio-economic conditions have had considerable influence on cropping systems in various parts in the tropics, it is recognized that the introduction of well-planned multiple cropping practices is still one of the more feasible ways of raising agricultural production in the tropics (Beets, 1982).

Practiced in various forms and for various reasons, multiple cropping is an intensive production system that is used mainly to increase land productivity through efficient utilization of space, soil moisture and fertility, solar radiation and other environmental growth factors. This resulted in numerous advantages over mono-cropping such as: higher overall-productivity, better yield stability, better spread of production over longer growth period, reduced adverse effects of pests and, the most important, higher returns.

Despite the considerable number of investigations done on evaluating spatial and time arrangements in multiple cropping systems (Okigbo and Greenland, 1976), the problem of soil fertility management and fertilizer use has not received adequate attention, primarily owing to the complexity of the systems (Roy and Braun, 1983).

Although the philosophy of fertilizer practice in multiple cropping is essentially similar to that of monocrop (Oelsigie et al., 1976), fertilizer requirement for different intercropping systems may often differ considerably from just the combined requirements for the monocrops. Growing together two or more crops may result in a better utilization of soil nutrient recourses than will monocropping, despite the fact that some competition for nutrients between the crops may occur. It should be noted, that competition for nutrients is sometimes also inter-related with competition for light (Reddy et al., 1983).

Fertilizer use can play an important role in increasing the productivity of multiple cropping systems, however, high fertilizer prices and scarcity in many developing countries may limit the use. There is a compelling need to seek additional information for more efficient fertilizer use in the multiple cropping systems where fertilizer use is essential. Priority should be given to minimizing fertilizer use by increasing its efficiency and taking full advantage of biologically fixed nitrogen. This information is particularly needed for the humid tropics where only limited data are available. For this purpose, trials were carried out at the IITA high rain fall substation at Onne in southern Nigeria where N-leaching losses are a problem (Pleysier and Juo, 1981), in order to determine the utilization of nitrogen in selected cropping systems. Some of the results of these investigations are presented in this paper.

II. NITROGEN USE IN MULTIPLE CROPPING SYSTEMS

Intercropping (growing of two or more crops simultaneously on the same field) and relay cropping (growing of two or more crops simultaneously during part of each plant's life cycle) as defined by Andrews and Kassam (1976) are commonly practiced in humid tropical Africa. Sequential cropping (growing of two or more crops in sequence on the same field per year) although practiced is of less importance in the area.

There has been a lot of improvement in the productivity of selected multicropping systems without fertilizer use. This is for instance the case if only one component crop requires fertilizer and there is little competition between the component crops for the nutrient concerned. Reddy et al. (1983) for example showed, that in an intercropping study with sorghum and pigeonpea in which N was applied to only sorghum and not to pigeonpea, the yield of sorghum was slightly lower compared to sole cropped sorghum.

Nitrogen utilization in intercropping systems largely depends on the intercropped species. In cereal-cereal intercropping involving for example millets, a system which is widely practiced in the semi-arid tropics of Africa, millet is known to be highly competitive and easily dominating other cereals in the rotation. Kassam and Stockinger (1973) observed that millet utilized 80% of the total N removed by the millet-sorghum intercropping systems. In maize-cassava intercropping, which is widely used in the humid regions of Africa, maize has shown to respond more to applied N than the associated cassava crop (Wilson and Agboola, 1979), while application of N can even depress cassava yields (Kang and Wilson, 1980).

Of more importance is the intercropping with legumes, which offers considerable benefits because of the ability of the legumes to fix nitrogen. According to Reddy et al. (1983) there are two types of benefits from intercropping with legumes as far as the supply in Nitrogen is concerned:

1. Current transfer, in which transfer of N from legume occurs during the life of the intercropped species, and
2. Residual effects, in which N fixed by the legumes becomes available to an associated non-legume which is grown in relay intercrop or in sequential cropping after senescence of the legume and the decomposition of its residues.

The question of current or direct transfer is still a controversial issue. Remison (1978) and Eaglesham et al. (1981) indicate some transfer of fixed N from cowpea to maize. Reddy et al. (1983) could not detect transfer of N from groundnut to a companion crop.

The residual effects from legumes are well known, particularly where no plant parts are removed. Agboola and Fayemi (1972) reported, that cowpea and calopogonium interplanted with maize did not directly benefit the associated maize crop, but benefitted the subsequent maize crop as a green manure.

Reddy et al. (1983) summarizing results from ICRISAT showed low residual effects of groundnuts. Sole groundnut had a residual effect equivalent to 15 kg N/ha on the subsequent sorghum. Residual effects on maize were detected where groundnut was grown either sole or inter cropped, but only if the maize received N-fertilizer. In intercrop studies with cowpea and sorghum, only sole cowpea produces a measurable residual effect equivalent to 20-50 kg N/ha. Kang (1983) also showed significant residual effects from sole soybean and particularly sole cowpea on the subsequent maize crop.

Leguminous cover crops such as Psophocarpus palustris, grown in live mulch systems, can add up to 60 kg N/ha to the associated maize crop (Akobundu, 1980). In alley cropping systems, woody legumes such as Leucaena leucophala can also contribute significantly to the N-requirement of the intercropped maize (Kang et al., 1981).

Although inclusion of legumes can substantially contribute to the nitrogen requirement of various cropping systems, more quantitative data are needed on the nitrogen utilization from native, biological or fertilizer sources in the farming systems in the humid tropics.

III. MATERIALS AND METHODS

3.1 Experimental areas

The experiment was conducted at the International Institute of Tropical Agriculture's high rainfall substation at Onne ($0^0 43''$E, $07^0 01''$E) near Port Harcourt in south-eastern Nigeria. The station has a monomodal rainfall with annual precipitation of 2400 mm. Rain starts in early March and ends in later November. Precipitation exceeds evapotranspiration from March to October. The mean relative humidity is high for most of the year an average of 89%. The temperature of the area is generally moderate, February to April are the warmest months (about 27 C) and July is the coollest month (25 C). Solar radiation is generally low with a high degree of overcast, averaging about 4.2 hours per day.

The soil of the experimental area is derived from a plio-pleistocene sedimentary coastal plain formation and is classified as a kaolinitic Ultisol (Typic paleudult) with a sandy loam texture. The soil is strongly leached, acidic with low base saturation. Some of the properties of the soil are shown in Table 1.

Table 1. Some properties of soil profile of Typic paleudult from Onne (after 12 years of bush fallow).

Depth/cm	0-10	10-20	20-30	60-70	140-150
Mechanical analysis					
Sand (%)	82	76	71	62	62
Silt (%)	8	7	6	4	6
Clay (%)	10	17	23	34	32
pH-H2O	4.8	4.6	4.6	4.5	4.5
pH-KCL	4.0	4.0	4.0	4.0	4.0
Org. C (%)	1.18	0.77	0.62	0.55	0.37
Total N (%)	0.165	0.088	0.082	0.079	0.062
1N NH Acetate exch. cations (me/100 grams)					
Ca	1.05	0.30	0.30	0.22	0.22
Mg	0.12	0.03	0.03	0.01	0.01
K	0.31	0.04	0.03	0.03	0.03
Na	0.19	0.16	0.18	0.12	0.13
Total acidity	0.84	1.82	2.11	2.20	1.46
ECEC (me/100g)	2.51	2.35	2.65	2.59	1.85
Bray-P (mg/kg)	56.4	16.6	44.6	50.5	21.2

The experimental area was hand cleared (not destumped) from secondary fallow (estimated at over 12 years) dominated by shrubby species of Alchornea cordifolia (Euphorbiceae) and mainly Antonatha macrophylla (Caesalpiniaceae). The plots were cleared during the dry season of 1981-1982 and burned early 1982. The amount and mineral composition of the fallow vegetation and plant ash are given in Table 2.

3.2 Treatments.

Five nitrogen levels (0, 45, 90, 135 and 180 kg N/ha/yr and the following cropping systems were compared:

1. Intercropping maize (first season) and cassava (whole year)

2. Maize (first season) followed by cowpea (second season)

3. Maize (first season) followed by Stylosanthes guianensis (second season, 1982) or by Mucuna utilis (second season 1983),

and

4. Intercropping maize (first season), cassava and tree type Pigeonpea (for a year).

The trial was set up using a split design with four replications. Nitrogen levels were the main plot treatment, while the cropping patterns were the subplots. Maize (CV TZPB) was planted at 25 x 100 cm cassava (CV TMS 30572) was planted at 100 x 100 cm and pigeonpea (local CV. from Sierra Leone) was planted at 100 x 400 cm. Mucuna utilis was planted at 0.5 x 25 cm and Stylosanthes guianensis was drilled in rows spaced 50 cm apart.

In micro plots 3 x 5 meter, N labelled urea (about 1.6 atom % excess N), was used in cropping system 1 and 2 at the 90 kg N/ha rate. The microplots were surrounded by mats of woven palm leaves to minimize surface or subsoil cross-contamination of nitrogen.

Nitrogen fertilizer as urea was applied annually in the first season in 3 equal split doses; at planting, 4 weeks after sowing (WAS) and at 8 WAS. Urea was banded at depth of about 2 cm. The first season crop received annually 90 kg P205 (as single super phosphate), 96 K20 (as muriate of potash), 20 kg Mg as magnesium sulphate, and 2 kg Zn as zinc- sulphate at planting.

Soil and plant samples were taken at periodic intervals for analysis. Total N in plant sample was determined using micro Kjeldahl method. N was determined using mass spectrometer (Buresh et al., 1982).

IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1. Effect of burning.

Following the traditional practice in the area, the experimental plot was manually cleared and the fallow vegetation was burnt to clear up the plot for cultivation. As shown in Table 2 the dry biomass yield of the natural fallow is estimated at about 22 tons/ha. Following incomplete burning, the amount of plant ash present in the plot is estimated at about 1.2 tons/ha. Although the nutrient content in the plant ash is low, it plays an important role on these low fertility and acid soils (Table 1). As the plant ash also raises soil pH following burning to pH 5.2, this sufficiently reduces the extractable soil Al* level to render the soil suitable for maize cropping.

Table 2. Dry matter weight and nutrient composition of fallow vegetation and plant ash following land clearing and burning at Onne.

Material	Dry matter (tons/ha)	N	P	K	Ca	Mg	Zn	Mn
		(%)					(mg/kg)	
Fallow vegetation	20.89	1.03	0.16	0.30	0.94	0.19	18.3	278
Plant ash	1.22	0.58	0.49	0.69	1.92	0.46	59.5	961

4.2 Crop Response to Nitrogen

Maize:

The maize crop responded significantly to N application on the newly cleared land despite a fallow period of over 12 years (Figure 1), giving returns of approximately 20 kg. of maize per kg. of N up to a rate of 90 kg N/ha. The monocropped maize yielded better than the intercropped maize. In both instances, there were curvilinear yield responses to N application. The nitrogen response was more pronounced with the monocropped maize. Although maize grain yield increased with application of up to 180 kg N/ha, significant yield increases were observed at lower N application rates of < 90 kg N/ha. With the intercrop maize there was only a significant yield response with application of 45 kg N/ha. Higher rates of N application with intercropping, stimulated more vegetative growth of the cassava crop which in turn caused an increased shading to the maize crop, resulting in lower maize yields. In Onne area, where incoming solar radiation is very low during the cropping season, the application of 180 kg N/ha, was lower than with 135 kg N/ha due to excessive shading from the cassava crop maize yield.

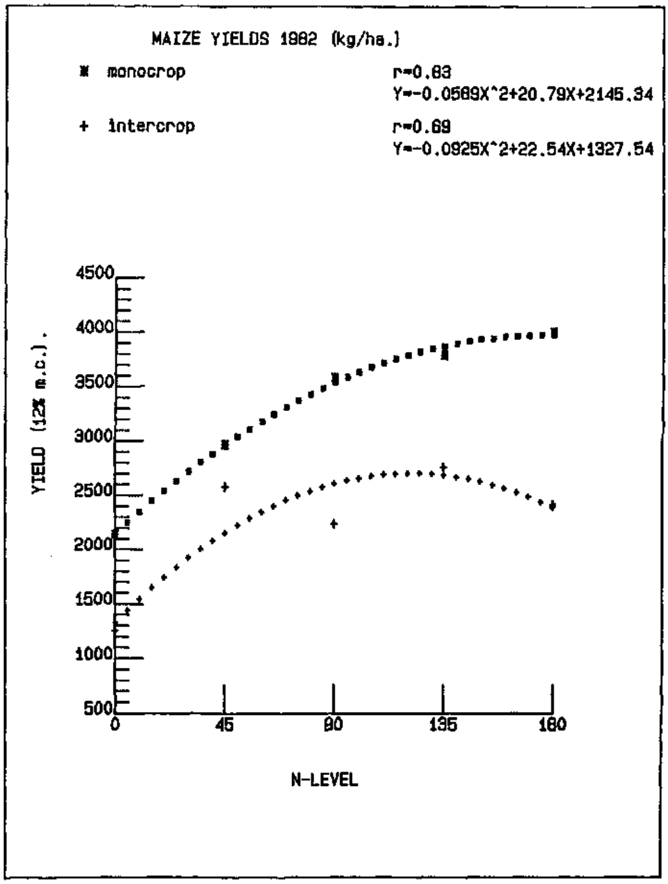

Figure 1. Effect of nitrogen rates on the grain yield of monocropped maize and maize intercropped with cassava on newly cleared land at Onne (Nigeria) in 1982.

In the second year after land clearing, maize yield was considerably lower than in the previous year (Table 3). With or without intercropping maize yield with no N application was reduced to less than half. As expected yield of intercropped maize was also lower than the monocropped maize. Except for a curvilinear yield response curve following cowpea, there were only linear responses to N application in the second cropping year, indicating more pronounced N responses. Monocropped as well as intercropped maize responded significantly to application of 180 kg N/ha.

Inclusion of pigeonpea's in the intercropped maize and cassava did not affect maize yield. Due to heavy shading from the maize and cassava crops, the pigeonpea did not establish well. Maize yield was higher following Stylosanthes (planted second season 1982) than after cowpea. The lesser effect of cowpea in part is due to N removal with the cowpea crop.

Table 3. Effect of N- rates and cropping systems on maize grain yield at Onne, 1983.

N- treatment	MONO CROPPING after Cowpea	after Stylosanthes	INTERCROPPING with Cassava	with Cassava and Pigeonpea	Mean
	------------------	(kg/ha)	------------------		
0	879	1055	484	646	766
45	1608	1874	1132	973	1397
90	2266	2490	1466	1546	1942
135	2693	2760	1979	1946	2336
180	2750	3190	2238	2154	2583
Mean	1846	2065	1297	1319	

LSD.05 Between N- rate, 251
Between cropping system mean, 174
Between cropping system for same N- rate, 301
Between cropping system for different N- rate, 369

In the third year (1984) maize yield was at about the same level as in 1983 (Table 4). A highly significant response to N application was observed with the four cropping systems at all fertilizer levels. There was no difference in maize yield following cowpea or Mucuna utilis (planted during second season of 1983), showing no benefit from one short season planting of mucuna as compared to cowpea.

Because of the severe competition for light observed in previous years, maize plant density was reduced to half in 1984 in the maize/cassava/ pigeonpea cropping system. Reducing plant density decreased maize yield at high N- rates (>90 kg N/ha) but had no effect on maize yield at a low N- rate (45 kg N/ha). It even had a beneficial, although not significant, effect with no N application, so that it appears that lower maize plant densities may be required with no or low N application rates.

Table 4. Effect on N- rates and cropping systems on maize grain yield at Onne, 1984.

N- treatment	MONOCROPPING after Cowpea	after Mucuna	INTERCROPPING with Cassava	with Cassava and Pigeonpea*	Mean
	(kg/ha)				
0	646	691	552	776	666
45	1659	1991	1554	1428	1658
90	2331	2597	2224	1612	2191
135	3165	2848	2924	2014	2738
180	3532	3363	2976	2052	2980
Mean	1996	2030	1797	1443	

LSD.05 Between N- rate mean, 251.0
Between cropping system mean, 139
Between cropping system for same N- rate, 340
Between cropping system for different N- rates, 340

*) Plantdensities are half of those in other cropping systems.

Cassava:

In Table 5 the cassava tuber yield is shown. The first cassava crop (planted in 1982 and harvested in 1983) showed higher yield than the succeeding crop with no N application and at low N- rates. At a high N rate of 180 kg N/ha, the second crop gave higher yield. The first cassava crop showed drastic tuber yield reduction with N application irrespective of the cropping system. The second crop however, showed no significant effect of N application. Interplanting of pigeonpea had no significant effect on cassava yield as the growth of pigeonpea was suppressed by the cassava and maize crops.

Cowpea:

The second season 1982 cowpea crop gave low yield (mean, 571 kg/ha) and showed no residual effect to the proceeding maize crop.

Table 5. Effect of N- rates and cropping systems on dry tuber yield of cassava at Onne from 1983 and 1984 harvest.

N-rates (kg N/ha)	Intercrop with Maize		Intercrop with Maize and Pigeonmpea		Mean	
	1983	1984	1983	1984	1983	1984
	(kg N/ha)					
0	9508	6659	9277	7213	9393	6936
45	7441	8763	8598	7053	8019	7908
90	7043	7323	9240	7240	8142	7281
135	8124	6710	7625	4960	7874	5835
180	5614	7455	6550	7535	6082	7495
Mean	7837	7261	8428	6869		

LSD.05 Between N- applications mean, 1915 n.s.*
Between cropping systems, 965, n.s.*

* Not significant

V. NITROGEN RECOVERY

The apparent N-recovery data of the maize crop is calculated as the percentage of N-content at a certain N-rate minus the N-content with no N fertilizer application (control) devided by the N-rate applied. Data for the maize (Table 6) as expected showed lower apparent N-recovery with increasing N application rates. The apparent N-recovery was lower in the second crop (1983) particularly at low N-rates except for the maize crop following cowpea. This was also confirmed by the N-15 recovery data at 90 kg N/ha (Table 8). There was higher N recovery in the third crop.

The apparent N recoveries at different stages of growth of the crop for 1982 and 1983 are shown in Table 7. It appears, that the lower recovery rates in the second maize planting occur early, particularly during the first four weeks after planting, when little fertilizer N was utilized.

The high maize and cassava plant populations used in the 1982 and 1983 experiments resulted in severe competition for light and nutrients between the maize and cassava crops. Nitrogen application resulted in increased vegetative growth of the maize crop particularly at high N-rates causing severe shading to the young cassava plants. Consequentely, cassava grown in the control (No N) plots was at a relative advantage compared to the fertilized treatments, resulting in negative apparent N- recovery figures for the cassava crop with N-application.

Table 6. Percentage apparent N- recovery in maize for the various harvests.

Kg N/ha	Maize/Cassava			Maize/Cassava/ Pigeonpea			Maize/Cowpea			Maize/ Sylosantes	Maize/ Mucuna	
	'82	'83	'84	'82	'83	'84	'82	'83	'84	'83	'83	'84
45	60	36	47	44	26	31	26	51	30	65	29	48
90	32	31	46	41	29	22	29	36	28	52	35	44
135	29	29	35	31	27	23	26	30	35	35	28	36
180	20	24	30	20	22	16	30	31	30	31	29	31

Table 7. Percentage apparent N recovery in maize with age for the 1982 and 1983 crops with application of 90 kg N/ha.

Croppping system	4 WAS*		8 WAS		12 WAS		Harvest (16 WAS)	
	'82	'83	'82	'83	'82	'83	'82	'83
Maize/Cassava	9	9	26	19	20		32	31
Maize/Cowpea	19	4	25	24	23		29	36
Maize/Stylosanthes	6		17		22		52	
Maize/Mucuna		1		22				35
Maize/Cassava/Pigeonpea	14	6	25	20	12		41	29

* WAS = weeks after sowing

The negative apparent N-recovery figures for cassava are in contrast to the 15-N recovery data as shown in Table 8, which indicate a considerable uptake of fertilizer N by the cassava crop during the 1982 season when intercropped with maize with application of 90 kg N/ha.

Table 8. Recovery of 15-N in maize, cassava and cowpea crops grown with 90 kg N/ha in 2 cropping systems in 1982.

		1982
Maize/Cassava 3 months after planting :	Maize	19.7 % *
	Cassava	24.7 % **
	Total	44.8 % **
Maize/Cassava 6 months after planting :	Maize	19.7 % *
	Cassava	23.8 % *
	Total	46.3 % **
Maize/Cassava at harvest :	Maize	19.7 % *
	Cassava	25.7 & **
	Total	45.4 % **
Maize followed by cowpea at harvest :	Maize	28.7 % **
	Cowpea	1.2 % *
	Total	29.9 % *

* = average of 4 replications
** = average of 3 replications

Data in Table 8 also show that cowpea, following monocrop of maize, did not benefit from any residual N- fertilizer, applied to the preceding monocropped maize.

At 90 kg N/ha maize, grown as monocrop, used more fertilizer-N than when intercropped with cassava. The maize and cassava intercropped system as a whole showed higher fertilizer-N recovery compared to monocropped maize at the same fertilizer rate.

VI DISCUSSIONS AND CONCLUSIONS

The first three years field data presented in this paper show some interesting points with regard to N responses with different cropping systems following land clearing from a long bush fallow period. Yield of maize and cassava whether monocropped or intercropped appears to be higher following land clearing and burning than the subsequent crops despite high rates of fertilizer application. With continuous cropping the N requirement increased with subsequent cropping and yield of maize and cassava stabilized at lower level with an application of 135 kg N/ha. Inclusion of cowpea, *Mucuna utilis* and *Stylosanthes* in the rotation system appears to be beneficial to the succeeding maize crop (Table 3 and 4). Although for one season cropping stylosanthes and cowpea are quite promising, establishment of stylosanthes is a problem in the Onne area due to the slow early growth which requires frequent weeding. Further studies need to be carried out to better quantify the N- contribution of mucuna and cowpea to the succeeding crop.

Following long fallow period intercropped cassava does not respond positively to N application. The first crop yields of over 9.0 tons/ha with no N application equals to yields of monocropped cassava grown at Onne (Hahn and Chukwuma, 1981) indicating that inclusion of maize had no adverse effect on cassava yield.

The decline in cassava tuber yield on newly cleared land with N application was also observed in other trials with monocrop cassava at Onne (IITA, 1982). However, as mentioned earlier this decline may in part be attributed to excessive vegetative growth and shading by the maize crop. On the relatively fertile soil following land clearing and burning addition of N may also delay bulking of the cassava tuber. As the cassava crop was harvested at 12 months, which is reflected in lower tuber yields.

There was low apparent recovery of applied nitrogen by the maize crop during early growth. Maximum recovery occurs at about 12 weeks after planting (table 7). Irrespective of cropping systems, apparent recovery ranged from 42% at 45 kg N/ha to 27% at 180 kg N/ha. Because of competition for nutrients in the intercropping system between the maize and cassava crops, fertilizer N uptake by the intercropped maize was lower at 90 kg N/ha; though most of the fertilizer N taken up by the cassava crop appears to originate from the excess fertilizer-N in the soil.

Although the apparent N-recovery data of cassava in the first year of the experiment did not reflect the actual fertilizer-N uptake of a monocrop, the first results of the 15-N analysis indicate that the efficiency of N-fertilizer use was considerably increased by the intercropped cassava. The cassava crop recovered about 25% of the 90 kg/ha intercropping system, as compared to monocropped maize.

At an application rate of 90 kg N/ha, the cassava crop did not take up any of the applied N-fertilizer beyond a period of three months after planting. Moreover, N application had a negative effect on tuber yield in the first year, and no effect in the second.

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NITROGEN MANAGEMENT IN CROPPING SYSTEMS WITH PARTICULAR REFERENCE TO RAINFED LANDS OF INDIA - A COUNTRY REPORT

Key words: Bio-fertilizers Crop Rotation Drylands Green Leaf Manuring Intercropping Systems Lay Farming Systems Nitrogen Use Efficiency Residual Effect Residual Nitrogen Rhizobium Inoculation Sequential Cropping System Slow Release Nitrogenous Fertilizers Transfer of Nitrogen

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SUMMARY

Low N content in drylands and low recovery of applied N pose a serious problem in N-management. However, economic response to applied fertilizers has been obtained in drylands. Management practices for increasing the N-use efficiency have been developed. Application in 2-3 splits and deep placement of N for post-monsoon season crops increased yields with a given amount of N. Use of bio-fertilizers and green leaf manuring was found to reduce the requirement of fertilizer N under rainfed conditions.

Inclusion of a leguminous crop in the intercropping systems and with judicious fertilization, a saving of 20-30kg N/ha could be obtained. This indicated current/direct transfer of N from the legume to the cereal crop. In sequential cropping systems having a legume component, a saving of 12-30kg N/ha was possible for the succeeding crop. Fodder legumes were reported to be more efficient than grain legumes. No discernible effect in terms of residual N was observed in sequences where legume component was not included.

INTRODUCTION:

Nitrogen is referred to as the 'key' element in crop production. Almost all rainfed cultivated soils in India are deficient in nitrogen. A recent report on available nitrogen status of Indian soils made by Ghosh and Hassan (1980) showed that 62.5 per cent of the total Indian districts surveyed are low in available nitrogen, while 32.6 per cent fall under medium fertility class.

Heavy losses of N and low N-recovery in tropical soils make nitrogen management a difficult task.

The work done on N-management in India with particular reference to drylands is reviewed in this paper.

1.0. FERTILIZER N IN INDIAN AGRICULTURE:

From humble beginnings in 1941, India today (1983-84) is producing 3500 thousand tonnes nitrogen per year in 34 factories. The consumption of nitrogen has kept pace with the increased food production in the country. The real boost in fertilizer use came during the late sixties with the adoption of fertilizer responsive, non-lodging and high yielding varieties of cereals.

2.0. FERTILIZER USE IN DRYLANDS:

Limited survey conducted on use of fertilizers in drylands of India revealed that fertilizer consumption per hectare is about 10 kg only, as against the present national average of 36.6 kg/ha. Fertilizer use in rainfed lands has been substantially low. This aspect has been a major concern in the development of dryland agriculture in India.

3.0. CROP RESPONSE TO N APPLICATION:

Large volume of available data suggest clear cut response of field crops to nitrogen application both under rainfed and irrigated conditions.

These have been reviewed and reported from time to time by several authors (Mahapatra et al 1973; Kanwar et al 1972; Kanwar 1973; Ray and Kanwar 1979; Kulkarni 1980 a, 1980 b; Singh 1982; Rao and Das 1982; Prasad & Subbiah 1982; Randhawa and Singh 1983). Economic response to nitrogen application has been demonstrated on drylands both on experimental stations and farmers' fields.

The salient features of the nitrogen response studies are presented below:

Cereals, millets, pulses, oilseeds, tubers and fibre crops respond to applied nitrogen under the agro-climatic conditions of India; higher response is obtained with lower doses of applied nitrogen; the same crop shows variable response to applied nitrogen in different soil types; higher responses and returns are obtained under improved crop management technology than under traditional management practices followed under rainfed conditions; response to nitrogen application under rainfed conditions increases, with an increase in rainfall and available moisture storage capacity of the soil profile; some varieties are more efficient than others in producing more yield with a given amount of nitrogen; nitrogen application produces higher response when the deficiency of other elements, particularly phosphorus and potassium, is corrected.

4.0. NITROGEN USE EFFICIENCY:

Nitrogen utilisation efficiency is rather low. It has very little residual effect. Prasad and Thomas (1982) have reviewed the work done on nitrogen recovery from applied fertilizers in different crops. It has been generally observed that nitrogen use efficiency is lower in the case of monsoon-season crops than in crops grown in the post-monsoon season.

The reason for low recovery of applied nitrogen has been attributed to the various mechanisms by which nitrogen is lost to crop use. Denitrification loss is important under flooded conditions. Run-off loss is extremely hazardous in rainfed slopy lands. Data compiled by Tandon (1977) revealed that under Indian conditions 1.4 to 60 per cent of applied nitrogen is lost through ammonia volatilization. Studies on denitrification showed that the amount of loss might be as low as 3 per cent to as high as 99 per cent of applied nitrogen.

Ammonium fixation in some Indian soils was found to vary from 5 to 69.9 per cent of applied nitrogen (Tandon, 1974). That a large amount of applied nitrogen is immobilised in soil was reported by Subbiah and Sachdev (1981) from studies using N^{15}. Krishnappa and Shinde (1980) also observed from similar studies that 26 per cent of applied nitrogen gets immobilised in soil.

Realising the importance of the need of increasing the use efficiency of applied nitrogen, concerted research efforts were made by a number of scientists in this direction. Various means and methods were tried by them for increasing the N-use efficiency which are presented hereunder.

4.1. Source of Nitrogen Carriers: In India, urea is the major source of nitrogenous fertilizer. Results obtained in upland crops showed no significant difference between the ammonium and nitrate containing N fertilizers in terms of their efficacies. However, for rice, ammonical fertilizers were reported to be superior to nitrate-containing sources (Prasad et al 1980). The response to applied nitrogen by sesamum was found to be more with urea as compared to calcium ammonium nitrate and ammonium sulphate as reported by Ankineedu et al (1983).

4.2. Time of Application: Nitrogen requirement of crops vary with the stage of crop growth. Split (2 to 3) application of nitrogen matching the nitrogen requirements of the crop has been found useful for most of the crops grown under irrigated conditions and under high rainfall rainfed situations (Table-1).

TABLE-1: Yield of Crops as Affected by Split Application of N

Centre	Crop	No.of applications	Dose (kg/ha)	Grain yield (q/ha)
Samba	Pearl millet	1	60	23.1
		2		24.9
		3		25.1
Ranchi	Rice	1	50	20.0
		2		23.0
		3		26.4
		4		26.9
Bhubaneswar	Rice	1	100	12.3
		2		11.1
		3		13.5
		4		13.1
		10		17.2
Dehra Dun	Maize	1	100	47.3
		2		55.6
		3		56.2

Source : Rao & Das (1982)

Although split application of N does not confer any yield advantage under dryland conditions, the practice of split application has been found useful in combating weather aberration situations.

4.3. Placement of Fertilizer Nitrogen: Placement of nitrogen (5-8 cm below soil surface) has been found to be useful for rice. For dryland crops, separate application of seeds and fertilizers help in avoiding direct contact between them which otherwise in adverse weather conditions result in seedling mortality. Deep placement (10-15 cm below seed) is important for post-rainy season crops grown under rainfed conditions (Table-2). Yield and nitrogen recovery by safflower was found to increase considerably by deep placement of nitrogen.

TABLE-2: Grain Yield, Nutrient Removal and Fertilizer N and P Recovery by Safflower as Affected by Methods of Fertilizer Application

Methods	Grain yield (q/ha)	Nutrient removal (kg/ha)			Calculated N and P recovery (%)	
		N	P	K	N	P
Control	4.1	13.1	2.1	31.6	-	-
<u>Kera</u> (15 cm by the side of row)	7.5	20.9	2.3	29.7	19.4	1.5
<u>Pora</u> (10 cm below seed)	11.7	32.6	4.4	67.0	48.7	17.4
<u>Pora</u> (16 cm below seed)	12.5	35.2	4.5	68.4	55.3	17.8

Source: Das <u>et al</u> (1978)

4.4. Foliar Application of Nitrogen: A number of trials have been conducted on foliar application of nitrogen in conjunction with soil application. Results so far obtained point to the conclusion that foliar feeding of nitrogen might be useful for late application to dryland crops, on sodic soils, and in submerged rice fields where soil application is not possible (Prasad and Thomas 1982).

4.5. Residue Management: Incorporation of crop residues in soils with low organic matter content was found to confer a distinct advantage in terms of improving the fertility status and soil physical conditions under dryland conditions. The organic matter status of the soil improved from 0.55 per cent in the control plot to 0.90 per cent in the plot receiving maize residue @ 4 tonnes/ha per year (Randhawa and Singh, 1983).

4.6. Bio-fertilizers: Use of <u>rhizobium</u> cultures in pulse crops has not been found to benefit the crops significantly under dryland conditions, though some reports on the usefulness of this practice are available under irrigated conditions. Free living N-fixing bacteria, viz., azospirillum appears to be promising for sorghum, pearl millet and sesamum under rainfed conditions (Table-3).

TABLE-3: Effect of Nitrogen Application and Seed Inoculation with Azospirillum on the Grain Yield of Sorghum and Pearl millet in Semi-arid Red Soils of Hyderabad

N levels (kg/ha)	Grain yield in q/ha (mean of 2 years)			
	Sorghum		Pearl millet	
	Control	Inoculated	Control	Inoculated
0	15.5	15.4	9.3	9.8
13.3	21.7	26.8	14.2	17.2
20	23.8	25.9	14.6	16.3
40	26.7	31.7	18.1	21.2
Mean	21.9	24.9	14.1	16.1

Source: Das et al (1982 b)

A saving of about 20 kg N/ha could be achieved by inoculating seeds with azospirillum. Some other reports are also available on the fixation of atmospheric nitrogen through cultures of azotobacter, particularly under irrigated conditions (Subba Rao 1979). A saving of 25-30 kg N/ha can be achieved through the use of azolla and blue green algae in case of low land rice.

4.7. Slow-release Fertilizer Nitrogen and Nitrification Inhibitors: Use of slow release nitrogenous fertilizers and nitrification inhibitors have been extensively tried in low land rice. Slow release fertilizers which have slow to extremely slow rate of dissolution tried and found useful include isobutylidene diurea (IBDU) and N-lignin. Coated fertilizers having moisture barrier which result in slow release of the nitrogen tested in India are sulphur coated urea (SCU) and shellac-coated urea. Urea super grannules and urea briquettes have also been tested. These materials have been found to be promising.

Nitrification inhibitors having properties of retarding the rate of nitrification, thereby reducing the loss of nitrate through leaching and denitrification, have been found very effective for low land rice. The nitrification inhibitors tested include N-serve (2-choloro-6 (trichloromethyl pyridine.), AM (2-amino, 4 chloro 6 methyl pyridine), ST (2-sulphanilamidethiazole) and dicyandiamide. Indigenous alternatives of these materials to inhibit nitrification which have been found useful are neem cake coated urea and karanj cake coated urea. The literature on the above subjects has been extensively reviewed by Prasad et al 1971; Prasad 1974 and Prasad 1979.

5.0. NITROGEN MANAGEMENT IN CROPPING SYSTEMS:

Broadly, the prevailing stable cropping systems are: mono-cropping in arid and semi-arid regions; intercropping in semi-arid regions; sequence cropping in assured rainfall regions and irrigated conditions; and multiple cropping (more than 2 crops per year) in irrigated areas.

5.1. Nitrogen Management in Intercropping Systems: The major interest in nitrogen management remains on the current or direct transfer of nitrogen from the leguminous component to the non-legume one. Nitrogen management in an intercropping system in deep sierozemic soil having moisture storage capacity of 80-90 mm/90 cm was first studied in 1975 at the Central Arid Zone Research Institute, Jodhpur (Singh & Singh 1977) where evidences of current transfer of nitrogen were available (Table-4).

TABLE-4: Seed and Grain Yield (q/ha) of Principal and Companion Crops as Influenced by Nitrogen Application

Cropping systems	N levels (kg/ha)	Sunflower 1975 (507.2) mm	Sunflower 1976 (490.6) mm	Sunflower Mean	Companion crops 1975	Companion crops 1976	Companion crops Mean	Mean total productivity (q/ha)
Pure sunflower	0	4.3	2.0	3.1	-	-	-	3.1
-do-	30	7.4	3.0	5.2	-	-	-	5.2
-do-	60	10.7	5.3	8.0	-	-	-	8.0
Sunflower+ Greengram	0	1.9	1.2	1.6	12.9	7.6	10.3	11.8
-do-	30	6.1	3.4	4.8	14.2	8.5	11.3	16.1
-do-	60	9.1	4.1	6.6	14.4	8.5	11.4	18.0
Sunflower+ Cowpea	0	1.5	1.4	1.4	14.2	4.3	9.3	10.6
-do-	30	6.9	3.4	5.1	16.0	4.8	10.4	15.5
-do-	60	9.2	4.1	6.6	17.1	5.8	11.5	18.1
Pure greengram	15	-	-	-	15.1	12.0	13.5	13.5
Pure cowpea	15	-	-	-	19.0	6.3	12.7	12.7
S.Em±		0.07	0.04					
C.D.0.05		0.20	0.11					

Figures in parenthesis indicate the amount of rainfall received during the year

Source: Singh & Singh (1977)

Again, results obtained from another study carried out on sierozemic soils at Hissar with pearlmillet + greengram/cowpea (fodder) intercropping systems showed that when pearlmillet was intercropped with greengram or cowpea (fodder), 50 per cent reduction of the recommended dose of nitrogen was possible. This amounts to a saving of 20 kg N/ha. Fodder cowpea was found to be more efficient than greengram in maintaining higher productivity of the principal crop of pearlmillet. An indirect evidence of current transfer of nitrogen to the extent of 20kg N/ha from legume to cereal was thus obtained corroborating the earlier findings of Singh & Singh (1977).

Response of cereals to applied nitrogen in intercrop systems was studied at International Crops Research Institute for Semi-arid Tropics (ICRISAT) based on sorghum + pigeon pea (2:1) and millet + groundnut (1:3 or 1:2) in both red and black soils. From these studies it was evident that there was not much current transfer of nitrogen from legume to companion crop (Kanwar and Rego 1983). However, two points which emerge from their data need consideration. These are:

i) In red soil (alfisol) there was not much difference in yield of sorghum between sole and intercrop systems,

ii) The base crop yield of sorghum without any nitrogen application in vertisol was found to be more in intercrop system than in sole crop system.

Perhaps, there is a small amount of direct transfer of nitrogen from legumes to cereals.

Hegde and Saraf (1972) studied the changes in soil fertility as affected by sole crop of pigeon pea and pigeon pea intercropped with greengram/blackgram/cowpea. Their results revealed that total nitrogen content in soil under intercropped treatments was generally higher than under pure crop of pigeon pea (Table-5).

TABLE-5: Total N, Available P and K in Soil After the Harvest of Pigeon pea as Affected by Intercropping and Phosphorus Levels

Treatments	Total N%	Available P (kg/ha)	Available K (kg/ha)
Intercropping			
Pigeon pea alone	0.043	21.0	300.9
Pigeon pea + moong	0.044	17.4	316.4
Pigeon pea + urd	0.046	17.3	316.5
" + cowpea(G)	0.053	17.1	332.2
" + " (F)	0.047	19.2	299.9
P_2O_5 levels (kg/ha)			
0	0.040	10.7	311.7
40	0.049	19.2	312.3
80	0.050	25.9	315.4
C.D. 5%	N.S	2.4	N.S.

Source: Hegde and Saraf (1978)

From the preceding discussion it appears that there is direct transfer of nitrogen from legume to cereal. A saving of 20-30 kg N/ha is thus possible. Intensive studies on these lines are required to be done in India.

5.2. Nitrogen Management in Sequence Cropping Systems: Sequence crop system could either be legume based or non-legume based. Nitrogen management in sequence crop systems are discussed below:

5.2.1. Legume-based Cropping Systems: Legume-based cropping systems are generally practiced in drylands. The legume is taken either as a monsoon or a post-monsoon season crop.

Short duration fodder legumes like cowpea, clusterbean, mothbean and soybean were found to enrich the soil fertility, thereby providing highly beneficial residual effect to the succeeding barley crop in a deep alluvial soil of north India (Giri and De, 1981). The grain yield of barley was found to be higher when taken after the legume fodders than after the non-legume fodder, pearl millet.

Benefits accruing from the previous fodder legumes were equivalent to or more than 40kg N/ha of chemical fertilizer. Mothbean was found to produce the highest residual effect, followed by cowpea, clusterbean and soybean. Similar beneficial effects of forage crops on the residual fertility were also observed in alluvial soils at Agra. The results reviewed by Singh (1982) showed that mustard seed yield was significantly higher when taken after pearl millet + cowpea, as compared to pearl millet + clusterbean or sorghum + clusterbean combinations. Further, it was observed that increased levels of nitrogen applied to monsoon season crops led to significantly higher yields of mustard. However, it was not clear in this study, whether nitrogen applied to monsoon season crop had its direct or indirect effect in increasing the mustard yield.

Dryland Research Centre at Varanasi studied the residual effect of maize and blackgram on the succeeding mustard, barley and wheat crops on an alluvial soil (Tiwari 1981). The results suggest that a saving of 20-30 kg N/ha could be achieved if barley and wheat are grown after blackgram. Mustard seed yield did not show any consistant trend.

The beneficial effects of taking a greengram crop in a monsoon season, preceding safflower were evident in the medium to deep black soils at Akola. Residual effect of groundnut equivalent of 15kg N/ha was observed at ICRISAT where maize was grown after groundnut, the maize crop being fertilized in this case. Sole cowpea was also found to produce residual effect to the extent of 25-50 kg N/ha (Reddy _et al_ 1982).

Singh and Sahu (1981) concluded that in a groundnut based cropping system, groundnut leaves behind considerable mineralizable nitrogen in soil and as such the succeeding crop of cereal or a non-legume be fertilized with nitrogen, reducing the dose by atleast 20-25 kg/ha.

It thus appears that in a sequential cropping system either rainfed or irrigated, inclusion of a legume component helps in reducing the fertilizer nitrogen requirement of the succeeding crop. Fodder legumes are very efficient in this regard. Mothbean, cowpea, clusterbean and soybean when taken as fodder crops leave behind residual effect equivalent to or more than 30 kg N/ha irrespective of different soil types. Benefits accrued from grain legumes like blackgram, cowpea and greengram ranged from 12 to 30kg N/ha. The possible advantages of straw incorporation of greengram in soil after picking up the pod was reported by Meelu and Rekhi (1981). They suggested that green manuring of greengram straw could save as much as 60kg N/ha for the succeeding crop of rice. This is a new avenue for saving considerable amount of nitrogen and could be tried with other crops like cowpea and groundnut both under irrigated and rainfed conditions.

5.2.2: Cropping Systems Excluding Legumes:

The experience gained from drylands revealed that when recommended doses of nitrogen are applied, no residual effect is perceptible in the second crop. In the maize-wheat sequential system tried on sub-montane sandy loam and loamy sand soils of Ludhiana, the advantage of application of nitrogen was confined to maize crop, the same not being reflected in the unfertilized wheat crop following maize.

Progressive response to nitrogen applied to wheat following maize was observed suggesting that both the crops need to be fertilized with nitrogen independently (Singh 1982).

However, monsoon fallowing which is a common practice in some dryland areas in India has shown to produce definite advantage in saving nitrogen for the safflower crop grown in post-monsoon season. Results of the experiments conducted by Das *et al* (1982 in medium black soils of Hyderabad to study the response of safflower to nitrogen and phosphorus application in fallow-safflower and sorghum-safflower cropping systems showed that 20kg N/ha could be saved by monsoon fallowing.

Evaluation of residual use of fertilizer nitrogen using N-15 was made at ICRISAT, Hyderabad, in black soil using sorghum-safflower sequence cropping system (Kanwar and Rego 1983). Sorghum was fertilized with N-15 urea at the rate of 74 kg/ha during the monsoon season. Nitrogen recovered by the first crop of sorghum was found to vary from 28.9 per cent to 55.6 per cent depending on the method of application (Table-6), split band application method, resulting in higher recovery (55.6 per cent) of applied nitrogen.

TABLE-6: Effect of Method of Application on the Fate of 74kg Labelled Urea N/ha Applied to Rainy Season Sorghum on a Vertisol in 1981

Application method	N% recovered			N% loss or unaccounted
	Soil	Plant	Total	
Split band	38.6	55.6	94.2	5.8
Surface	41.8	30.5	72.3	27.7
Incorporation	45.2	28.9	74.1	25.9
S.E.±	2.69	1.55	2.08	

Source: Kanwar and Rego (1983)

A significant amount of the applied nitrogen (38.6 per cent to 45.2 per cent) was left out in the soil. Safflower grown in post-rainy season could recover 1.1 to 3.1kg N/ha of the fertilizer nitrogen applied to sorghum. This further suggests that a considerable amount of nitrogen is left unutilized in the soil.

It is thus clear that nitrogen should be managed independently crop-wise in a cropping system, as no residual effect of N is discernible. In the case of potato-wheat sequence, however, nitrogen could be used judiciously. On the other hand, wheat after pearl millet or sorghum will be requiring about 25 per cent more nitrogen in addition to the recommended dose.

5.3. Green Manuring in Cropping Systems: The recent interests in green manuring are: i) to adjust the crop to be manured into the system without sacrificing any crop, ii) to quantify the gain in nitrogen by green manuring so that the balance amount could be applied in chemical form, and iii) to study the long term effect of green manuring. Most of the studies made in India fulfilled the first two objectives. For drylands, three situations have been identified where green manuring/ green leaf manuring is feasible and considerable economy in nitrogen is possible. They are:

i) Sowing a crop like greengram with the earliest monsoon showers, picking up the pods of the first flush, ploughing in the residues and then sowing the late monsoon crop or early post-monsoon crop. This practice is in vogue in some deep black soil tracts of Andhra Pradesh. Feasibility of this practice has also been demonstrated in deep red soils of Bangalore.

ii) Experiments carried out at Hyderabad showed that castor manured with 10kg N+cowpea green manuring yielded as much as did the castor fertilized with 40kg N/ha, indicating a legume effect of 30kg N/ha in the third year.

iii) By green leaf manuring coupled with small dose of nitrogen (25kg N/ha) reasonably good yield of sorghum was possible to harvest. This system holds great promise for dryland crops.

5.4. Nitrogen Management in Crop Rotations:

5.4.1. Legume-based Crop Rotations: Studies conducted at Jodhpur by Singh et al (1981b) in medium to deep sierozemic soils with greengram-pearl millet crop rotation showed that the highest productivity was obtained when greengram was inoculated and fertilized with 40kg P_2O_5/ha, followed by top dressing of pearl millet with 20kg N/ha (Table-7).

TABLE-7: Mean Productivity of Greengram - Pearl millet Sequence System (1976-1979)

Treatments		Mean productivity (q/ha)	Net Income (Rs./ha)
Fertilizer applied to greengram	N applied to Pearl millet		
1. Control (without P and inoculation)	N_0	17.5 (8.5)	4,235
	N_{20}	20.5 (11.4)	4,540
2. 40kg P/ha+ inoculation	N_0	20.8 (10.4)	4,730
	N_{20}	24.9 (14.5)	5,173
3. 40kg P/ha only	N_0	20.1 (9.9)	4,608
	N_{20}	24.4 (14.2)	5,075
4. Inoculated only	N_0	20.1 (10.0)	4,775
	N_{20}	22.7 (12.7)	5,030

Note: Figures in parenthesis indicate the grain yield of pearl millet

Source: Singh et al (1981b)

The effect of legume-based crop rotations on the succeeding crop of sorghum in shallow red soils of Hyderabad was studied by Das et al (1982b). Results obtained from their study showed that sorghum yield was increased when sown after cowpea, greengram and groundnut (Table-8).

TABLE-8: Effect of Preceding Cropping Systems on the Grain Yield of Sorghum Taken in 1982

Preceding crops	Average grain yield of sorghum (q/ha)
Castor	21.7
Sorghum + redgram (2:1)	20.7
Redgram	20.2
Groundnut	24.5
Cowpea	27.3
Greengram	26.2
Fallow	23.6

Source: Das et al (1982b)

5.4.2. Cereal-based Crop Rotations: In a long term study, it was observed that application of sheep manure, in general, gave substantially higher productivity of rainfed pearl millet grown in continuous pearl millet - pearl millet system than application of urea (Singh et al 1981a). However, the efficacy of the organic source of manure was pronounced with time when the chemical source of nitrogen was more effective in the initial year. Application of urea at the rate of 40kg N/ha every year produced higher yield than that obtained with sheep manure applied at the rate of 40 tonnes/ha once in two years. In subsequent years, application of sheep manure gave significantly and consistantly higher grain yield and moisture use efficiency.

The residual beneficial effects of application of farm yard manure (FYM) at the rate of 20 to 40 tonnes/ha once in two years to pearl millet in pearl millet - pearl millet cropping systems were conspicuous in case of seed yield of clusterbean taken after five years of continuous pearl millet cropping systems (Table-9).

TABLE-9: Seed Yield (q/ha) of Clusterbean (FS-277) Taken after 5 Years of Continuously Fertilized Pearl millet-Pearl millet Cropping Systems, Jodhpur (1980)

Treatments	Seed yield (q/ha)	% increase in yield over control
1. Control	4.7	-
2. 20kg N/ha inorganic every year	5.9	27.7
3. 40kg -do-	5.3	13.5
4. 40kg N/ha once in 2 years	5.9	27.5
5. 10 t FYM + 10kg N/ha every year	7.0	49.9
6. 20 t FYM once in two years	7.1	51.8
7. 40 t FYM once in 2 years	7.7	65.6

C.D. 0.05 = 0.11

Source: Singh (1982)

5.5. Nitrogen Management in Alternate Land Use Systems: Preliminary studies on the scope of lay farming in poor soils under dryland conditions have been made. Studies conducted by Reddy et al (1981) on shallow red soils at Hyderabad have shown that sorghum grain yields were significantly higher in the system where stylosanthes was grown consecutively for two years when compared to the system in which traditional crops were grown. Stylosanthes being a leguminous crop had helped to build up the soil fertility which was reflected in better plant growth and enhanced yields when sorghum was taken after stylosanthes.

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NITROGEN MANAGEMENT IN RICE-BASED CROPPING SYSTEMS

KEY WORDS: Acid sulphate soils Azolla Deepwater rice Dry seed rice Nitrogen loss Rainfed rice Ratoon rice Rice straw Saline affected soils Green manures Delayed release N fertilizers.

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SUMMARY

Nitrogen is essential for higher productivity of rice-based cropping systems. As crop intensity increases, the nitrogen status of the soil under each system must be balanced and enriched. Nitrogen management should begin during the growth of the dryland crop planted before or after the main rice crop to assure optimum soil fertility. Better N efficiency can be obtained by continuous application of organic matter such as rice straw mulch, green manures especially *Azolla* and *Sesbania* spp. in addition to good timing of N fertilization. Delayed release N fertilizer sources may be useful.

Through the years, by trial and error, the Asian farmer has developed cropping systems best suited to his conditions. He takes advantages of his existing land qualities, weather and climate, crop varieties, and available labor force to make higher and higher economic return. From the most primitive hillside slash-and-burn farmer or from the tidal swamp farmer, to the most modern fully irrigated dryland or wetland farmer, there are always appropriate ways and means to get some benefit out of available natural and human resources.

The various cropping systems in Asia has been reviewed by various authors. Whether rainfed or irrigated, main rice cultivation usually coincides with the period of highest rainfall. Before and after the main rice crop, farmers may grow one or two dryland crops, or even another rice crop. There is a great diversity in dryland crops most of which are short of duration to fit the most favorable climatic conditions for crop growth. The dryland crops may include wheat, maize, sorghum, millet, jute, cotton, tobacco, sugarcane, etc.

However, the potential production has not been tapped. One of the constraints is maintenance of soil fertility with intensive cultivation. For the rice farmers, this is more pronounced especially when improved rice varieties are used. While in some areas double- or triple-rice cropping causes yield decline, the better managed areas produce 15 to 18 t/ha with three crops a year in the Mekong Delta. This paper will briefly review the various methods for maintaining nitrogen fertility status of rice soils planted in rotation with other crops.

EFFECT OF CROP ESTABLISHMENT ON PLANT GROWTH

The ability of a crop to response to management inputs depends largely on its early establishment. This may be affected by land preparation, soil acidity or salinity, water quality, flooding, rainfall and temperature. Particular attention is paid to the establishment of a dryland crop on puddled rice soil. Because rice soils in tropical regions are usually puddled, a process that destroys soil aggregates, planting of dryland crop after rice often involves problems. A recent study (IRRI 1984), showed reduced productivity, possibly due to a low response to applied fertilizers. It is not surprising that many farmers choose the rice-rice or even the rice-rice-rice patterns for greater benefits. Even so, with rainfed rice yield of the second rice crop was low compared to the first crop (IRRI 1983). The causes for this low yield were high insect infestation (IRRI 1982), physiological disorder, and diseases. N fertilization should be tailored to give good response. Dryland crops after rice suffer from poor soil structure and cannot efficiently utilize nitrogen. Poor growth of soybean plants has been observed with short roots confined to the dibbled holes, when grown on a no-till puddled rice soil.

INORGANIC NITROGEN FERTILIZATION

In rice-based cropping systems it is esstential that all effort should gear toward maximizing the yield of the main rice crop. The fertility of the soil can be maintained or improved before, during, or after growing rice. Dei and Yamasaki (1979) found, that drying the soil during the fallow period increases the release of soil nitrogen.

Management Before and After the Main Rainfed Rice Crop

The dryland crop before or after the main crop should receive sufficient NPK fertilizers in combination with mulching by straw (Syarifuddin 1982, Zandstra 1982, IRRI 1978) in order to attain good yield and to assure good rice yields afterward. Studies of delayed release N sources such as sulfur coated urea (SCU), urea supergranules (USG) and prilled urea (PU) on corn before rice, showed no significant difference (IRRI 1983). Apparently a dryland crop before rice would leave more organic matter to the soil, thus increasing N supplying power of the soil. For acid sulphate soils we observed that a dryland crop during the dry season in fact suppressed the formation of acid producing substances, hence the following rice crop is less vulnerable to acidity of the soils.

During the last few years, dry seeded rice (DSR) becomes more popular as a crop preceding wetland transplanted rice (TPR). In the United States, irrigated DSR is a normal practice. Experiences there showed that for DSR, it is better to place preplant N fertilizer below the soil surface or with the seed rather than preplant broadcast (Miears and Harell, 1959). For only basal application or for early N application, SCU is more advantageous (Patnaik and Rao, 1978). Polthanee (1980) found that for DSR, PU fertilizer broadcast in 3 splits gave the highest grain yield. Although rainfed DSR had not received due attention, Hopper (1982) in reviewing available results found that split application of N fertilizers is better. In the Mekong Delta of Vietnam, DSR is a solution for double cropping of rice in moderate acid sulphate soils and saline-affected soils where, in the old days farmers had to wait for good rain to leach off toxic substances before they could transplant their only yearly rice crop.

Management of Deepwater Rice Areas

In deepwater rice areas, effective tillers that contribute to yields were those developed prior to the rise of floodwater. N fertilizer therefore is applied to the field when there is sufficient moisture in the soil during early establishment. Application of 25 kg N/ha at field capacity for Nang Tay C floating rice variety was the optimum dose (Table 1). A farmer's field survey in Bangladesh revealed no response to N fertilizer in deepwater rice (Catling and Alam, 1981). The thick biomass produced by the deepwater rice crop is crucial for the success of the next dryland crop. It is an excellent mulch, for retaining of residual moisture. It decomposes gradually to increase moisture and nutrient holding capability of the soil.

Table 1. Panicle Number and Yield of Nang Tay C Floating Rice as Affected by 4 Methods of N Fertilization. The total rate per treatment was 25 kg N/ha. (University of Cantho 1973, Unpublished Data).

Treatments*	Panicle No./sq m	Grain Yields (t/ha)
14 DE	56	1.55
14 DE - 30 DE	65	1.82
FC	91	2.45
FC - PI	92	2.62

* DE = days after emergence
FC = field capacity
PI = foliar spray at panicle initiation

Mungbean, soybean, sesame, corn, etc. after deepwater rice need little additional water to grow. Water is only used to dissolve urea into solution for application with a sprinkling bucket. Along the river where complete irrigation control is available, two rice crops are planted, respectively at the start and at the end of the flood season, resulting in a rice-flood fallow-rice cropping pattern. If the area is flooded early and water rises rapidly so that the first crop is submerged, jute can be planted instead of rice.

In other places where residual moisture is limited, a ratoon rice crop of more or less 1 month, is an economical practice. Ratoon rice yield can be optimized if N fertilizer is applied 3 days before harvest of the first crop. With 60 kg N/ha, a rice ratoon may yield upto 41 % of main crop yield in less than a month (IRRI 1983).

Management in Tidal Swamp Rice Areas

Soils in tidal swamp areas are mostly unripe. They can be ridged if half ripe or ripe, to form successions of furrows and raised beds. Dryland crops such as corn, soybean, sweet potato, mungbean, etc. are planted on the raised beds and rice in the furrows. The soils are often peaty in the upper 20-50 cm underlain by potential acid sulphate clay. The raised beds should not bring up the clay on the top of the beds. The clayed furrows should always be flooded to prevent oxidation of the sulfidic materials. Hence rice roots are healthy, ready to absorb applied fertilizers. Where the soil is unripe, however, ridging is impossible.

Some indigenous farmers have created a shrimp-rice pattern. The shrimp encatchment simultaneously brings in fresh marine sediment every dry season. In rainy season, if the first few rains flush away the salinity, then a good rice crop is possible, yielding more than 4 t/ha paddy with little added N fertilizer.

Management of the Main Rice Crop

It was observed that nitrogen loss through floodwater can amount to 50 - 70 % of the total fertilizer, if applied by broadcast in floodwater (Prasad and De Datta 1979, Khan et al., 1983). Studies in tailoring N requirements of the rice plant showed, that the amount as well as the time of application of N fertilizers depend largely on the rice variety, soil type and the planting season. Depending on a specific situation, a specific "researcher's best split" method of N application is prescribed. Other methods for reducing N losses in rice field are:

(1) Cultural method, i.e. through incorporation of fertilizer materials into the soil;

(2) Use of non convential N sources such as USG, SCU, PCU (silica polymer coated forestry grade urea), urea briquettes, mudballs (Prasad and De Datta 1979). Among them SCU seems to be relatively effective;

(3) Deep placement of N fertilizer at a depth of 10 cm below the soil surface. A point that needs to be emphasized here is that the closing of the fertilizer furrows must be guaranteed. Khan et al (1983) have designed hand machines to perform such an operation;

(4) Use of urease inhibitors such as neem cake at 100 kg/ha (IRRI 1982) can remain effective 1 to 5 weeks after applicaiton, or phenyl phosphoro-diamidate (PPD) at 1 % (wt/wt) (IRRI 1983 and IRRI 1984).

Table 2. Effect of NPK on yield of IR30 on a moderate acidic alluvial soil.(5th Consecutive Crop, Univ. of Cantho, Wet Season 1976).

N - P - K Rates	Grain Yields (t/ha)		Index (%)
0 - 0- 0	1.09	a	100
0 - 0-30	1.58	a	146
0 -40- 0	2.12	ab	196
0 -40-30	2.79	bc	258
0 -80- 0	2.96	bc	274
0 -80-30	2.98	bc	276
50 - 0- 0	1.33	a	123
50 - 0-30	1.28	a	118
50 -40- 0	4.45	de	412
50 -40-30	3.28	bc e	303
50 -80- 0	4.46	de	413
50 -80-30	3.91	c e	362
100- 0- 0	2.11	a	195
100- 0-30	1.15	a	106
100-40- 0	4.36	e	403
100-40-30	3.87	c e	358
100-80- 0	3.75	c e	347
100-80-30	3.66	c e	339

(Means followed by same letter(s) are not significantly different at 5%)

Withholding of N Fertilizer

There are field conditions where N fertilizer instead of being applied more, should be withheld temporarily:

1. In P-deficient soils, particularly acid soils, the correction of soil chemical qualities by moderate liming and P application is a condition for better utilization of applied N by rice roots. If only N is supplied (tab. 2) a higher rate of N negates its own effect (Vo-Tong Xuan and Ha Trieu Hiep 1976);
2. During the second rice crop establishment, (a) after the harvest of the first one, or (b) after incorporating fresh weeds and other organic material into the soil, a peak production of organic acids and hydrogen sulfide will soon occur. Rice leaves turn yellow and roots are turning black. If N fertilizer is applied at this time, the rice plant turns yellow more quickly and dies within a week. The additional N stimulates microbial activities which produce greater amounts of toxic substances. In this case, N fertilizer should not be used, and field water should be drained several times a week. When new rice roots appear, it is safe to apply more N.
3. If the rice crop suffers from some diseases, especially rice blast, sheath blight or bacterial leaf blight, N fertilizers must not be used until disease symptoms disappear.

ORGANIC NITROGEN FERTILIZATION

Organic matter is well known for its effect not only on improving soil physical conditions but also on increasing nitrogen supplying capacity of the soils. Dei and Yamasaki (1979) proved that as the amount of N contained in the organic matter is continuously applied to soils for a long period of cultivation, it maintains the N supplying power of the soils. However, the maximum limit of organic matter to give optimum rice yield is about 5% (Oh 1979).

Rice Straw

In tropical Asia, before the invention of Improved varieties, farmers grow photosensitive rice. Only one crop per year was possible. The rice straw left after harvest was a source of organic fertilizer for the soil for the next year's rice crop. As improved varieties are planted widely, the return of straw becomes erratic. Studies on the decomposition of rice straw showed that the straw decomposes quickly in submerged soils. Adding more straw adds ammonium-N and K (IRRI 1984). The contribution of straw in biological nitrogen fixation in rice soils cannot be overlooked.

Azolla

This water fern has long been a winter crop in rotation with rice in northern Vietnam. The first use of Azolla as green manure for rice was studied by Nguyen Cong Tieu (1930). Today, using improved varieties, Vietnamese farmers practice the following cropping systems (Dao The Tuan and Tran Quang Thuyet 1979, and Tran Quang Thuyet 1980):

(1) Spring Rice (Impr. var.)-Early Summer Rice (Impr. var.)-Azolla (or soybean)
(2) Spring Rice (Impr. var.)-Late Summer Rice (traditional)-Azolla
(3) Winter/Spring Rice (traditional)-Azolla-Late Summer Rice (traditional)

In these systems, the Azolla crop grows in the period of lowest temperature when growing rice is impossible. The Azolla crop may produce in 2 months about 10 t/ha of biomass, equivalent to 25 kg N/ha. This huge mass is then incorporated into the soil before transplanting rice. In China, Azolla is grown either together with rice in between rows of rice plants or as a separate crop (Chu 1979). Azolla turned in under the soil once, gave a rice yield increase of 632 kg/ha, while turning twice gave 1.27 t/ha increase (Chu 1979).

Sesbania spp.

Another popular leguminous shrub grown in rotation or in multiple cropping with rice in Vietnam is *Sesbania* spp. to produce N for the succeeding crop. Four methods of using *Sesbania* spp. are distinghuished:

(1) Rice seedling nursery - *Sesbania cannabina*

(2) *S. cannabina* intercropped with sweet potato - Rice

(3) *S. cannabina* sown on raised beds or mounts between rows of rice at dough stage; then, after 2 months, the plants are turned under in the soil together with rice straw.

(4) In southern Vietnam *S. sesban* and *S. paludosa* cuttings are planted in between every 4 rows of rice plants at heading time. The plants continue growing long after the harvest of rice, also in the dry season while covering the soil from excessive dehydratation.

Each ton of *cannabine* produces approximately 5 kg N/ha (Do Anh 1980).

CONCLUSION

As fossil-based nitrogen fertilizers become limiting, organic and biologically fixed nitrogen should be an appropriate answer to meet the crop's needs. The techniques described above, can be made more popular among rice-based cropping systems farmers to help improving their income and at the same time to maintain our environment.

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SYSTEMS APPROACH TO NUTRIENT MANAGEMENT WITH SPECIAL EMPHASIS TO NITROGEN

Key Words: Soil Fertility Integrated Plant Nutrition Systems

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SUMMARY

For meeting their food requirements, developing countries as a group will have to increase their fertilizer consumption four to five fold by the year 2000. This projection, however, has to be viewed in the context of high prices of fertilizers and reduced availability of foreign exchange for their purchase. High efficiency of mineral fertilizers use as well as maximum use of available alternative renewable sources of plant nutrients such as organic materials and biological nitrogen fixation need to be ensured. The concept of systems approach to plant nutrition, received increasing attention in recent years.

INTRODUCTION

The FAO study 'Agriculture: Toward 2000' (FAO, 1979) estimates that to match the food requirements of increasing population in developing countries, a doubling of agricultural production between 1980 and 2000 would be necessary. The production growth rates envisaged require almost an agricultural revolution involving not only sustained and substantial expansion of the land and water base but also intensification of the production process itself.

The future availability of agricultural land and the agricultural labour situation will strongly influence the specific country pattern of input use. In countries with little new land to bring under cultivation, almost all increases in crop production will need to come from raising yields and cropping intensity. By contrast, land-abundant countries follow a development path of more equal shares between expansion of arable area and intensification of its use.

Any system of intensive cropping drains from the soil very heavily the available plant nutrients which should be replenished. This is reflected in the estimate of a fivefold increase in fertilizer consumption in 2000.

The intensification of developing-country agriculture through an increased input of commercial energy may seem a paradox in an age of energy shortages, their high prices and reduced availability of foreign exchange for their purchase. However, this seems to be inevitable for acceleration of their food crop production. If it should come to a choice of priorities in allocating scarce energy supplies, agriculture must be assured of its supplies at equitable prices.

At the same time, for reasons of economy and energy conservation, FAO is very much concerned about development and transfer of technologies for achieving the highest possible efficiency in the use of mineral fertilizers and renewable sources of plant nutrients like organic materials and biologically fixed nitrogen. The concept of systems approach to plant nutrition, integrating all sources of plant nutrients especially N into a productive agricultural system has therefore received increasing attention during recent years.

CONCEPT

Systems approach to plant nutrition conceptually integrates three systems: (1) soil fertility conserving and enhancing soil management and cropping systems; (2) plant nutrition based on cropping system as a whole rather than for a single crop in the system, and (3) integrated plant nutrition systems (IPNS) for maintenance and possibly increase of soil fertility for sustain or increased crop production.

The aproach is not new, appropriate crop rotations, and the simultaneous and complementary use of mineral fertilizers and organic materials have been practiced for many years. Efficiency oriented research has since brought about new technologies and better methods of production and use of mineral fertilizers and organic materials. At the same time, soil fertility conserving and enhancing cropping practices and systems had been developed and are still being further developed. What is needed, is to increase implementation of this approach.

COMPONENTS AND TECHNOLOGY

(1) Soil Fertility Conserving and Enhancing Systems

With continuous and intensive cultivation and use of high yielding varieties the nutrient supplying capacity of soil may be limiting. To enhance the soil nutrient supply the following should receive greater attention:

- Appropriate soil management and conservation practices to reduce losses of nutrient;
- Improvement of soil physical conditions to assure maximum possible efficiency of applied nutrients;
- Amelioration of problem soils in mobilising unavailable nutrients;
- Use of appropriate crop varieties, cultural practices and cropping systems to maximize utilization of available nutrients;
- Introduction of a legume crop in the cropping system, that can benefit the accompanying or the succeeding non-legume crop;
- Introduction of alley-cropping system with quick growing leguminous trees like Leucaena leucocephala with cereal/root crops. In this system soil nitrogen will be conserved and regenerated along with other nutrients, through exploitation from the deeper soil zone and recycle to the surface by the green loppings. The loppings would also serve as mulch adding organic matter, conserving soil moisture and for protection from erosion. The twigs could be used as a source of fuel, saving partly valuable cowdungs for manurial purposes.

(2) Plant Nutrition based on Cropping Systems

Until recently, research efforts have been directed to finding an optimal fertilizer formule based on single crops. It is increasingly recognized, that fertilizer use efficiency can be further increased if an optimal fertilizer could be prescribed for a cropping system. This takes into account the various components, such as:

- Effect of previous crop and its fertilization on the succeeding crop;
- Contribution of legumes in the cropping system;

- Residual effect of applied fertilizers particularly of P;

- Best time and method of application of fertilizers;

- Level of soilwater-crop management;

- Cumulative effect of organic manures etc.

Roy and Braun (1983) recently reviewed the fertilizer management practices for multiple cropping systems. An expert Consultation meeting on this subject has identified some principles for nutrient schedules for some important cropping systems (FAO, 1983) as summarized below.

(a) Sequential Cropping

(i) In a low fertility soil, for crops requiring large amount of nutrients, it is necessary to apply recommended doses to all the crops grown in sequence.

(ii) In the absence of any appreciable residual effect, each crop should receive the optimum dose of fertilizer N, particularly in rotations which do not include a legume.

(iii) With inoculation and adequate P fertilization, a legume crop requires small amount of nitrogen (starter dose of 20 kg N/ha can be adequate). It can also provide N in its residues (20-50 kg N/ha) for the succeeding crop.

(iv) For nitrogen economy, organic manures should be applied to the wet season crop rather than to dry season crop.

(v) Proper phasing of fertilizer application appears essential for maximum efficiency on the succeeding crop. For potato based cropping systems for example, application of P and K to the potato crop gives better results. Similarly, in a legume based system, P should be applied to the legume crop.

(vi) For medium fertility soil P should be applied to the dry season crops , so that the benefit of residual P accrues to the following wet season crop. Similarly, K application in wet season crops has been found more profitable.

It is suggested, that fertilizer schedules for efficient and widely used sequential cropping systems for the various agro-ecological zones should be worked out, superimposing some of the above mentioned fertilizer recommendations for individual crops. This should be followed up by adaptive trials in farmers' field to refine the formules.

(b) Intercropping

(i) When two or more crops are grown together in subsistence farming, the level of fertilizer use is generally low as available supplies of fertilizers are often limited. Under these conditions additional fertilizers application will be beneficial.

(ii) When intercropping is practiced to enhance the utilization of limited agronomical inputs such as irrigation water, no extra fertilizer is added to the intercrop.

(iii) The same holds true if an intercrop is grown not so much for its extra yield but for its weed -suppressing effect or as a green manure. Small amounts of nitrogen may be given in such cases in order to avoid any decrease in yield of the main crop as a result of competition for nitrogen between the main crop and the intercrop.

(iv) If the objective is to maximize plant production per unit of area and time, optimum quantity of nutrients must be applied to all crops in the combination.

(v) Intercropping has shown better fertilizer utilization than any of the component crops grown alone.

(vii) Calculation of fertilizer requirement based on nutrient balance can be used as a rough guide.

(viii) Most intercropping patterns allow localized placement of a particular nutrient depending on specific crop needs. This is very important for nitrogen application in cereal-legume combinations.

(ix) Intercropping cereals with legumes is a promising method for providing N to a subsequent cereal crop without special investment of time and land for growing a green manure crop.

(x) The most suitable rate of N in cereal-cereal combination is higher than the cereal-legume combination.

Integration of response functions, residual effects, etc. into a dynamic model based on long term soil fertility experiments is needed. Soil testing calibrated for fertilizer recommendation for cropping systems rather than for component crops of the system is also needed.

(3) Integrated Plant Nutrition Systems (IPNS)

Efficient use of various external plant nutrient sources including mineral fertilizers, organic manures, biologically fixed N and N from precipitation. The primary aim of the integrated approach is to utilize the available sources in judicious and efficient ways.

(a) Mineral Fertilizers

Mineral fertilizers play an important role for sustaining and improving agricultural production. Four-to-five fold increase in fertilizer consumption is expected in the developing countries as a group by 2000.

Because of the high price and unavailability of foreign exchange and danger of pollution with excessive fertilizer use there is a need to increase efficiency of fertilizer use.

Various agro-techniques for optimizing fertilizer use efficiency are available (Braun and Roy, 1983) including:

- better scheduling of recommendations based on a cropping system rather than for a single crop in the system.

- identification of specific fertilizer material for certain soils and crops.

- minimizing losses with appropriate time and methods of applications.

- manipulation of particle size, use of coating materials and chemicals to reduce the dissolution rate and bio-chemical processes in the soil.

- balanced application, including secondary and micronutrients for synergistic interactions.

- improving all other production factors like water management, disease and pest control, weed control, etc.

(b) Organic sources

The Nutrients present in dung, crop residues and other organic materials can be utilized as farmyard manure, compost or for direct application at organic residues and mulch. Though these practices are commonly used by farmers, considerable improvements are possibly, as shown below:

-Farmyards Manures:

Theoretically, the maximum benefits if increased soil fertility and tilth are derived from the direct application of fresh manure to the land. As farmers commonly use animal wastes and crop residues to make farmyard manure, its quality is affected by the methods of preparation, storage and application. The quality and composition vary widely depending on the type and age of animal, feed composition and of use to which the animal is put. The solid and liquid excreta are rich in nitrogen, while straw and plant residues used for bedding have large amounts of carbon and small amounts of nitrogen. Storage in small heaps, exposed to sun, air and rainfall accounts for substantial nutrient losses. If straw and crop residues are used as bedding, the manure stocks should be stored in large heaps protected from sun, kept moist during storage to minimize losses in nutrients. The manure when applied at the time of land preparation for cultivation, will give highest benefit.

-Rural Composting:

Though improved technology is now available, yet in most cases it is not used by farmers. It is therefore important to motivate farmers not to waste the farm residues but to conserve and compost them in the correct way.

-Mechanical Composting:

Establishing compost plants in the urban areas to process the refuse for agricultural purposes has been successful in many developed countries. However, this has been of limited success in developing countries due to higher cost of production and transportation of a low grade nutrient source.

-Incorporation of Crop Residues and Mulching:

Crop residues are important renewable, organic sources readily available to farmers. When composting cannot be practiced, they could be directly applied to the field. Their effect on improving soil properties, conserving soil moisture and controlling weeds are well recognized. However, their availability is very often constrained as they are used by farmers as a source of fuel and feed for the cattle. While using wide C/N ratio materials, care should be taken to supplement with nitrogen and phosphorus. Otherwise crop growth will suffer due to their deficiency caused by microbial immobilization during the initial period of decomposition.

-Sewage/Sludge:

Special consideration should be given to sewage treatment. Disposal of sewage sludge by incineration, fresh water dilution, land-fill and ocean dumping should be discontinued. As sewage sludge is a valuable organic resource consisting of about 40 to 60% organic matter and contains both macro and micro-nutrients, the proper land application methods for its disposal should be adopted. Even though both sludge and treated sewage water can be produced in a safe way for agricultural uses, lack of public acceptance can be a problem and strong publicity campaigns would be needed to promote their use.

-Biogas Technology and Uses:

Biogas technology was evolved on experimental basis during the second World War and has gained popularity especially in China and India where the biogas plants at present exceed one million and 100,000 units, respectively. The process of biogas generation is essentially a digestion of organic wastes under controlled anaerobic conditions, whereby a mixture of methane (combustible gas) and carbon dioxide is produced. The biogas manure obtained is relatively high in nitrogen content (e.g. 1.5% against 0.75% in farmyard manure), free from offensive odour and parasites. The overall process conserves local fuel, wood or imported oil and upgrades it into an excellent organic manure from crop, animal and human wastes. Since the World Food Conference in 1974, FAO has undertaken an active role in the implementation of the organic recycling programmes.

-Biological Sources:

Legumes contribute to soil fertility directly through their unique ability to fix atmospheric molecular nitrogen in association with rhizobia. Nitrogen fixed by select leguminous plants/trees can be incorporated in the soil as green manures. Nitrogen fixation through some symbiotic and non-symbiotic micro-organisms can also be made available to the associated field crop.

-Green Manuring:

Raising of quick growing leguminous plants and burying them after 45 to 60 days has been practiced by the farmers for a long time. A leguminous green manure crop contributes about 30-40 kg N/ha to the succeeding crop. In the late fifties and sixties, with easy availability of mineral nitrogeneous fertilizers, the farmers found it cheaper and easier to buy nitrogen than to grow a green manure crop. However, with the present limited availability and high price of fertilizers, green manuring can be economically utilized. The practice has a higher chance for adoption by the farmer when part of the crop can be used for food or forage. For these reasons, the concept of "Alley Cropping", the combination of leguminous trees and field crops, seems to be a better alternative.

-Rhizobium Inoculants:

Enough is known to generate optimisms about prospects of enhancing the efficiency of the Rhizobium- legume symbiosis and to expand other associations to a considerable extent with a view to their large-scale adoption by farmers. Transfer of available knowledge from research to the farmer is urgently needed. In pursuance to this, work on Biological Nitrogen Fixation has been considerably strengthened by FAO, and field activities including trials, demonstration, training, inoculant production support, etc., have been started.

-Blue Green Algae and Azolla:

Considerable interest has been generated in the use of blue green algea and azolla for nitrogen fixation in water-logged rice fields. It is estimated that at the farm level they can contribute to about 25-30 kg N/ha. In the case of Azolla, application of phosphorus to maintain a certain minimum concentration in the water, the control of insect pests, etc. are essential for the proper growth of the fern. In the case of blue green algae (BGA) considerable variation in the amount of nitrogen fixation has been observed. Competition by native strains, presence of applied mineral nitrogeneous fertilizers, storage and transportation of the culture often posed limitations to its wider adoption. An assessment of the cost-benefit ratio to this technology in the overall rice production system would be necessary. FAO is actively engaged, specially in Asia, in supporting and promoting Azolla and BGA technology.

-Other Micro-organisms:

The beneficial effects of Azotobacter sp., Azospirillum, Mycorrhizae, etc. are also gaining importance. However, more information is needed before their use can be advocated to farmers.

PRACTICAL APPLICATION OF THE SYSTEMS APPROACH

To test the complementary and supplementary role of mineral fertilizers, organic materials and biological fixed nitrogen in crop production for different agro-ecological zones, research-cum-demonstration trials in farmers' fields are initiated in 17 countries in Asia and Africa within the framework of the FAO Fertilizer Programme.

CONCLUSIONS

The task of achieving the food production target by the turn of the century is undoubtedly colossal. However, if past experience is any indication, there is no doubt that the target can be achieved and the use of fertilizers will continue to play an important role in any strategy that is adopted for intensive farming. To economize on non-renewable energy sources, to improve the farmers' benefit/cost ratio and to safeguard from the probable deterioration of environmental quality, mineral fertilizers must be used in the correct way, integrated with other available renewable sources, to maximize their use efficiency. Plant nutrition should, therefore, be seen as an integral part of the farming system.

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DISCUSSION SUMMARIES AND RECOMMENDATIONS

Session I: DYNAMICS OF SOIL NITROGEN

J.N. Ladd, Chairman
A.T. Halm, Reporter

Observations from the Papers Presented

* The papers are collectively concerned with several processes of the nitrogen cycle (immobilization, mineralization turnover, nitrification, leaching and denitrification).

* Soil fertility will depend more on the level of "young" soil organic matter, formed by microbial transformation of crop residues during the previous 25 years, than on "total" soil organic matter. A large fraction of "old" soil organic matter may release little or no plant nutrient. Therefore, the higher the relative contribution of young soil organic matter in nitrogen flow, the greater and faster the loss in soil fertility when the supply of fresh organic material is neglected. The model for nitrogen mineralization/immobilization gives us better insight into the basic processes involved in organic matter and nitrogen turnover in soils, but its value has yet to be proven under farming conditions in the humid tropics.

* The highly weathered soils of the humid tropics are characterized by a large proportion of macro (or transmission) pores, resulting in rapid downward movement of excess water and leaving little time for equilibration with solutes in storage pores. Thus, the rate of nitrate leaching is lower than expected based on soil waterholding capacity and rainfall (intensity). The same factors may also reduce N losses caused by denitrification. Suitable management practices (timing of planting and fertilizer application) would minimize N losses.

* The processes in the nitrogen cycle that are considered relevant for a soil in the humid tropics were described by rate equations and incorporated into a simulation model. Some runs were made with this model under conditions (climate and soil properties) chosen to correspond as closely as possible to the situation at the IITA high rainfall substantion at Onne in south-eastern Nigeria. The results indicate that the potential uptake of N by a crop was largely determined by the depth of the root zone. Experimental results at Onne have shown that the maximal rooting depth is approximately 50 cm, even when lime is applied.

* Before management strategies can be developed for achieving optimal N use by crops, the various competitive processes must be quantified and integrated. Models can be useful tools for clarifying the interplay and interaction of the various processes in the soil nitrogen cycle. When a model has proven its reliability in numerous validation studies, it can be used to predict quantitatively the effects of management and can thus assist in the development of measures leading to more eficient use of both fertilizer and soil native nitrogen.

Recommendations

* There is an overwhelming need for data from a range of ecosystems and especially from tropical environments to test and validate new and existing models. This data from field experiments should be complemented with data from laboratory studies and should meet model requirements, as determined by sensitivity analysis. Information on root-soil interactions and root performance within the total rooting zone is particularly scarce.

* Because most N cycling processes are biological and responsible to the chemical-physical properties of the environment, serious consideration should be given to collaborative projects involving personnel in various disciplines. A close relationship should exist between the scientists who develop the models and those who conduct the experiments.

* Data should be obtained from: (1) detailed studies at one or more sites, and (2) studies designed to measure residual effects of applied fertilizer or organic N.

Session II: NITROGEN CYCLING IN DIFFERENT ECOLOGIES.

N. Ahmed, Chairman
R. Sylvester-Bradley, Reporter

Observations from the Papers Presented

* The aim of this session was to compare nitrogen cycling in a forest ecosystem from which the forest has been cleared and which has been colonized with secondary growth with that in a farming system based on a legume-cereal rotation.

* The trend of changes in N content in soils and leaves of secondary regrowth following clearing is not the same in mixed Dipterocarp forest as in Kerangas forest. In the Dipterocarp forest and its succession the trend of N content is primary forest < young secondary forest < old secondary forest. In the leaves the trend in N content is the opposite of that in the soil. In the Kerangas forest, the trend of soil N content is primary fores > young secondary forest and old secondary forest; in the leaves the trend is young forest > primary forest > old secondary forest.

* The role of legumes and fertilizers in supplying N to wheat crops and in maintaining soil organic N levels was investigated using 15-N methodology. The processes measured included:

  (I) N-fixation and N-uptake by legumes as influenced by soil available N and competition with rye grass.

  (II) Release of N and supply to wheat crops from decomposing legume residues amd fertilizers.

  (III) Release and uptake of soil-derived N after soil amendment with legume residues.

  Total recovery of 15-N in the soil and plant were calculated. Rates of decomposition of 14-C labelled legume materials in southern Australia were compared with decomposition of rye grass in U.K./Nigeria.

* The paper on nitrogen cycling in a forest ecosystem was not presented. In its place data on maize response to nitrogen and moisture status in sandy soils in a humid tropical climate were presented. On sandy soil the crop could suffer from moisture stress during the wet season as a result of low available water and shallow rooting. One day of moisture stress during the critical period of crop development caused a loss grain yield of 100 kg/ha. Under the humid conditions of Surinam, the best time to plant maize is April and the optimum N rate is between 170 and 250 kg/ha, giving a yield of 4.5 to 6.5. tons/ha. Under these conditions yield increase per kilogram of applied N was between 16 and 20 kg.

Recommendations

* Since some fast growing nonleguminous woody species are able to extract more soil N than others, they can be used as indicators of the N-supplying capacity of different soils in forest regrowth. These species can also be used in agroforestry systems and rehabilitation of wasteland.

* There is a need for more quantification of the key processes of nitrogen cycling in cereal-legume rotations. This data is the basis of sound management decisions for optimizing N use by crops. For each ecosystem studies should include wherever possible:

  (I) Direct measurement of various processes.

  (II) Use of 15-N methodology to determine the fate of specific N sources and their residues.

  (III) Measurement of total plant N, soil organic N and profile inorganic N at frequent intervals.

Session III: NITROGEN SOURCES AND CROP RESPONSES

K.W. Smilde, Chairman
H. Riswan, reporter

Observations from the Papers Presented

Biological Nitrogen Fixation (BNF)

* In many agricultural systems mineral N (soil and fertilizer N) may inhibit BNF. There is considerable potential for selection of legumes and rhizobia that are able to fix nitrogen in the presence of mineral N.

* In intercropping systems of legumes and nonlegumes, BNF is often limited by competition for other nutrients. It is important to study fertilizer requirements that maintain N-fixation under mixed cropping conditions.

* The need for inoculation of grain legumes should be assessed.

* Legume breeding programs should be conducted in the absence of N fertilizer.

* Research is needed to make inoculants more readily available and manageable under tropical conditions.

* The amount of N fixed by various legumes and the N release pattern of their mulch should be quantified so as to maximize N use. Cropping systems and cultural practices should be identified which will reduce N losses.

* Considering the potential of associative BNF, studies on the basic principles of the system should be continued in well-equipped research institutes.

* The use of Azolla sp. should be extended to more crops and more parts of the world wherever possible.

* Woody legumes that could be used for agroforestry/alley cropping/forage production should be identified, especially for the humid tropics dominated by acid soil conditions.

* Little work has been done so far on organic matter decomposition in acid Oxisols and Ultisols. It would be beneficial for teams of microbiologists, soil scientists and agronomists to undertake such work.

Nitrogen Fertilizer Use and Soil Acidification

* Continuous application of N fertilizers, such as urea and calcium ammonium nitrate, results in acidification of the soil, especially in low-activity clay soils and other soils of low buffering capacity. This process should be minimized by reducing N fertilizer use (avoiding losses by proper timing and split applications), practicing intercropping or alley cropping with legumes, and applying lime if possible.

* Liming acid mineral soils in the tropics should be directed toward neutralizing excessive amounts of exchangeable aluminium.

* Since lime is often not readily available or is too costly, further research should be done on the selection of acid-tolerant species and cultivars.

* Lime should be applied in crop rotations prior to the least acid-tolerant crop.

* Acid mineral soil mapping in the humid tropics, based on buffering components, exchangeable aluminium and manganese, is recommended.

Session IV: NITROGEN MANAGEMENT IN DIFFERENT FARMING SYSTEMS.

L.A. Nnadi, Chairman
S.K. Mughogho, Reporter

Observations from the Papers Presented

* The numerous and diverse farming systems of the tropics, based largely on the practice of shifting cultivation, have provided sufficient food as long as land was abundant and the population relatively small. However, with rapid increases in population, the fallow period has been drastically

decreased, resulting in lower productivity of the land and reduced food production. To reverse this trend, it is important that new and better systems be introduced or old ones modified. One of the best ways of increasing the productivity of farming systems is to include legumes; this minimizes the use of N fertilizers and is a good soil management practice.

* Nitrogen balance studies are important for tropical farming systems in West Africa. Use of proper crop residues, better fertilizer management, and more information on rotation, nitrogen mineralization/immobilization, leaching, etc., are essential for more efficient N management.

* Future work should aim at measuring N losses to the atmosphere and the effect of including animals in N cycling and balance.

* In alley cropping systems, use of high N-fixing shrubs could partially replace N application in cereals and provide a stable and low input alternative to shifting cultivation. If these shrubs are planted in hedgerows and their clippings applied to the soil, a maize yield of 2 t/ha from each crop can be maintained; yield declines sharply if no clippings are used. Leucaena hedgerows can contribute 40-60 kg N/ha to the companion crop. Alley cropping also reduces soil losses and increases the amount of soil moisture retained in the soil. More research is required to find trees/shrubs for alley cropping in acid soils.

* In live mulch systems of maize with leguminous cover crops, it was observed that maize and the cover crop seem to compete on a newly established field but not in an older field. The causes of competition (for moisture, nutrients, etc.) between crops and cover crops in the system should be studied further. Direct seeding of cereals and increasing N-fixation of cover crops also require greater attention.

* In nitrogen management studies conducted on acid Ultisols in the high-rainfall region of southeastern Nigeria, it was found that in selected cropping systems maize yield declines after the first year of cropping and that production can subsequently be maintained at a moderate level without large quantities of N. Cassava did not respond at all to N in the crop mixtures. Maize yield was highest following leguminous cover crops. On-farm research should be intiated in cooper ration with national institutions. Socioeconomists should be involved in monitoring and evaluating soil fertility trials. More research should be carried at suboptimal input levels (no lime, no fertilizer). Multiple cropping should be recognized as a proven and adequate farming system for low-input farming.

* Studies of nitrogen management in cropping systems on rainfed land in some semiarid regions of India support the following conclusions: (I) N use can be made more efficient by 2 to 3 split applications and deep placement of fertilizer for postmonsoonal crops; (2) use of bio-fertilizers (azospirillum, etc.) could add 20 to 30 kg N/ha; and (3) under ley farming the use of S. hamata in rotation with sorghum and pearl millet could contribute 100 kg N/ha/yr to these cereal crops. More studies are required on possible competition for moisture in alley cropping in semiarid combining alley-cropping and water harvesting needs wider testing. Attention should be given

to including animals in cropping systems. Also, dual purpose legumes should be found for leys so that farmers will not object their use.

* Nitrogen is essential for higher productivity of rice-based cropping systems. As crop intensity increases, the nitrogen status of the soil under each system must be balanced and enriched. Better N efficiency can be obtained by continuous application of organic matter such as straw and green manures, especially Azolla and Sesbania.

* FAO's systems approach to nitrogen management stresses the need to determine optimum fertilizer recommendations for cropping systems as a whole, taking into account the complementary and supplementary effects of organic sources and biologically fixed nitrogen.

MAIN RECOMMENDATION

* THE SYMPOSIUM RECOGNIZES THE ESSENTIAL CONTRIBUTION THAT NITROGEN MUST MAKE TO INCREASED CROP PRODUCTION IN THE TROPICS. IF FOOD CROP PRODUCTION IS TO MEET THE NEEDS OF INCREASING POPULATIONS IN THE FUTURE, ADVANTAGE MUST BE TAKEN OF BOTH NITROGEN FERTILIZERS AND BIOLOGICAL NITROGEN FIXATION. THE MEETING THEREFORE RECOMMENDS THAT INCREASED SUPPORT BE GIVEN TO RESEARCH ON NITROGEN FERTILIZER USE AND ON BIOLOGICAL NITROGEN FIXATION.

* RECOMMENDATIONS FROM THE SYMPOSIUM'S FOUR SESSIONS GIVE DETAILS ABOUT PARTICULAR RESEARCH NEEDS.

* TO ENSURE THAT FULL ADVANTAGE IS TAKEN OF RESEARCH BEING CONDUCTED IN DIFFERENT COUNTRIES OF THE TROPICS, IN DEVELOPED COUNTRIES AND AT THE INTERNATIONAL AGRICULTURAL RESEARCH CENTERS, A WORKING GROUP SHOULD BE ESTABLISHED, WHICH WILL MEET PERIODICALLY TO SHARE RESEARCH INFORMATION, ORGANIZE CONFERENCES, AND PROMOTE TRAINING AND TRANSFER OF TECHNOLOGY.

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