INORGANIC NITROGEN DYNAMICS UNDER DIFFERENT LAND-USE SYSTEMS ON AN OXISOL IN WESTERN KENYA

MSc Thesis
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Alfred E. Hartemink
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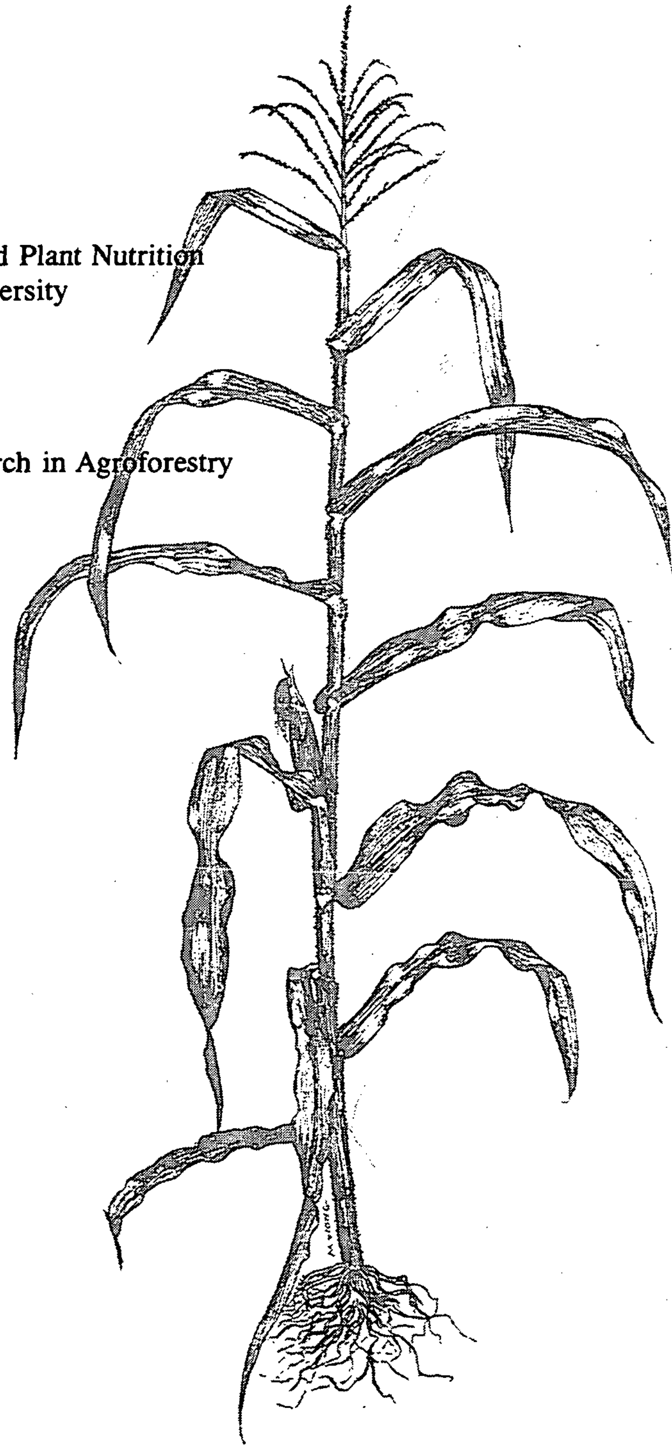

'If then the soil is to continue to grow plants for us, in turn we must grow plants for the soil'
George Milne, 1940

Wageningen Agricultural University

ICRAF
INTERNATIONAL CENTRE FOR RESEARCH IN AGROFORESTRY

PREFACE

This report presents the results of a 5 month period at the International Centre for Research in Agroforestry (ICRAF). During that period I conducted soil fertility research in Western Kenya and was based at Maseno Agroforestry Station. It served as partial fulfilment for a MSc-course '*Soil & Water*' at Wageningen Agricultural University in The Netherlands. It could not have been carried out without the help of many persons and I would like to single out a number of them:

I am greatly indebted to Bert Janssen, senior lecturer soil science and plant nutrition at Wageningen Agricultural University. Without his initiative I would not have been at ICRAF. He is also acknowledged for the efficacious discussions on the interpretation of the experimental data and the helpful suggestions for the final report. Bedankt Bert!

Roland Buresh, senior soil scientist at ICRAF and head of the nutrient management programme, is gratefully acknowledged for his tremendous support and supervision during my stay in Kenya. He shapened my scientific skills and interest to a great deal. Moreover his kind hospitality and the arrangements so that I could participate in a workshop on carbon cycling (TSBF/ICRAF etc., Feb. 1994), are deeply appreciated. In the leisurely hours we shared, he even taught me an American type of ball-game. Roland, thanks a lot!

I am further indebted to Bashir Jama, postdoctoral research fellow of the nutrient management programme in Maseno, for his good guidance, the daily fruitful discussions and his excellent flexibility when competing for limited research resources. Without Bashir my stay at Maseno Agroforestry Station would not have been so productive and pleasant. Asante sana daktari!

About 15 field workers at Ochinga farm who augered cumulatively more than 2.5 km deep are kindly acknowledged. They were headed by the professional foreman Tom Ochinga who never seems to lose his energy and sense of humour despite my preference for long days in the field.

Nancy, Rosalyn and Elijah of the laboratory in Maseno who carried out a little over 1800 extractions and filtrations, even at odd hours, weekends and public holidays, are gratefully acknowledged.

Director and staff of Maseno Agroforestry Research Station for their hospitality, and in particular the enjoyable discussions at lunch time, are kindly acknowledged.

The help of Richard Coe, senior statistician at ICRAF, is highly appreciated as he figured out the programme files for the statistical analysis of the experimental data. Moreover we had productive discussions on skewly distributed data and their analysis.

Peter Muraya, research officer at ICRAF, was so kind to solve a number of computer problems and adjusted configuration files for the statistical software.

Paul Smithson and other staff of the laboratory in Machakos are kindly acknowledged for the ammonium and nitrate analysis. Despite the time pressure and what perhaps looked like an endless stream of polycons from Maseno to Machakos, all results became available before I left Kenya which was extremely helpful.
John Kimble, Thomas Calhoun (SCS-NSSC) and Stan Buol (NC state Un.) are acknowledged for their help in soil classification.
John Ingram of Oxford University is thanked for the copy of the book and diskettes of the annotated bibliography on soil fertility research in East Africa.
This thesis is dedicated to Ariane and Bertrand, for more reasons than I wish to allude to here.

Kisumu-Nairobi-Amsterdam, 1994

Alfred E. Hartemink

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ABSTRACT

Nutrient depletion is an important cause for the decline of soil productivity in the subhumid highlands of Western Kenya. For the losses of nitrogen, leaching and denitrification are considered the major pathways. Trees may reduce the leaching losses and improve nutrient cycling by taking up nitrogen which is below the rooting depth of annual crops. An experiment has been set-up to obtain indirect information on the likelihood of leaching and denitrification under fallows and maize. Hereto inorganic nitrogen was monitored during the short rains of 1993 and nitrogen and water uptake was compared between 4 different land-use systems: *Sesbania sesban* fallow, maize, weed fallow and bare fallow.

At the beginning of the rainy season inorganic nitrogen contents of the 00-100 cm soil horizon ranged from 112 to 127 kg ha^{-1}. Hereafter a decrease was found in the inorganic nitrogen contents of all land-use systems followed by a likewise increase at the end of October. There were no significant differences between maize and weed fallow during the season. Under sesbania inorganic nitrogen contents were lower compared to maize and weed fallow. Inorganic nitrogen contents under bare fallow increased significantly during the season due to lack of nitrogen uptake and higher mineralization rates. NO_3-N contents decreased in the subsoils of all land-use systems at the beginning of the season but this was compensated during the season by mineralization *in situ* or nitrate leached from the topsoil. NO_3-N contents in the subsoils of sesbania were lowest indicating deep uptake or reduced mineralization rates. Under maize and weed fallow NO_3-N contents hardly differed in the subsoils though an increase was observed under maize in January possibly as nitrogen uptake has stopped. NO_3-N contents before and after 200 mm irrigation differed with 30 kg ha^{-1} which was lost from the 00-30 cm soil horizon and no increase of NO_3-N in the subsoils was found. As there was 97 mm percolating water it is likely that the 30 kg NO_3-N ha^{-1} were lost by leaching rather than denitrification.Though leaching losses occurs, subsoils have good capacities to adsorb nitrate which may retard leaching. Losses of nitrogen by denitrification are likely to be small as the soil water-filled pore space rarely exceeded 0.7 mL mL^{-1} at which denitrification is said to become important.

In December biomass production of sesbania was only 2.6 Mg ha^{-1} and was lower than maize (3.6 Mg ha^{-1}) and weed fallow (3.3 Mg ha^{-1}). The low biomass production of sesbania is hitherto not fully understood. Some tentative calculations on nitrogen uptake have shown that nitrogen uptake is highest under weed fallow and approximately equivalent to the change in inorganic nitrogen between the beginning and end of the rainy season.

From this one season experiment, it is concluded that nitrogen losses by leaching are more likely than by denitrification. Improving the phosphorus status of the soils not only improves the productivity but also results in reduced nitrogen losses. *Sesbania sesban* is not the most suitable species for improved fallows in Western Kenya as it has a low biomass production and hence a low nitrogen uptake.

1 INTRODUCTION

1.1 Background and Objectives of the Research

Soil fertility depletion and nutrient management in Sub-Saharan Africa (SSA) have received considerable attention during the last decade (e.g. Mokwunye & Vlek, 1985; van Reuler & Prins 1993). For many land-use systems in SSA, gross nutrient outputs exceed nutrient inputs and manure and/or inorganic fertilizers are required to balance the nutrient status (Stoorvogel & Smaling, 1990). High levels of external inputs are, however, not a feasible option due to the risk for crop failures and the uncertain profitability of external inputs (Reijntjes *et al.*, 1992). Therefore alternatives to sustain and improve the soil's productivity are needed.
One of the options for soil fertility improvement is the deliberate integration of trees in land-use systems, also called *agroforestry* (King, 1979). Trees can have beneficial effects on the soil (Nair & Fernandes, 1984; Young, 1986 & 1989) and successful results were booked in the humid parts of West Africa (Kang *et al.* 1990) but the number of quantitative studies on the effect of trees on acid soils in the subhumid tropics is still limited (Szott *et al.*, 1991). The general soil-agroforestry hypotheses are that appropriate agroforestry systems have the potential to control erosion and run-off, maintain soil organic matter and physical properties and promote efficient nutrient cycling (Young, 1989; Szott *et al.*, 1991; Buresh, 1993a).
The International Centre for Research in Agroforestry (ICRAF) based in Nairobi (Kenya) has the mandate for process-oriented agroforestry research which is designed to test hypotheses and to obtain scientific data on nutrient cycling and how trees and crops compete for water and nutrients (ICRAF, 1993). In this context the present study took place in the subhumid highlands of Western Kenya where acid and low fertility soils are widely spread (Andriesse & van der Pouw, 1985). Nutrient depletion is considered one of the main causes for the decline of soil productivity in Western Kenya and agroforestry systems may be a way to improve the soil fertility (AFRENA, 1990; Onim *et al.*, 1990). Nutrient losses under the existing land-use systems were calculated by Shepherd *et al.* (1993) and they suggested that leaching and denitrification were the major pathways for the loss of nitrogen. Direct quantification of leaching and denitrification under field conditions is difficult (Buresh, 1993b). An experiment has been set up to obtain indirect information on probable leaching and denitrification losses through monitoring of inorganic nitrogen under different land-use systems in Western Kenya. The objectives of the experiment were to: (i) monitor inorganic nitrogen changes in natural and improved fallows and maize, and (ii) compare nitrogen and water uptake of fallows and maize in the short rains of 1993.

A problem with soil sampling in a tree-crop system is the actual location of the sample with respect to the distance from the tree. In many agroforestry trials soil samples are taken but seldom is defined how, or, taken in account the effects of tree roots. The problem was recognized by Jamison (1942) as he found that certain soil properties varied systematically with distance from orange trees in Florida and also Zinke (1962) reported spatial variability with relation to location of trees. Pritchett (1979) mentioned the problems of sampling in forested areas. Though Mongi *et al.* (1979) stressed the need for accurate sampling and the standardization of research in agroforestry, little is known yet on the spatial relation between trees and soil nutrients.

Therefore the study had as third objective: to gain insight in the spatial distribution of inorganic nitrogen in hedgerow intercropping systems with *Sesbania sesban*.

Fieldwork took place between September 1993 and January 1994 and was carried out by Alfred E. Hartemink, MSc-student of Wageningen Agricultural University (WAU), The Netherlands. In Kenya the research was supervised by Dr R.J. Buresh of ICRAF while in the Netherlands Dr B.H. Janssen of WAU took responsibility for guidance.

1.2 Research Location

The research was carried out at Ochinga farm which is located 10 km North-West from Maseno Agroforestry Station in Western Kenya (Fig. 1). The farm is located in Vihiga district, Emuhaya division.

The Agroforestry Station Maseno is a collaborative project of Kenya Forestry Research Institute (KEFRI), Kenya Agricultural Research Institute (KARI) and the International Centre for Research in Agroforestry (ICRAF). A number of research projects are based at Maseno and in 1993 the Nutrient Management Programme started its activities. The programme is headed by Dr R.J. Buresh while at the station research activities are coordinated by Dr B. Jama. Soil fertility research is conducted at farmer's fields, so-called on farm research, whereby all activities are induced and supervised by the scientist of the project. The farmer receives the yield of the experiments or is compensated for losses resulting from research activities.

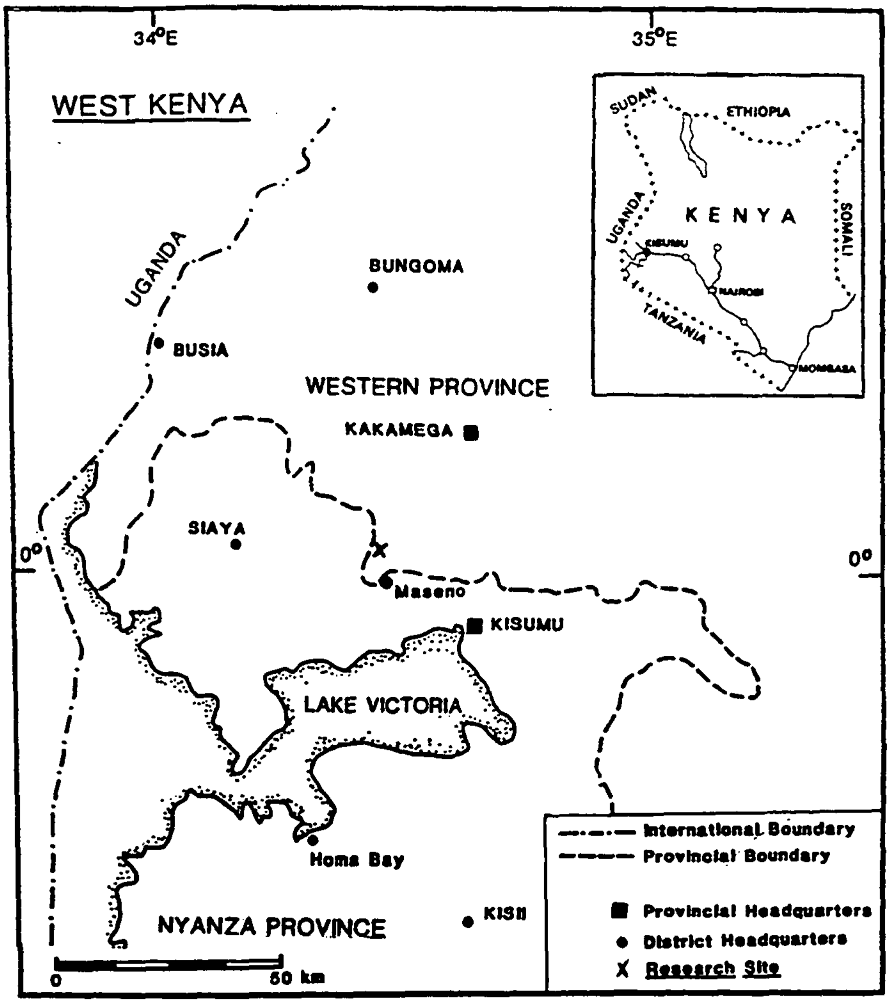

Fig. 1 *Location research site in Western Kenya*

1.3 This Thesis

Results of this experiment were presented on seminars held on 14th and 25th January 1994 in Maseno for the staff of the station and directors and staff of ICRAF and TSBF, and on 4th May for staff and students of the department of Soil Science and Plant Nutrition of WAU. Ideas generated from discussions following these three seminars were incorporated in this report.

The report has two purposes: (i) as MSc-thesis for Wageningen Agricultural University, and (ii) as research report for the Nutrient Management Programme of ICRAF. These two purposes are not well served in one report and attempts have been made to suit the readers both in Wageningen and Nairobi. Therefore all collected data and some draft reports on various subjects related to the research, are given in the Appendixes.

The report starts with a literature review on nitrogen dynamics in tropical soils and some important processes are described illustrating the dynamic nature of nitrogen in the soil. Also reviewed are the effects of fallows and of improved fallows with *Sesbania sesban* in particular. The environmental conditions of the experimental area are given in the following chapter in which also the research methods are comprehensively described. Hereafter the results are given. The results are interpreted in the discussion and compared with the literature review of chapter 2. Some conclusions are given in the last chapter.

In the Appendixes all inorganic nitrogen and water-filled pore space data are given. Furthermore some draft reports and papers are added. Appendix III and IV contain detailed descriptions of the sampling and laboratory procedures and were originally written in October 1993 during the fieldwork. Both procedures are summarized in the chapter on materials and methods. Reports on the physical properties of the soil and on weeds of Ochinga farm are given in Appendix V and VI. The reports were written in December 1993 and parts of these reports are used in the description of the environmental conditions and for the discussion. Also added is a report on soil sampling in hedgerow intercropping systems (December 1993) of which results are mentioned in the discussion at the end of this thesis. Some observations on soils, crops and the weather during the fieldwork are given in Appendix IX. A paper on the statistical distribution of inorganic nitrogen data (November 1993) is given in Appendix VIII and it is summarized in the chapter on materials and methods. No efforts have been made to re-edit the draft reports and papers, only the page numbering was adjusted.

2 LITERATURE REVIEW

2.1 Literature Search

The major part of literature for this thesis was collected at the ICRAF library in Nairobi, the Central University library in Wageningen and some publications have been obtained from the personal libraries of Drs R.J. Buresh and K.D. Shepherd. Much use has been made from a recently published bibliography on soil fertility research in East Africa (CAB International, 1994).
For statistical analysis of the experiment and its interpretation use have been made from the standard books of Snedecor and Cochran (1989), Gomez & Gomez (1984) and the GENSTAT manual (Lane *et al.*, 1987).
Information on soil and crop analysis was obtained from the books of: ASA-SSSA (Page *et al.*, 1982), TSBF handbook of methods (Anderson & Ingram, 1992), Okalebo *et al.* (1993) and from the laboratory manual of Machakos (Buresh, unpublished).
For general information on nitrogen in (tropical) crop production Sanchez (1976), Hauck (1984) and Tisdale *et al.* (1993) were used. Literature on processes as denitrification and leaching was mainly taken from Soil Science Society of America Journal, Agronomy Journal, Fertilizer Research, Plant and Soil and some others.
Early work on nitrogen dynamics in East African soils was found in: Journal of Soil Science, Journal of Agricultural Science (Cambridge) and East African Agricultural (and Forestry) Journal.

2.2 Nitrogen Dynamics

2.2.1 Some Important Processes

Nitrogen is a mobile and dynamic nutrient, its fate and ultimate utility to the crop is governed by many competing physical and biological factors that interact over time (Hergert, 1987). Several processes in the nitrogen cycle are unique and contribute to the dynamic nature of the nutrient. Fig. 2 presents a simple nitrogen diagram showing the major pools and fluxes considered relevant in this study. Ammonia volatilization is not an important process for the soils of Ochinga farm as the soil reaction is too low. Also run-off, run-on and nitrogen input with dry deposition are not considered.

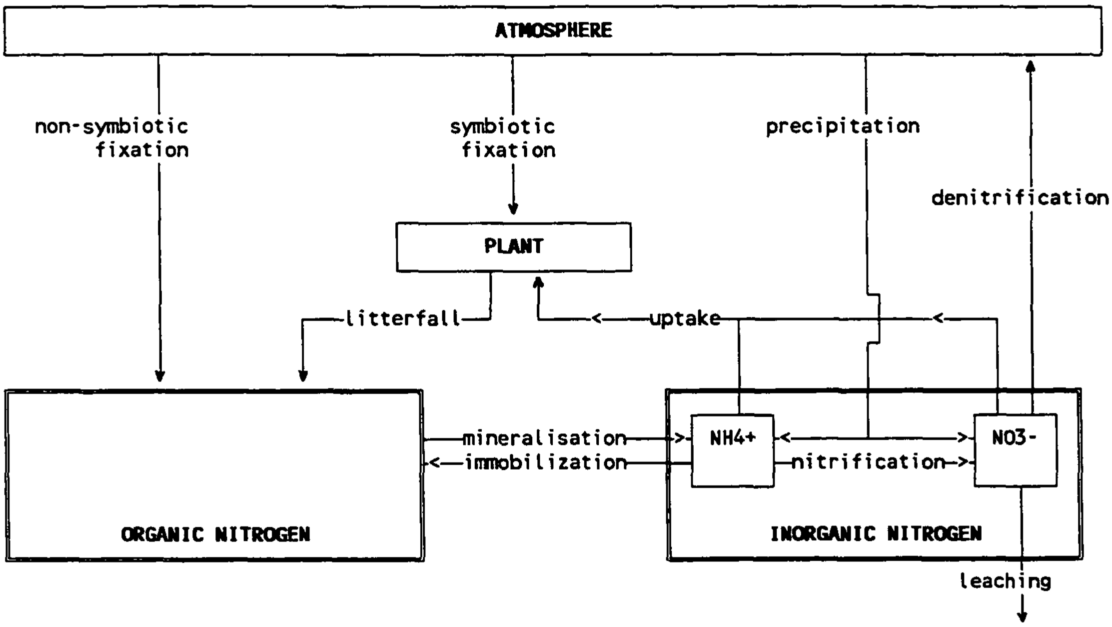

Fig. 2 ***Simple nitrogen diagram with major pools of soil nitrogen and processes of transfer (boxes are not to scale).***

The main processes of this diagram are discussed below including some notes on the methods for measurements.

Mineralization and Nitrification

Mineralization is the release of organically bound nitrogen to inorganic forms (NH_4^+ and NO_3^-). The process by which inorganic nitrogen is transformed into organic forms is usually termed immobilization. The mineralization process comprises three steps (Sanchez, 1976). In the first step (proteolysis or aminization), N is converted into amines and carbon-dioxide:

$$Organic\ N \rightarrow R\text{-}NH_2 + CO_2 \qquad \text{eq. (1)}$$

In the second step (ammonification) amines are transformed into ammonia and ammonium:

$$\begin{aligned} &R\text{-}NH_2 + H_2O \rightarrow R\text{-}OH + NH_3 \\ &NH_3 + H^+ \rightarrow NH_4^+ \end{aligned} \qquad \text{eq. (2)}$$

In the third step (nitrification) nitrifying bacteria oxidize ammonia into nitrate with a short intermediate stage of nitrite:

$$\begin{aligned} &NH_4^+ + \tfrac{3}{2}O_2 \rightarrow NO_2^- + H_2O + 2H^+ \\ &NO_2^- + \tfrac{1}{2}O_2 \rightarrow NO_3^- \end{aligned} \qquad \text{eq. (3)}$$

In most soils NH_4^+ that results from the mineralization of organic N is oxidized as rapidly as it is formed (Schmidt & Belser, 1982; Hageman, 1984).
Mineralization can be measured *in situ* and in the laboratory. In the first method undisturbed cores are incubated and this is theoretically the best method according to Anderson & Ingram (1993). Alternatively, aerobic or anaerobic incubation in the laboratory can be used, although aerobic incubation tends to overestimate N mineralization rates (Keeney, 1982).

Leaching

Leaching is a process whereby nutrients (cations and anions) are washed down through the soil profile by percolating water. Nutrients are generally considered lost for a soil-crop system if they are leached below the rooting zone of the crop. Leaching of nutrients will only occur if there is percolation down the profile and when there are nutrients in the soil solution, and the rate of leaching is the product of these two factors.
Three approaches are possible for studying leaching losses under field conditions (1) the auger method, (2) the use of lysimeters and, (3) use of porous cups as soil solution probes in combination with tensiometers and/or 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 (Grimme & Juo, 1985). Soil solution sampling and lysimetry are in detail discussed in the TSBF handbook (Anderson & Ingram, 1993). Further methods are discussed in Goulding & Webster (1992). An excellent overview of leaching problems in the temperate zone with quite a different perspective as for this study, is given in Addiscott *et al.* (1991)

Denitrification

The production of gaseous nitrogen by microbial reduction of nitrogenous oxides is known as biological denitrification. The usual substrates are nitrate and nitrite and the principal products are dinitrogen and nitrous oxide. The pathway of denitrification is thought to be (Tiedje, 1982):

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2 \qquad \text{eq. (4)}$$

The factors governing the process to take place at a significant rate are: presence of NO_3^-, presence of readily decomposable organic matter as an energy source, absence of oxygen and temperatures over 10°C (Grimme & Juo, 1985).
The simplest way to measure denitrification in field studies is the acetylene reduction technique. Acetylene at relatively low concentrations blocks the expression of N_2O reductase in most soils, so that the N_2O which might otherwise have been reduced to N_2 remains as N_2O, is easily measured against background atmospheric concentrations (Anderson & Ingram,

1993). Both chamber and soil core techniques are commonly used and yield similar results (Tiedje, 1982). An alternative approach for studying denitrification is by the use of isotopes. Both acetylene reduction techniques and the use of isotopes are effort intensive which limit the extent of the study (Christensen *et al.* 1990)

Nitrogen fixation

Biological nitrogen fixation is the biochemical process by which elemental nitrogen is combined into organic forms. It can be symbiotic i.e. legumes living together with bacteria, or non-symbiotic i.e. blue-green algae living in the soil. Particularly the symbiotic form of nitrogen fixation may contribute substantially to the nitrogen status of the soil (Sanchez, 1976).

For quantitative estimates of N_2 fixation in the field measurements of ^{15}N or the acetylene reduction array can be used (Weaver & Frederick, 1982). But Sprent & Sprent (1990) state in a one line conclusion: 'measurement of N_2 fixation, particular in the field, is not easy'.

2.2.2 Early Work on Nitrogen Dynamics 1950-1970

In order to increase fertilizer-use efficiency, nitrogen dynamics received considerable attention in East Africa in the 1950's and 1960's. In Kenya it was studied by the East African Agricultural and Forestry Organization at Muguga. Amongst the several publications from this organization is the well-known work from Birch. In Uganda nitrogen studies were undertaken at the Kawanda Research Station in Kampala, and in Tanzania some work on nitrogen dynamics was carried out by the Sisal Research Station in Mlingano. Research conducted in East Africa contributed significantly to the understanding of organic matter decomposition and factors governing mineralization in tropical soils.

Mineralization and the nitrogen flush

An overview of work on nitrogen dynamics from 1911 to 1957 was given by Greenland in 1958. He summarized the nitrate fluctuations in tropical soils as follows: A period of most rapid nitrate increase is at the start of the rains after a dry season. The rapid increase of soil nitrate content is usually followed by an almost equally rapid fall. This fall in surface nitrate content is accompanied by an increase in subsoil nitrates, and Greenland concluded that leaching causes some loss of surface nitrates. Furthermore losses of nitrate are attributed to, what he called then, 'microbial nitrate absorption', denitrification and plant uptake but he adds that the amount of nitrate taken up by the plants usually accounts for only part of the total which disappears.

Birch (1958) examined the rapid mineralization increase at the beginning of the rainy season, the so-called nitrogen flush or (unjust) the *Birch effect*. Birch explained the nitrogen flush by high metabolic activity of the early phase of the bacterial culture which has an ammonia production. Birch examined the relation between soil moisture and mineralization and found that with drying and rewetting mineralization rates decrease due to the decrease in readily decomposable organic matter. Rates of mineralization under alternate wetting and drying are, however, higher as compared to a constant optimum moisture level. Birch concluded that maximum nitrate production is obtained at the start of the rainy season, and that in low rainfall areas with a more frequent drying and wetting cycle, the nitrate production is high (1960).

Simpson (1960), working in Uganda reported that nitrate accumulation in the topsoil was also caused by capillary transport or diffusion, but he added that the major part of nitrate is from mineralization. Robinson & Gacoka (1962) researched nitrate movement in a Kikuyu red loam coffee soil in Kenya. They showed that particularly capillary rise in the dry season contributed to the nitrate increase as mineralization is limited under dry conditions. Robinson suggested in 1957 that mineralization ceases just below permanent wilting point (PWP). Ammonification did not cease at PWP and Robinson considered that the reason why ammonia nitrogen accumulates substantially in the dry season. Similar investigations were made by Simpson (1960), Dommergues (1960) and Semb & Robinson (1969).

The amount of nitrogen mineralized during the rainy season has been investigated by Semb & Robinson (1969). In topsoil samples collected from 13 sites in Kenya, Tanzania and Uganda the magnitude of the observed flush varied from 13 to 183 kg ha^{-1}. The magnitude was directly proportional to the duration and intensity of the preceding dry period.

Fallows

As shifting agriculture was commonly practised in East Africa, a fallow treatment was frequently included in the early research on nitrogen dynamics. Griffith (1951) reported high NO_3-N accumulations under bare fallow conditions and he found NO_3-N concentrations in the topsoil of 100 mg kg^{-1} with peaks over 400 mg kg^{-1}. Simpson (1961) found that total nitrogen contents in a grass fallow increased during a two year period with 230 kg ha^{-1} while under a legume fallow (*Stylosanthes gracilis*) total nitrogen levels in the topsoil increased with 286 kg ha^{-1}. Jones (1972) measured nitrogen increases in the 00-15 soil horizon after 2.5 years of grass fallow in Uganda, and reported an increase of 373 kg ha^{-1} (= 149 kg ha^{-1} y^{-1}). Nye & Greenland (1960) reported that non-symbiotic fixation was the most important contributor to the nitrogen increment in grass fallows and some increment may come from nitrogen in the rainfall.

Losses of nitrogen after the onset of rains were studied by Simpson (1961) in Uganda. He found the most intensive leaching occurring on a bare fallow and from the 00-15 cm soil horizon about 171 kg N ha^{-1} was lost in a two year period. Leutenegger (1956) working in Tanganyika, found however the lowest nitrate leaching under bare fallow. He concluded that on a bare soil loss of water by evaporation is much higher and therefore moisture infiltration to greater depths limited. In addition, higher run-off was found under bare fallows as the soil became capped on the surface by the impact of the raindrops.

2.2.3 Recent Work on Nitrogen Dynamics 1970-1993

While much of the early work on nitrogen dynamics was concerned with patterns during a cropping season, more recent work focuses on nitrogen management (e.g. Mokwunye & Vlek, 1986; van der Heide, 1989) and modeling its pathways (e.g. Janssen *et al.*, 1990a). For nitrogen management as well as for modeling exercises, detailed knowledge of the processes as discussed in Fig. 2 is essential and quite a number of studies have indicated the need for proper quantification (Janssen *et al.*, 1990b, Smaling, 1993). From some studies on nitrogen dynamics in upland soils of the tropics it appears that leaching and denitrification are important processes for nitrogen losses (e.g. Grimme & Juo, 1985; Shepherd *et al.* 1993). The literature on leaching and denitrification for (tropical) soils in general, and Kenya in particular, is reviewed below.

Leaching of nitrate

Sanchez (1976) compiled leaching results from various sources and found large variation which was attributed to rainfall, plant cover and cropping conditions. From an *in situ* lysimeter study in Ivory Coast, annual leaching losses on an ultisol cropped with rubber and bananas were resp. 79 and 235 kg N ha^{-1} (Charreau 1972, quoted by Sanchez, 1976). Poss & Saragoni (1992) used porous cups to measure leaching losses on an Oxisol in Togo and found that 29 to 85% of the total output for nitrogen was accounted for by leaching. They estimated leaching losses ranging from 36 to 153 kg N ha^{-1}. Seyfried & Rao (1991) compared leaching losses under monocropped annual and multicropped perennial systems from soil solution samplings and estimated losses of NO_3-N to be 56 and 1 kg ha^{-1} resp. for the 2 land-use systems. Wong *et al.* (1992) found leaching of 22.4 kg NO_3-N ha^{-1} under unfertilized conditions in south-eastern Nigeria.

Further quantitative studies on nutrient leaching from agricultural fields in the tropics and more in particular from SSA, are rare as was already stated by Grimme & Juo (1985), Seyfried & Rao (1991) and recently by Smaling (1993).

There is a strong impact of rainfall and management on the losses of nitrogen (Birch, 1960) and timely sowing may reduce leaching. For example in Brazil major amounts of inorganic N were lost during the first 60 days of a maize crop, probably before the period of N uptake was completed (Cahn *et al.*, 1993). Silvertooth *et al.* (1992) found the highest degree of leaching potential early in the season when soil water depletions were the lowest. Also in Togo nitrate leaching was higher at the start of the rainy season than during the rest of the rainy period (Poss & Saragoni, 1992).

Nitrate leached below the rooting zone of the crop at the beginning of the season is not necessarily lost. It may be adsorbed or be taken up later in the season (Long and Huck, 1980). Kinjo and Pratt (1971) found that positive adsorption of NO_3^- occurs in soils with an advanced stage of weathering. The highest NO_3^- adsorption was obtained at the lowest pH. Wild (1972) found maximum adsorption capacities in the subsoils of Northern Nigeria of 28 mg NO_3-N kg^{-1}. Arora and Juo (1982) reported that the anion-exchange capacity (AEC) of Ultisols at IITA can adsorb 28 to 66 kg NO_3^- ha^{-1} (= 6 to 15 kg N ha^{-1}). Cahn *et al.* (1992) found that leaching was retarded in the soil deeper than 40 cm which could serve as a temporary storage for NO_3^-.

When nitrates have once moved beyond the root zone it is doubtful if their concentration in the soil solution will be diminished appreciably (Olsen *et al.*, 1970). The numbers of micro-organisms and amounts of energy material usually decrease rapidly with soil depth, and so losses of nitrates by denitrification and microbial immobilization processes would likewise decrease markedly.

Denitrification

Denitrification will only occur in soil when at a certain place and time oxygen is absent and bacteria capable of denitrification, water, nitrate and decomposable organic compounds are present (Leffelaar, 1986). Accurate measurements of denitrification under field conditions are limited according to Smaling (1993), and he attributed this to the complexity of the processes involved and the lack of methods for direct measurements. Moreover there is high spatial variation in denitrification under field conditions of the temperate region (Folorunso & Rolston, 1984; Christensen *et al.*, 1990; Elliot & de Jong, 1993) but also in one of the few studies in upland soils of the tropics, the authors conclude that any attempt to quantify denitrification will be fruitful only if the soil heterogeneity is taken into account (Lensi *et al.*, 1992).

Linn & Doran (1984) investigated the relation between water content and soil microbial activity and found that aerobic microbial activity increases with soil water content until a point is reached where water displaces air and restricts the diffusion and availability of oxygen. They found that soil water-filled pore space (WFPS) was well correlated with

microbial activity and suggested 0.7 mL mL^{-1} WFPS as the boundary where anaerobic microbial activity dominates and denitrification becomes significant. Nommik (1956) quoted by Linn & Doran (1984) suggested that denitrification losses from soil only occur when porosity filled by water exceed 0.8 mL mL^{-1}.
Besides anaerobiosis, denitrification rates are also governed by carbon. Burford & Bremner (1975) found high correlation between water soluble carbon and denitrification. Weier *et al.* (1993) found that denitrification is limited at high N concentrations in the absence of an available C-source but increased with increasing available carbon. They found no difference in denitrification rates in a slightly acid silty clay loam when porosity filled by water (WFPS) increased from 0.6 to 0.9 mL mL^{-1} in the absence of carbon.

Leaching and Denitrification in Kenya

Stoorvogel & Smaling (1990) calculated nitrogen losses for all countries in SSA and arrived for Kenya at 42 and 46 kg N ha^{-1} for the years 1983 and 2000. On a more detailed level, Smaling *et al.* (1993) calculated for Kisii district (Southwestern Kenya) nitrogen losses of 16 land utilization types to be on average 112 kg ha^{-1} per year. Removal of harvested product was the strongest negative contributor followed by leaching and water erosion (Smaling & Fresco, 1993).
Shepherd *et al.* (1993) suggested that leaching and denitrification are the main causes for nitrogen losses of farming systems in Western Kenya. A farming system (i.e. a combination of land-use systems) was described as having 0.8 ha with foodcrops (maize, beans, cassava, bananas, sweet potatoes and sorghum) and 0.2 ha for a hedgerow (*Leucaena leucocephala, Calliandra calothyrsus*) which was mainly used as firewood. Most farms keep 2 to 3 unimproved breeds of zebu. Shepherd *et al.* estimated for such a farm annual nitrogen losses and arrived at a rate of 60 kg ha^{-1} y^{-1}. The figure was calculated using pedotransfer functions of Smaling *et al.* (1993). Smaling *et al.* based their leaching estimates on clay content and rainfall and derived their function from Arora & Juo (1982), Omoti *et al.* (1983) and Walters & Malzer (1990). For denitrification Smaling *et al.* used a function given by Dubey & Fox (1974) working in Puerto Rico, where denitrification losses were correlated with moisture level, organic carbon content and texture. Shepherd *et al.* (1993) calculated the leaching losses in Western Kenya per ha as 26 % of the inorganic nitrogen. Inorganic nitrogen was calculated from measured total soil N assuming a fixed annual nitrogen mineralization rate of 3% (taken from Young, 1989). Total nitrogen contents in the soils of Western Kenya for the 00-50 cm layer were measured and ranged from 3.3 to 8.2 Mg N ha^{-1} (median 4.9 Mg ha^{-1}) giving predicted leaching rates of 26 to 64 kg N ha^{-1} (median 39 kg ha^{-1}). Denitrification losses were estimated at 15% of the inorganic N, giving rates of 15 to 37 kg N ha^{-1} median (21 kg ha^{-1}) and total yearly nitrogen losses of 60 kg ha^{-1} (sum of medians).

2.3 Fallows

Natural fallows have been a way to overcome fertility depletion due to continuous cropping in shifting cultivation agriculture. The role of a fallow period in the regeneration of the soil productivity and its importance was investigated by Nye & Greenland (1960). Vine reported in 1968 that restoration of soil organic matter and of nutrient supply are amongst the chief functions of fallows.
Under the pressure of increasing population and other competing land use demands, (long) natural fallow periods are no longer possible in densely populated areas. As a result, farmers have to shift to permanent agriculture with systems that optimize nutrient cycling to minimize external inputs and maximize the efficiency of their use (Sanchez, 1994). Within that paradigm fits soil improving technologies like improved fallows.

Improved fallows
In 1940 George Milne, working as a soil scientist in Tanganyika, wrote the famous words *'If then the soil is to continue to grow plants for us, in turn we must grow plants for the soil'*. Even at that time the viewpoint was not new although the accent was on herbaceous plants (green manures), rather than woody species. Despite the good results achieved with green manures, farmers in the tropics have never adopted it on a wide scale. Today, much research in fertility of tropical soils includes woody plant production for the soil's benefit like alley farming (or hedgerow intercropping systems) and improved fallows. Research in alley farming is well advanced and was reviewed by Kang *et al.* in 1990, but not much is known so far on the effect of improved fallows with woody species on soil's productivity.
Improved tree fallows can be defined as a rotational system that uses preferred tree species as the fallow species in rotation with cultivated crops (Nair, 1993). Sanchez & Salinas suggested that improved fallows have high potential and also Young (1989) mentioned that improved tree fallows could have benefits similar to or greater than natural fallow, but he also adds that there is little experimental evidence. An ideal fallow species would be one that grows fast and efficiently and takes up and recycles available nutrients within the system, thus shortening the time required to restore fertility. In addition, the trees should yield economic products. Young (1989) listed several species that had been quoted in earlier reviews by other workers and reports that the nitrogen fixer *Sesbania sesban* has a high potential to maintain or improve soil fertility. This is illustrated from an example in the Miombo woodlands of Zambia (Kwesiga & Coe, n.d.). Trials showed maize grain yields of 2.3, 5.6 and 6.0 Mg ha^{-1} after 1, 2 and 3 years of fallow with *Sesbania sesban* compared to control plots with 1.6, 1.2 and 1.8 Mg ha^{-1} of maize after 1, 2 and 3 years of continuous cropping. The authors conclude that short fallow rotations of 1 to 3 years using *Sesbania*

sesban have a potential in increasing maize yields even without fertilizers. They further mentioned that maize yields continued to increase 2 to 3 years after in fallow plots and attribute this to delayed mineralization of the root system.
Increase in maize yields after legume fallows have also been reported by Prinz in Rwanda (quoted by Reijntjes *et al.*, 1992) and after a 10-month fallow with species as *Tephrosia vogelii, Crotolaria spp. and Cajanus cajan* yields quadrupled as compared with the control. Onim *et al.* (1990) conducted an experiment at Maseno Agroforestry Station whereby sesbania was planted and prunings were incorporated in the soil during one year. Hereafter maize and beans were planted and yields were compared with maize yields after a one year of grass fallow. Cumulative dry matter and plant nutrients incorporated into the soil with the sesbania prunings were 13.6 Mg DM ha^{-1}, 448 kg N ha^{-1}, 31 kg P ha^{-1} and 125 kg K ha^{-1}. In the first season after the fallows, maize intercropped with beans on sesbania land yielded 6.4 Mg ha^{-1} compared to 2.5 Mg ha^{-1} on the grass fallow plots. In the second season with less rain, the effect was not so dramatic i.e. 3.0 Mg maize ha^{-1} on sesbania land compared to 2.0 Mg ha^{-1} on previous grass fallow land. Onim *et al.* concluded that incorporation of sesbania prunings over a period of 1 year significantly improved soil fertility but that improvement under grass fallow was very limited.

3 MATERIALS AND METHODS

3.1 The Environment

The experiment took place at Ochinga farm which is located in an undulating landscape at an altitude of 1420 m amsl. Rainfall is bimodal with an estimated total of about 1200 to 1400 mm y^{-1}. A long rainy period starts in March and ends in May followed by a dry spell till about September. A second rainy season starts in September and lasts till about November and is usually termed the short rains. The climate classes as Aw (Köppen).

Soils

The soils are developed in situ from igneous rocks of Precambrian age belonging to the Nyanzian system (Saggerson, 1952 quoted by Muchena, 1976). Soils are very deep (> 3 m) and have clay textures throughout the profile. Soil chemical data, obtained from the soil survey laboratories of USDA-SCS-NSSC, for a pedon sampled in July 1992 are given in Table 1. A full profile description is given in Appendix I.

Table 1 *Chemical characteristics and particle size distribution of the soils of Ochinga farm*

depth (cm)	pH H_2O	Org. C g kg^{-1}	Avail. P mg kg^{-1}	Exchangeable bases mmol(+) kg^{-1}			CEC mmol (+) kg^{-1}	texture g kg^{-1}		
			Bray I	Ca	Mg	K		sand	silt	clay
00-16	5.5	20.9	3	48	14	4	136	278	304	418
16-28	5.4	17.1	2	58	13	tr.	137	257	280	463
28-51	5.5	11.6	0	53	15	1	127	192	250	558
51-74	5.6	6.6	tr.	46	10	1	94	161	216	623
74-94	5.7	4.8	0	43	10	2	92	163	206	631
94-120	5.8	3.6	0	43	8	1	89	162	210	628
120-150	5.8	3.1	0	39	10	2	91	154	217	629
150-177	5.8	3.0	0	35	11	tr.	81	151	237	612
177-200	5.9	2.2	tr.	30	14	1	104	153	253	594

The chemical fertility data as appraised using interpretation keys of Booker Tropical Soil Manual (Landon, 1991) indicate: Topsoils (00-16 cm) have a low pH and extremely low levels of available P. Organic carbon contents in the topsoils of Ochinga farm are moderate according to Janssen (WAU, pers. comm.). Levels of exchangeable bases are high for

calcium and magnesium, and medium for potassium. The capacity of the topsoils to exchange cations is low to moderate.
Subsoils have a medium soil reaction and high levels of exchangeable calcium and magnesium. Levels of exchangeable potassium are low. The levels of available phosphorus are extremely low in the subsoils.
The soils are classified as very fine, kaolinitic, isohyperthermic Kandiudalfic Eutrudox (USDA-Soil Taxonomy) or Rhodic Ferralsols (Revised FAO-Unesco).

Soils physical properties
Soil physical characteristics of Ochinga farm were determined in December 1993. A detailed report on the physical properties is given in Appendix V and a summary is given below:
The soils have bulk densities of about 1.1 in the upper 50 cm and between 1.2 and 1.3 Mg m^{-3} in the subsoils. The pore volume of the soils based on the bulk density and assumed particle size density of 2.65 Mg m^{-3}, is 58% in the upper 50 cm and decreases with depth to about 52 %.
The soils have 60 mm of available water in the first 50 cm and 115 mm in the first meter. The topsoil (00-15 cm) stores only 18 mm of water. Available water in the in the 00-200 cm pedon is about 240 mm.
The topsoils are moderately to weakly structured possibly due to frequent tillage. The soils are vulnerable to splash erosion, and this has been observed after heavy rains (for details see Appendix IX). Although infiltration rates are relatively high (13 cm h^{-1}), splash erosion resulting in surface sealing lowers infiltration capacities. Runoff is therefore a problem especially when there is little or no soil cover.
Hydraulic conductivities measurements in the unsaturated soil at field-capacity, ranged from 0.5 to 0.8 m d^{-1} which is moderately fast.

3.2 Experimental Set-up

The experiment (no. NM1) consisted of a randomized complete block design with 4 treatments (land-use systems) and 4 blocks. A land-use system is defined as a combination of land utilization type and land unit. Each block contained 4 plots of 10 * 10 m located on two approximately 20 m wide terraces. A field lay-out of the experiment is given in Appendix II.
This report presents measurements made during the second season of 1993 in each of the four land-use systems sesbania, maize, weed fallow and bare fallow (Table 2). To meet the objectives as defined in Section 1.1, the following measurements were made during the short

rains of 1993: (i) inorganic nitrogen (NO_3-N and NH_4-N), (ii) gravimetric water content, (iii) biomass, (iv) nitrogen movement after irrigation and (v) nitrate adsorption.

Table 2 *Land-use systems for four growing seasons of experiment NM1 at Ochinga farm*

land-use system	1993 first season	1993 second season	1994 first season	1994 second season
1	maize/sesbania relay crop	sesbania	sesbania	maize
2	maize	maize	maize	maize
3	maize	weed fallow	weed fallow	maize
4	maize	bare fallow	bare fallow	maize

Before the experiment was started all plots were uniformly cropped with maize and striga was removed manually. *Sesbania sesban* (L.) Merr. (Kisii provenance) was direct seeded between maize rows on 4th April 1993 at a density of 11,110 plants ha^{-1} (2.25 * 0.4 m). Maize (hybrid 512) was sown on 3rd September and in October thinned to a density of 53,330 plants ha^{-1} (0.75 * 0.25 m). Maize was harvested on 20th January 1994.
All plots were weed free when the experiment commenced in September 1993. During the experiment weeds were removed manually in the sesbania and maize plots at regular intervals. In the bare fallow weeds were frequently removed by hand-pulling. In December trenches of 1 m deep were dug at the borders of the sesbania plots to stop roots growing outside the plots.

3.3 Soil and Plant Sampling

Sampling for Inorganic Nitrogen and Gravimetric Water Content
Measurements of inorganic nitrogen and gravimetric water content started 16th September 1993 and continued till 10th January 1994. During this period six sampling rounds were made. From September to November (short rains) sampling was carried out at approximately every 100 mm of cumulative rain. From November to January the soils were sampled at approx. 4 weeks intervals.
Soil samples were composites and taken from six depths: 00-15, 15-30, 30-50, 50-100, 100-150 and 150-200 cm. Sampling was done systematically in all 4 land-use systems although 2 different methods were used. Hergert (1987) found that NO_3^- values changed significantly in parallel and perpendicular directions with respect to the crop rows and were not predictable, indicating that a systematic or grid sampling plan is more representative than a random sampling scheme. Therefore for the sesbania plots a different sampling method was

developed, also to test the spatial distribution of inorganic nitrogen. A description of the 2 sampling methods is given below and a more detailed account is given in Appendix III.

Method I (maize, weed fallow, bare fallow)

The maize plots were sampled perpendicular to the rows. The first row at either side was considered as a borderrow and not sampled. Each sample till one meter depth was a composite of 8 subsamples, below one meter each sample consisted of 4 subsamples. Of the 8 sample locations, 4 were taken between the rows and 4 within the rows.

A transect perpendicular to the maize rows was used for two sampling rounds as indicated below (A for round 1 and B for round 2). After two rounds, the sampling line was moved 40 cm into the plot for sampling round 3 and 4.

```
::   ::   ::   ::   ::   ::   ::   ::   ::   ::   ::   ::   ::   maize rows
     + + + +       + + + +    + + + +       + + + +            sampling point
     A A B B       A A B B    A A B B       A A B B            sampling round
```

The distance between two sampling points of a pair (AA or BB) was 37.5 cm; between the sample pairs the distance was 187.5, 150 and 187.5 cm. For the weed and bare plots the same system of sampling was used.

Sampling was carried out by an Edelman auger (d=7 m) with a length up to 2 m. Subsampling for nitrogen analysis was done in the field after thoroughly mixing the soil and about 400 g soil was taken and transported in tightly closed plastic bags.

About 50 g of soil was taken for field moisture determination (gravimetric water content) which was used for the calculation of the water filled pore space. These samples were dried at 105°C for 24h. After sampling the augerhole was refilled to prevent free water movement.

Method II (sesbania)

For the sesbania fallow, soil samples were taken perpendicular to the hedgerows whereby the distance between two rows was divided into so-called strata (Rao & Coe, 1991). The distance between the rows of sesbania (225 cm) was divided into 9 strata with a width of 25 cm. There were 4 rows of sesbania in one plot so there were 3 * 9 = 27 strata. Samples were composites of these 27 strata within each sesbania plot.

The following figure shows a cross-section through the 4 sesbania rows and the sampling points:

```
 1                         2                         3                         4
::::::                  ::::::                    ::::::                    ::::::  Sesbania rows
   +  +  +  +  +  +  +  +  +  +  +  +  +  +  +  +  +  +  +  +  +  +  +  +  +  +  +   sampling points
   1  2  3  4  5  4  3  2  1  1  2  3  4  5  4  3  2  1  1  2  3  4  5  4  3  2  1   subsample numbers
```

The samples collected at sample points 1 were mixed into one sample which hence consisted of 6 subsamples. The same was done for samples at point 2, 3 and 4. Only sample 5 consisted of 3 subsamples. Six depths till 2 m were sampled for every sample point. With each sampling round, the line with the sample points was moved 40 cm into plot corresponding with the distance between two sesbania plants within a row. Methods of subsampling and refilling were the same as in method I.
As subsample 5 covered actually only 12.5 cm width of the transect, average inorganic nitrogen contents and porosity filled by water for each sesbania plot was calculated as: (2*#1+2*#2+2*#3+2*#4+1*#5)/9 whereby #x is the subsample number.

Ring Sampling for Bulk Density
On 7th October 1993 a soil pit was dug between plot 31 and 41 (see Appendix II). The pit was 2 meters deep and 100 cm^3 ringsamples were taken from the following depths 00-15, 15-30, 30-50, 50-100, 100-150, 150-200 cm. These depths correspond with the sampling depths for inorganic nitrogen and gravimetric water content. Per depth 4 rings were pushed gently in the soil and remaining soil outside the rings was removed. The rings were dried for 72 hours at 105°C. Of each horizon the bulk density was calculated and the average was taken for the 4 rings. More details on the bulk densities are given in Appendix V.

Plant Sampling
On 8th December 1993 biomass was sampled of the sesbania, maize and weed plots. In the sesbania plots, 4 plants at the end of the row were harvested and separated in leaves and wood (stem, branches and twigs). Total fresh weight was recorded and a subsample was taken for moisture determination. In each maize plots 26 plants were harvested and the total fresh weight was recorded whereafter a subsample was taken. In each weed fallow plot 4 subplots of 1.0 * 0.5 m were clean weeded and fresh biomass was recorded. Hereafter a subsample was taken for moisture determination.
Sesbania and maize were kept weed free during the season and weeding was done on 6th October and 23rd November 1993. Fresh weed weight was determined and subsamples were taken for moisture determination. All plant samples were dried in the ovens of the Maseno laboratory at 60°C for 72 h.

3.4 Irrigation and Nitrate Movement

On 10th January 4 mini plots were laid out North of plot 14, 24, 34, 44 (see Appendix II). Maize was cleared and an earth bund was constructed around every mini plot to create an

effective plot size of 100 * 100 cm. At 5 locations around each mini plot soil samples were taken to 200 cm depth for inorganic nitrogen and gravimetric water content. Samples of these 5 locations were mixed into 1 sample for each depth. The following depths were taken 00-15, 15-30, 30-50, 50-100, 100-150 and 150-200 cm. For the soil sampling an Edelman auger was used.
Each mini plot received 100 L water (=100 mm rain) in a time span of about 3 h. Care was taken to have only short periods (< 1 minute) of waterlogging. On 11th January each plot received again 100 L water following the same procedure.
On 12th January soil samples for inorganic nitrogen and gravimetric water content were taken at 5 locations in each mini plot. The samples of these 5 locations were mixed into 1 sample for each depth. Samples for gravimetric water content determination were dried at 105°C for 24 h. Soil samples for inorganic nitrogen were analyzed as described in section 3.6.

3.5 Nitrate Adsorption

Soil samples of 10th January 1994 for inorganic nitrogen analysis were also used for the determination of the nitrate adsorption isotherms. Hereto the samples of the 00-15 cm soil horizon of the 4 land-use systems were mixed and a subsample was taken for NO_3-N adsorption determination. The same done was done for the other 5 cm soil horizons.
Soil from each horizon was equilibrated with $Ca(NO_3)_2$ solutions of different concentrations as described in Cahn *et al.* (1992). The amount of NO_3^- adsorbed was estimated from the differences in solution concentration before and after equilibration.

3.6 Soil Analysis

Extraction and filtration
Soil samples coming from Ochinga farm were immediately stored in a refrigerator at a temperature of 5 to 8°C. About 10 g soil (range 9.60-10.40 g) was taken for extraction with 100 mL 2*M* KCl. The solution was shaken for 1 hour at 150 times per minute whereafter filtration was done by gravity using pre-washed Whatman 42 filterpapers. The filtrate was stored in a refrigerator and analyzed for ammonium and nitrate in the Machakos laboratory. Subsamples were taken for moisture determination (24 h at 105°C) to correct the amount of soil taken for extraction with the moisture content. More details are given in Appendix IV.

NH_4-N and NO_3-N determination

The extract was analyzed for NH_4-N by steam distillation (Bremner & Keeney, 1965) and for NO_3-N and NO_2-N by cadmium reduction (Dorich & Nelson, 1984) with subsequent colorimetric determination of nitrite (Hilsheimer & Harwig, 1976). No effort was made to separate nitrate and nitrite. Because nitrite is likely to be small relative to nitrate, the values will be reported as NO_3-N for sake of simplification.

3.5 Calculation Procedures, Pedotransfer Functions and Units

Gravimetric water content of the soils was calculated as follows:

$$\frac{(W_{moist}) - (W_{dry})}{(W_{dry})} * 100 = \% W_m \qquad \text{eq. (5)}$$

W_{moist} is the moist weight soil, W_{dry} the oven dry weight soil, and $\% W_m$ is the gravimetric water content. Based on the gravimetric water content in the field, the water-filled pore space (WFPS) was calculated as the ratio of the water volume of the soil over the pore space using bulk densities per soil layer and an assumed particle size density of 2.65 Mg m^{-3} (Linn and Doran, 1984):

$$\frac{\% W_m * \rho_D}{1 - (\rho_D / \rho_P)} = WFPS \qquad \text{eq. (6)}$$

where ρ_D is bulk density and ρ_P the particle size density.

Nitrogen analyses at Machakos laboratory was expressed in mg L^{-1} ($conc._A$). It was recalculated into mg kg^{-1} correcting for the blank ($conc._B$) and the moisture content of the soil thereby using the formula:

$$\frac{(conc._A - conc._B) * (100 + (W_{moist} - W_{dry}))}{W_{dry}} = N_{inorg.} \text{ in mg kg}^{-1} \qquad \text{eq. (7)}$$

For most figures and tables values were expressed on a kg ha^{-1} base taking in account the bulk density of the soil and the depth of the soil layer:

$$\frac{(\rho_D * 10^3) * (\frac{depth}{100}) * 10^4 * (N_{inorg.} \text{ in mg kg}^{-1})}{10^6} = N_{inorg.} \text{ in kg ha}^{-1} \qquad \text{eq. (8)}$$

Inorganic nitrogen was calculated as the sum of NH_4^+-N and NO_3^--N.

Table 3 present an overview of the units used in the calculation procedures and pedotransfer functions.

Table 3 *Parameters and their units used in this experiment*

(soil) parameter	unit
moist, dry soil weight	g
gravimetric water content	mL mL^{-1} or %
bulk density	Mg m^{-3}
particle size density	Mg m^{-3}
water-filled pore space	mL mL^{-1} or %
soil depth	cm
NH_4-N, NO_3-N concentration	mg kg^{-1}
NH_4-N, NO_3-N content	kg ha^{-1}

During extraction and the actual determination of NH_4-N and NO_3-N various errors can be made. The effects of erratic measurements differ widely per parameter and depend on the absolute value of NO_3-N or NH_4-N from the laboratory analysis. In Fig. 3 the effect of erratic measurements are shown for the parameters as given in eqs. (7) and (8).

The relation between the error in the measurement and the effect on the NO_3-N or NH_4-N content is linear for most parameters. Large errors (> 20%) in the measurement of gravimetric water content at the time of subsampling for extraction, and in the blank have little effect whereas errors in the bulk density and inorganic nitrogen analysis have substantial impact. Large effects can also be expected from errors in the weighing of soil for extraction.

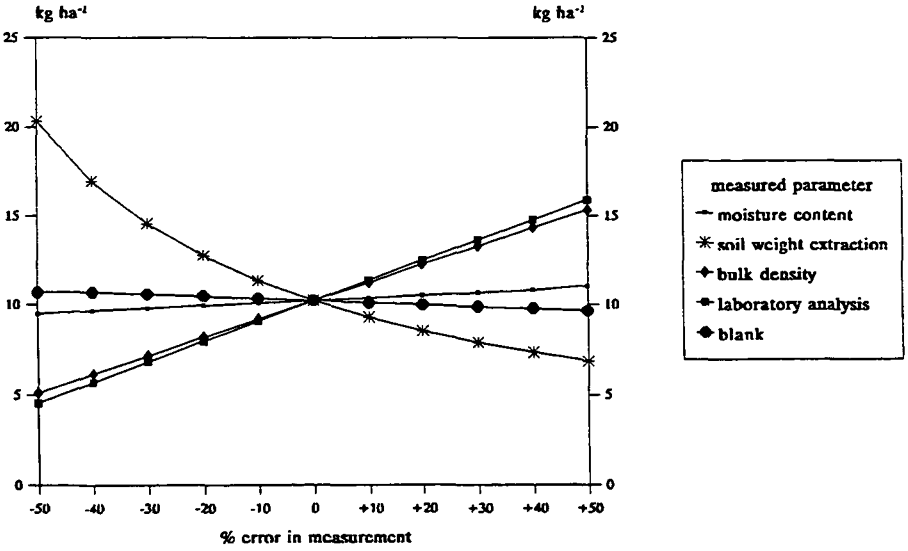

Fig. 3 Sensitivity Analysis for the calculations of NO_3-N or NH_4-N

Although erratic measurements in the laboratory may be substantial, it is generally known that errors in the field during the soil sampling have a much higher impact. Those errors are, however, very hard to quantify.

3.8 Statistical Procedures

Data transformation

Application of standard analysis of variance procedures requires several assumptions concerning the underlying error structure of the data, and among these is the assumption of normality. Soil variables often exhibit frequency distributions that are positively skewed and when this situation exists, the assumption of normality associated with statistical procedures is violated (Parkin, 1993). For such data the population mean and median have different values (Gomez & Gomez, 1984). Two common procedures have been recommended when data are not normally distributed (Snedecor & Cochran, 1989): (i) transform for normality, or (ii) apply non-parametrical statistical methods.

The NH_4-N and NO_3-N data of this experiment were tested for normality and found skewly distributed (see Appendix VIII). Logtransformation of data was chosen to overcome the skewed distribution as it allows conventional statistics (F-tests) by which it is easier to compare means (Coe, ICRAF HQ, pers. comm.). Transformation of data cannot be used directly for zero values and when some of the values are less than 10. For proper transformation of skewly distributed data, it is desirable to have a transformation which act like the square root for small values and like the logarithmic for large values (Steel and Torrie, 1980). Addition of 1 to each number prior to taking logarithms has the desired effect. That is, log(X+1) behaves like the square root transformation for numbers up to 10 and differs little from logX thereafter. Transformation of NH_4-N or NO_3-N data sets including values below 10 was carried out using the formula:

$$\textit{transformed value} = \textit{Log}\ (\textit{original value} + 1) \qquad \text{eq. (9)}$$

In other data sets the logarithm was taken of the original value without addition of 1. Analysis of variance and comparisons of means was done with transformed values. Antilog was used for transforming the data back into their original values:

$$\textit{original value} = (10^{\textit{transformed value}}) - 1 \qquad \text{eq. (10)}$$

Analysis of variance

Data were analyzed using a split-split-plot analysis whereby both depth and time were treated as sub-plots, so it is similar to a strip-plot design (Coe, ICRAF HQ, pers. comm.). Lay-out of the ANOVA table with the sources of variation and degree of freedom is presented in Table 4. This type of ANOVA was used to test main effects, separate ANOVA were run for the irrigation experiment and for the transect sampling in the sesbania.

Table 4 *Lay-out of an ANOVA table for a split-split-plot design*

source of variation	degree of freedom
block (b)	(b-1) = 3
land-use system (l)	(l-1) = 3
residual	(b-1)(l-1) = 9
depth (d)	(d-1) = 5
land-use system*depth	(l-1)(d-1) = 15
residual	(b-1)(d-1) + (l-1)(d-1)(b-1) = 60
times (t)	(t-1) = 5
land-use system*times	(l-1)(t-1) = 15
residual	(b-1)(t-1) + (l-1)(t-1)(b-1) = 60
depth*times	(d-1)(t-1) = 25
land-use system*depth*times	(l-1)(d-1)(t-1) = 75
residual	(b-1)(d-1)(t-1) + (b-1)(l-1)(d-1)(t-1) = 300
Total	bldt - 1 = 575

When the analysis of variance is carried out with log-transformed data comparing means of such data can only be done on the log-transformed scale i.e. log X kg ha^{-1}. In this report, tables and figures contain two sets of data: one on the untransformed scale presenting the absolute figure in kg ha^{-1} or mg kg^{-1} and the other data set on a transformed scale for comparison of means. Hereto the SE (standard error of the difference) is given, which multiplied with a *t*-value gives the least significant difference (LSD). A *t*-table is included in the back of this report. For the discussion of tables and figures probability levels of 5% (α=0.05) are used.

3.9 Use of software

Before the analysis of data was started, computer programmes were selected which allow (relatively) easy exchange of data. The following software packages have been used for the data analysis and report preparation:

Table 5 *Computer programmes used in this experiment*

task	programme	version
calculations	LOTUS 123	2.4
	QPRO	1.0
figures	Harvard Graphics	3.0
drawings	CoralDraw	2.0
analysis of variance regression analysis	GENSTAT	5
wordprocessing	WORDPERFECT	5.1
	DOS editor	5.0

Lotus and QPRO were used for the calculations of inorganic nitrogen and water-filled pore space data. Calculated data were imported in Harvard Graphics for the construction of figures whereafter the figures were imported in WP. The LOTUS and QPRO data were also imported in WP as tables, and in the DOS editor in conjunction with GENSTAT. Output files of GENSTAT were imported in LOTUS and than into WP. Switching between programmes was done with the DOS-task swapper, not so convenient but it worked.

4 RESULTS

4.1 Analysis of Variance

For each variate in this experiment probability levels were calculated for the sources of variation and their interactions (Table 6). NH_4-N, NO_3-N and inorganic nitrogen were logtransformed before analysis of variance. For water-filled pore space (WFPS) an ANOVA was run with original (untransformed) values.

Table 6 *Analysis of variance with probability levels for NH_4-N, NO_3-N, Inorg. N and WFPS*

sources of variation	d.f.	probability			
		NH_4-N	NO_3-N	Inorganic N	WFPS
block	3				
land-use system	3	0.428	< 0.001	< 0.001	0.001
residual	9				
depth	5	< 0.001	< 0.001	< 0.001	< 0.001
land-use system*depth	15	0.028	0.001	0.011	< 0.001
residual	60				
sampling time	5	< 0.001	0.044	< 0.001	< 0.001
land-use system*sampling time	15	0.964	< 0.001	< 0.001	< 0.001
residual	60				
depth*sampling time	25	0.035	< 0.001	< 0.001	< 0.001
land-use system*depth*sampling time	75	0.016	0.134	0.011	< 0.001
residual	300				
total	575				

NH_4-N levels were strongly affected by soil depth and sampling time, but not by land-use system. Levels of NH_4-N were significantly ($\alpha=0.016$) related to the interaction of soil depth and sampling time with the land-use systems.

Levels of NO_3-N were highly affected by land-use system and soil depth ($\alpha<0.001$) but less by sampling time ($\alpha=0.044$). There was no significant interaction between land-use system, soil depth and sampling time but NO_3-N levels were highly affected by the interaction between land-use system and depth, between land-use system and sampling time and between soil depth and sampling time.

Analysis of variance of the inorganic nitrogen data revealed that there was a strong interaction ($\alpha<0.001$) between land-use system, soil depth and sampling time. Also water-filled pore space was strongly affected by land-use system, soil depth and sampling time and interactions were highly significant.

4.2 Inorganic Nitrogen

Inorganic nitrogen contents in the 00-200 cm soil horizon changed over time but the pattern differed between land-use systems (Fig. 4).

In September 1993, at the beginning of the growing season, inorganic nitrogen contents ranged from 164 kg N ha^{-1} in the sesbania to 208 kg N ha^{-1} in the weed fallow but differences were not statistically significant at $\alpha=0.05$ (Table 7). With the second sampling time in October, inorganic nitrogen contents had decreased in all land-use systems. The decrease was highest under maize and weed fallow and inorganic nitrogen contents were resp. 75 and 77 kg N ha^{-1} lower as compared to September. Towards the end of October inorganic nitrogen contents increased significantly under maize and bare fallow. Under bare-fallow inorganic nitrogen contents were 194 kg ha^{-1} and significantly higher compared to the sesbania (111 kg ha^{-1}) but not statistically different from the maize and weed fallow systems which had resp. 157 and 161 kg N ha^{-1}.

During the period October to February levels of inorganic nitrogen increased significantly in the soils of the bare fallow and reached 295 kg ha^{-1} in January 1994. There were no significant differences in the inorganic nitrogen contents of the maize and weed fallow in the period September to January. Inorganic nitrogen contents under sesbania were lower than under maize and weed fallow. Patterns of sesbania and weed fallow were remarkably similar but total levels of inorganic nitrogen contents under sesbania were about 45 kg N ha^{-1} lower. Under maize, levels of inorganic nitrogen increased significantly between December and January with 41 kg N ha^{-1} while in the same period inorganic nitrogen contents did not change significantly under weed fallow. This is possibly caused by the lack of uptake by the maize as the growing period of maize ended in December while weeds proceeded growing by which uptake also continued.

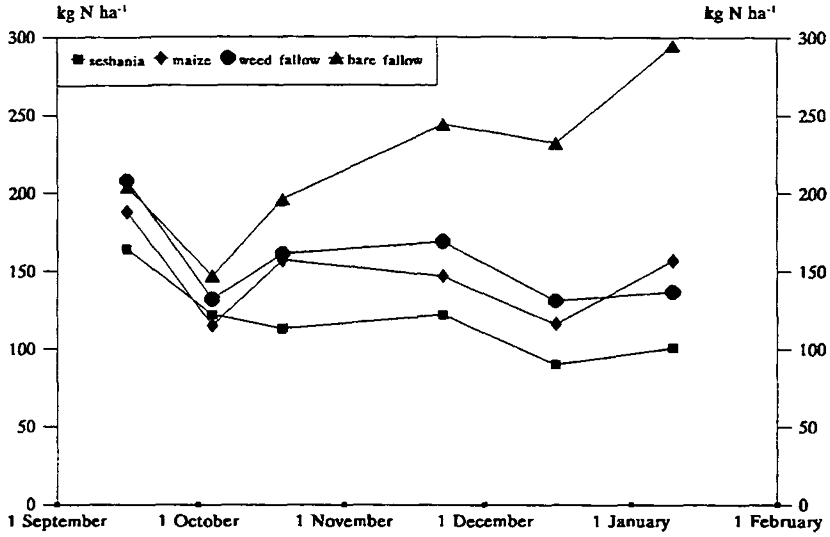

Fig. 4 Inorganic nitrogen contents (00-200 cm) of the land-use systems during the period September 1993-January 1994.

Table 7 *Transformed inorganic nitrogen contents of the land-use systems (log kg ha^{-1} * 10^2)*

sampling date	sesbania	maize	weed fallow	bare fallow
16 September	222	228	232	231
4 October	209	206	212	217
19 October	205	220	221	229
22 November	209	217	223	239
16 December	195	207	212	237
10 January	200	220	214	247
SE comparing means between land-use systems			6 (60 d.f.)	
SE comparing means within a land-use system			5 (9 d.f.)	

The difference in inorganic nitrogen levels were the result of changes in both NH_4-N and NO_3-N contents but the pattern varied between depths and land-use systems (Table 8). The decrease in inorganic nitrogen content under sesbania was due to about an equal loss of NO_3-N (42 kg ha^{-1}) and NH_4-N (36 kg ha^{-1}). Under maize the decrease of NH_4-N (16 kg ha^{-1}) was two times larger than the decrease in NO_3-N (8 kg ha^{-1}) while under weed fallow the decrease of NO_3-N (41 kg ha^{-1}) was higher than that of NH_4-N (26 kg ha^{-1}). The increase of inorganic nitrogen under bare fallow was caused by NO_3-N (127 kg ha^{-1}) while NH_4-N contents decreased with 34 kg ha^{-1} which was similar as under sesbania.

Large changes in NO_3-N and NH_4-N contents were found in the 00-50 and 50-100 cm soil horizons of sesbania, in the 100-150 cm soil horizon of the weed fallow and in the 00-50 cm soil horizon of the bare fallow. NO_3-N contents in the 00-50 cm soil horizon of the sesbania decreased significantly with 22 kg ha^{-1} while in the same period NO_3-N contents under bare fallow increased with 71 kg ha^{-1}. Changes in NO_3-N contents of the 00-50 cm soil horizon of the maize and weed fallow was not significant between September and January.
Changes in the NH_4-N contents were irregular and in none of the horizons of the 4 land-use systems, NH_4-N contents increased significantly.
When the NO_3-N and NH_4-N contents of the 4 depths in September are compared, it appears that there is a relative increase of NH_4-N compared to NO_3-N with depth in all 4 land-use systems. This may be an indication that conditions favouring nitrification are limited with depth. In January this trend is less pronounced.

Table 8 *NH_4-N and NO_3-N contents of the soil horizons in September and January*

land-use	depth	untransformed values NH_4-N (kg ha^{-1})			NO_3-N (kg ha^{-1})			transformed values * 10^2 NH_4-N (log kg ha^{-1})		NO_3-N (log kg ha^{-1})	
system	(cm)	Sep.	Jan.	Δ	Sep.	Jan.	Δ	Sep.	Jan.	Sep.	Jan.
sesbania	00-50	22	18	-4	42	20	-22	135	125	163	131
	50-100	23	12	-11	25	14	-11	140	109	140	114
	100-150	18	11	-7	17	11	-6	127	104	124	106
	150-200	26	12	-14	10	7	-3	142	109	99	82
	Total	89	53	-36	94	52	-42				
maize	00-50	25	21	-4	44	31	-13	141	132	164	149
	50-100	25	11	-14	29	33	+4	140	105	146	151
	100-150	9	12	3	15	18	+3	96	106	119	126
	150-200	14	13	-1	12	10	-2	114	112	108	100
	Total	73	57	-16	100	92	-8				
weed fallow	00-50	20	19	-1	48	30	-18	131	127	169	148
	50-100	14	17	+3	33	25	-8	114	123	152	139
	100-150	31	11	-20	19	15	-4	149	104	127	117
	150-200	13	5	-8	17	6	-11	113	67	124	80
	Total	78	52	-26	117	76	-41				
bare fallow	00-50	19	16	-3	48	120	+71	129	122	168	208
	50-100	24	11	-13	26	52	+26	139	103	141	171
	100-150	26	19	-7	14	39	+25	142	128	114	159
	150-200	21	10	-11	9	14	+5	132	98	95	115
	Total	90	56	-34	97	225	+127				
SE for comparing depths between sampling times in a land-use system:								12.3 (36 d.f.)		10.9 (36 d.f.)	
SE for comparing depths within a sampling time in a land-use system:								14.4 (12 d.f.)		12.9 (12 d.f.)	
SE for comparing depths between sampling times and land-use systems:								16.9 (36 d.f.)		12.8 (36 d.f.)	

4.3 Rainfall and Water-Filled Pore Space

Rainfall during the growing season was fairly well distributed over the months with 124 mm in September, 145 mm in October, 108 mm in November and 66 mm in December. Total rainfall in these 4 months was 443 mm. Though rainfall over the months was well distributed, within the months, however, peaks of heavy rainfall as well as short dry spells happened. Rainfall peaks occurred in October (48 mm d^{-1}) and in November (71 mm in 2 d) and these conditions of excess rainfall over evapotranspiration may favour nitrogen losses by leaching and/or denitrification.

Water-filled pore space (WFPS)

WFPS data were averaged of the 4 land-use systems for 3 depths and plotted against daily rainfall (Fig. 5). During the period September to February WFPS levels in the topsoil (00-15 cm) ranged from 0.37 to 0.53 mL mL^{-1} and showed the largest variation of the three soil horizons. WFPS in the 00-15 cm soil horizon was the lowest compared to the 30-50 and 100-150 cm. Despite the irregular precipitation, average WFPS in the 100-150 soil horizons varied only from 0.62 to 0.69 mL mL^{-1} during the season; variation in the 30-50 cm soil horizon was 0.44 to 0.56 mL mL^{-1}. The 100-150 cm soil horizon remained near fieldcapacity till December whereafter the moisture contents decreased gradually. The soils in the 30-50 cm horizon were near fieldcapacity at the beginning of the rainy season but moisture contents decreased from November onwards.

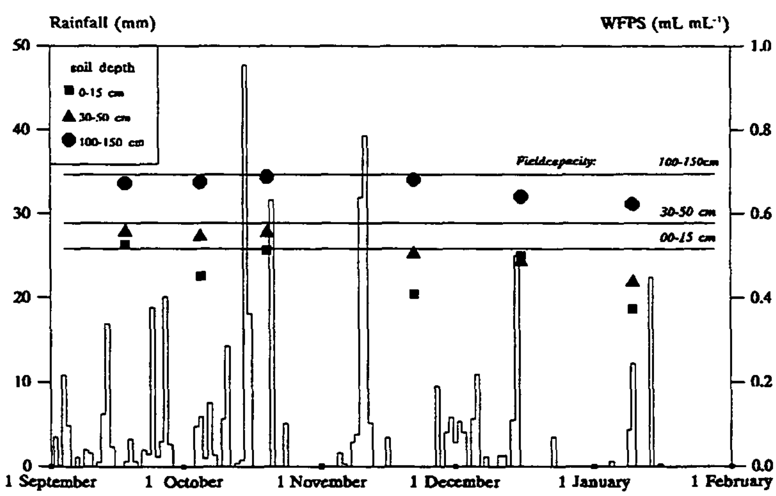

Fig. 5 Daily rainfall and water-filled pore space (WFPS) during the period September 1993 to February 1994

Water filled pore space and land-use systems

Water-filled pore space was strongly affected by land use system, soil depth and time of sampling. At the beginning of the season little difference was found between WFPS with depth in the 4 land-use systems and moisture contents were in most soil horizons near fieldcapacity (Fig. 6). WFPS in the 00-15 and 15-30 cm soil horizon of the sesbania was, however, significantly lower. This might be due to a larger water uptake as compared to maize and weeds.

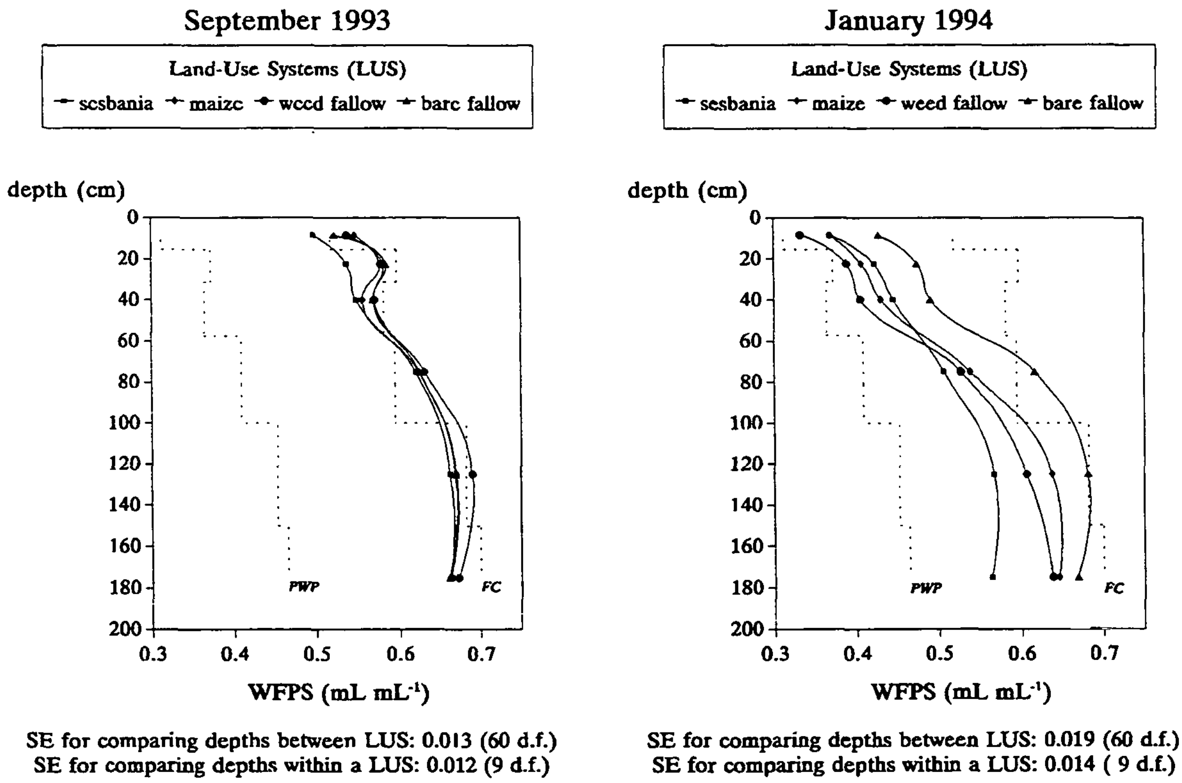

Fig. 6 ***Water-filled pore space of the land-use systems in September and January with permanent wilting point (PWP) and field capacity (FC) boundaries.***

With the sampling in January after only 8 mm rain had fallen in 4 weeks, WFPS in the soils of the bare fallow was highest in all horizons and remained near fieldcapacity (FC) below 50 cm depth. In the 00-15 cm soil horizon WFPS of bare fallow was 0.43 mL mL^{-1} compared to 0.33 mL mL^{-1} in the topsoil of the weed fallow which was near permanent wilting point (PWP). Throughout the profile, WFPS under bare fallow remained 0.06 to 0.10 mL mL^{-1} higher compared to maize and weed fallow except at 150-200 cm depth where there was no difference between WFPS of the maize, weed fallow and bare fallow. WFPS of sesbania, maize and weed fallow were similar in the 00-100 cm soil horizons but at 100-150 cm depth WFPS of sesbania was 0.04 mL mL^{-1} lower compared to the maize and 0.07 mL mL^{-1} lower than the weed fallow. In the 150-200 cm soil horizon WFPS of sesbania differed 0.09 mL mL^{-1} with the maize, 0.08 mL mL^{-1} with the weed fallow and 0.11 mL mL^{-1} with the bare fallow. The pattern of maize and weed fallow is similar throughout the profile and differences were not significant.

The data of January suggest that there was uptake of water by sesbania below 1 m depth, and that soil water was conserved under bare fallow.

4.4 Nitrate-Nitrogen

4.4.1 NO_3-N Concentrations over Time

Similar to the porosity filled by water, nitrate-nitrogen concentrations of the land-use systems were compared between September 1993 and January 1994 (Fig. 7).

In September, NO_3-N concentrations decreased significantly with depth in all 4 land-use systems (Table 9). Concentrations in the 00-15 cm soil horizon were 13 mg kg^{-1} under sesbania, maize and bare fallow and 12 mg kg^{-1} in the weed fallow. NO_3-N concentrations decreased in the 15-30 cm soil horizon to 7 mg kg^{-1} under sesbania and maize, and to 9 mg kg^{-1} under weed fallow and bare fallow. Sesbania had 4 mg NO_3-N kg^{-1} in the 30-50 cm soil horizon which was significantly lower ($\alpha=0.05$) compared to the weed and bare fallow which had concentrations over 5 mg kg^{-1}. Below 100 cm soil depth, NO_3-N concentrations were lower than 3 mg kg^{-1} and little difference was found between the land-use systems, only NO_3-N concentrations in the 100-150 cm soil horizon of the weed fallow were higher compared to the other land-use systems.

In January, NO_3-N concentrations were considerably lower in the 00-15 cm soil horizons of the sesbania, maize and weed fallow plots but had increased with 17 mg NO_3-N kg^{-1} in the bare fallow to 30 mg kg^{-1}. Throughout the profile the bare fallow had the highest concentrations of NO_3-N while the sesbania had concentrations lower than 3.5 mg kg^{-1}. Maize and weed fallow took intermediate positions and showed an irregular pattern in the first 50 cm.

The NO_3-N patterns of September and January suggest a strong depletion of NO_3-N in the 00-30 cm soil horizons under sesbania, maize and weed fallow while a significant increase throughout the soil profile was found under bare fallow possibly due to continuous and enhanced mineralization and the lack of nitrogen uptake.

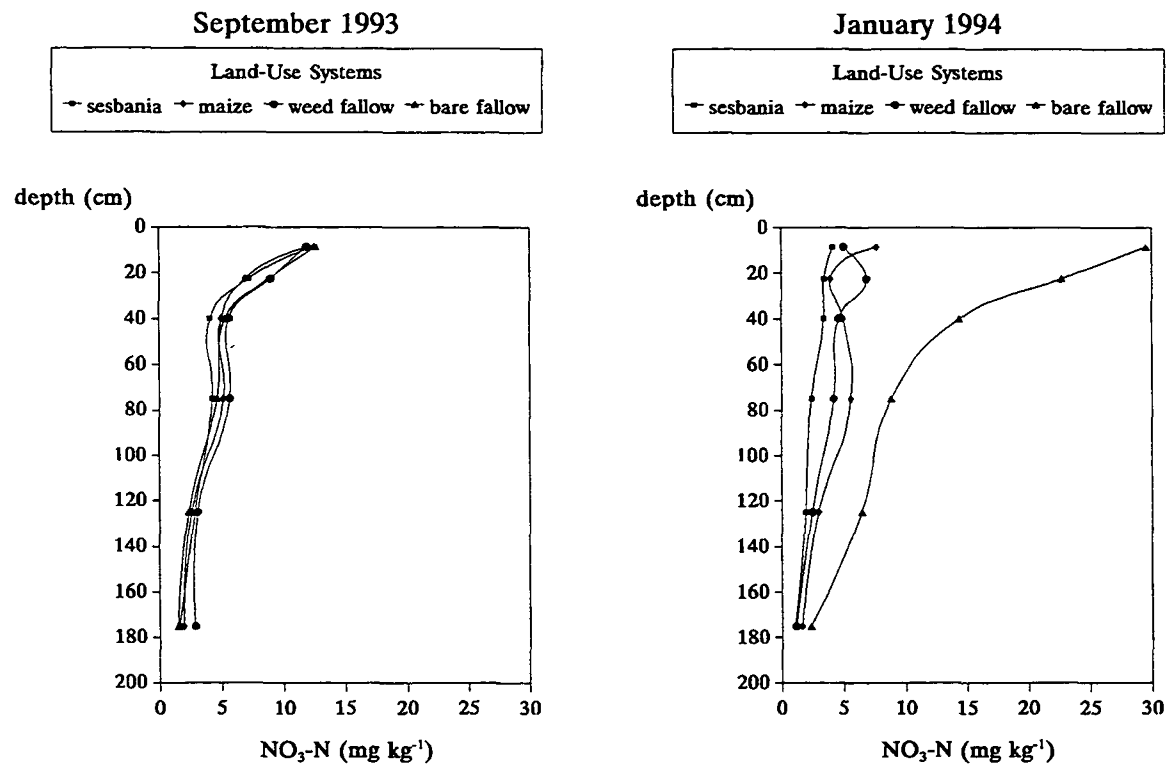

Fig. 7 *NO_3-N concentrations of the land-use systems in September and January*

Table 9 *Transformed NO_3-N concentrations in Sep. and Jan. (log mg kg^{-1}+1 * 10^3).*

depth	September 1993				January 1994			
(cm)	sesbania	maize	weed	bare	sesbania	maize	weed	bare
00-15	1133	1132	1112	1136	712	937	780	1485
15-30	914	899	993	992	647	695	895	1375
30-50	709	777	821	799	647	777	750	1187
50-100	723	788	823	750	532	820	715	992
100-150	584	549	607	527	462	597	537	870
150-200	411	468	585	389	317	415	327	520

	Sep.	d.f.	Jan.	d.f
SE for comparing depths between land-use systems:	9.8	60	10.7	60
SE for comparing depths within a land use system:	9.3	9	10.2	9

4.4.2 Rainfall and NO_3-N Contents

NO_3-N contents were affected by land-use system and sampling time and it may be expected that the contents in the subsoil are related to deep mineralization and/or leaching. NO_3-N contents in the subsoil (50-200 cm) were therefore plotted over time with cumulative rainfall (Fig 8).

A similar pattern as for the inorganic nitrogen contents of the 00-200 cm profile (Fig. 4) can be recognized. Under sesbania an almost linear decrease was found and contents in September were 22 kg ha^{-1} lower than in January. Maize and weed fallow show an irregular pattern with a sharp decrease in October and an increase in November and December. The increase was significant under weed fallow (Table 10). NO_3-N contents increased significantly under bare fallow and in January 115 kg ha^{-1} was found in the 50-200 cm soil horizon.

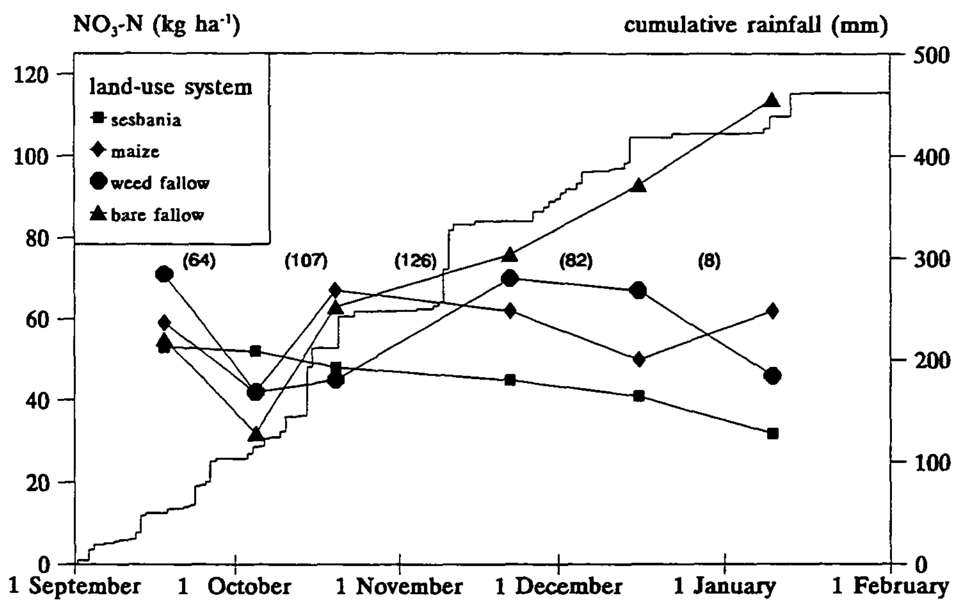

Fig. 8 Cumulative rainfall and NO_3-N contents at 50-200 cm depth during the period September 1993 to February 1994
(figure in parentheses is amount of rain in mm between the sampling times)

NO_3-N contents of the subsoils of maize and bare fallow tended to increase between December and January although it was not statistically significant. It is not very likely that leaching has caused this increase in the subsoil as there fell only 8 mm rain during this period and hence no percolating water. The trend is probably caused by a surplus of deep mineralization over NO_3-N uptake.

Table 10 *Transformed NO_3-N contents at 50-200 cm depth during the period September 1993 to January 1994 (log kg ha^{-1} * 10^2)*

Sampling time	16-09-93	04-10-93	19-10-93	22-11-93	16-12-93	10-01-94
sesbania	173	172	168	165	160	151
maize	177	163	183	179	169	179
weed fallow	185	162	165	185	182	167
bare fallow	174	151	180	189	197	206
SE for comparing land-use systems within a sampling time:				10.0 (60 d.f.)		
SE for comparing sampling time within a land-use system:				8.4 (9 d.f.)		

4.4.3 Irrigation and Nitrate Movement

To further investigate the relation between NO_3-N and rainfall a small experiment was conducted in which measurements were made before and after irrigation (see Section 3.4 for full description). Two days after irrigation with 200 mm, 40 kg ha^{-1} inorganic nitrogen was lost from the profile of which 30 kg ha^{-1} was in the NO_3-N form and 10 kg ha^{-1} in the NH_4-N form (Table 11).

Table 11 *NH_4-N, NO_3-N and inorganic nitrogen contents (kg ha^{-1}) with standard deviations in the 00-200 cm soil horizon before and after irrigation with 200 mm*

time of sampling	NH_4-N	SD	NO_3-N	SD	Inorganic nitrogen
before irrigation	47	7	137	30	184
after irrigation	37	9	107	19	144

Particularly the NO_3-N pattern in the soil was influenced by the irrigation. Before the irrigation, NO_3-N concentrations in the 00-15 and 15-30 cm soil horizon were 12 and 11 mg kg^{-1} resp. (Fig. 9) and differed significantly from NO_3-N concentrations below 100 cm (Table 12). After the irrigation, NO_3-N concentrations had decreased significantly (α=0.05) to 6 mg kg^{-1} in the 00-15 and 15-30 cm soil horizons. Below 30 cm depth no significant changes occurred in the NO_3-N concentrations.

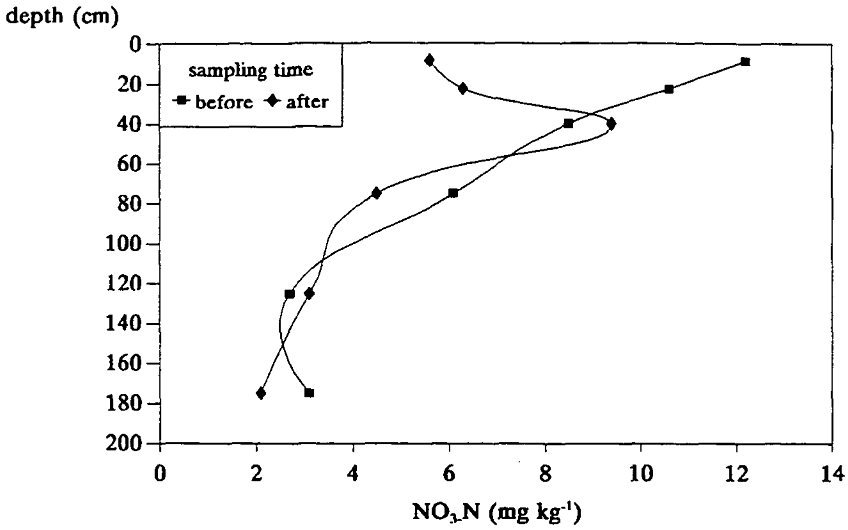

Fig. 9 NO_3-N concentrations before and after irrigation with 200 mm

Table 12 *Transformed NO_3-N concentrations before and after irrigation with 200 mm (in log mg kg^{-1}+1 * 10^2).*

soil depth (cm)	before irrigation	after irrigation
00-15	112	82
15-30	107	87
30-50	98	102
50-100	85	74
100-150	57	62
150-200	61	49
SE for comparing NO_3-N concentrations between sampling times:		11.1 (30 d.f.)
SE for comparing NO_3-N concentrations within a sampling time:		11.3 (3 d.f.)

Irrigation increased porosity filled by water with 0.23 mL mL^{-1} in the 00-15 cm soil horizon, 0.20 mL mL^{-1} in the 15-30 cm soil horizon and with 0.15 mL mL^{-1} in the 30-50 and 50-100 cm soil horizons (Fig. 10). The WFPS increase was significant in all soil horizons (α=0.05) although there was only a slight increase in the 150-200 cm soil horizon with 0.05 mL mL^{-1}. The 15-30, 30-50 and 100-150 cm soil horizons were near fieldcapacity (FC) after irrigation while the 00-15 and 50-100 cm soil horizons had moisture contents over fieldcapacity. Before irrigation, WFPS decreased significantly with depth but did not change below 100 cm depth. After irrigation, a more heterogeneous moisture profile was found and there were no significant differences between the soil horizons in the upper 50 cm. Below 50 cm soil depth,

WFPS increased significantly but differences between the 50-100, 100-150 and 150-200 cm soil horizons were not significant.
Total soil water in the profile has increased with 103 mm due to the irrigation. In other words, 97 mm of the applied 200 mm has drained below 2 m in less than 48 h. It may be that the NO_3-N lost from the topsoil has been taken by the 97 mm percolating water.

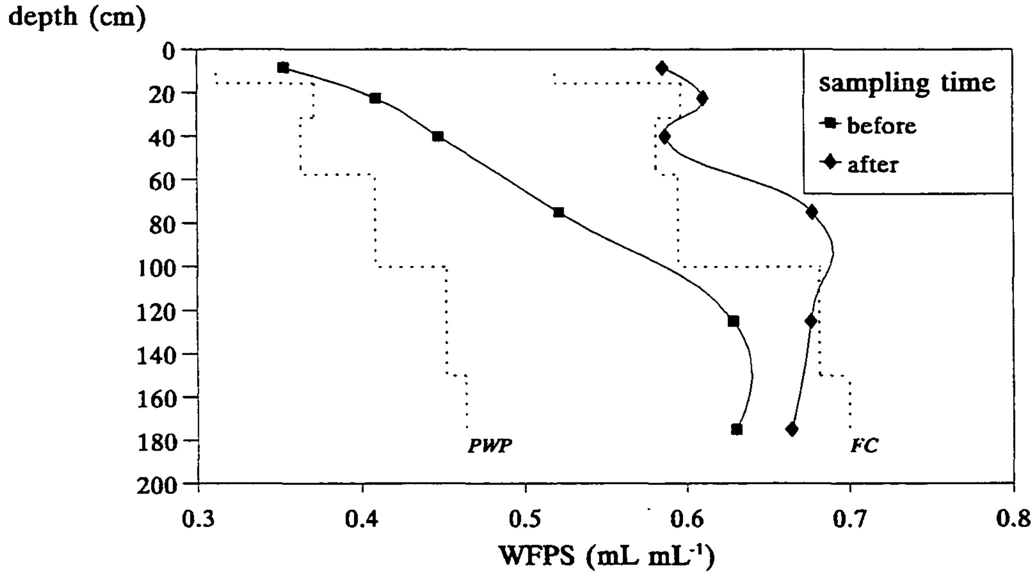

Fig. 10 Water-filled pore space before and after irrigation with 200 mm
SE for comparing depths between sampling times: 0.013 (30 d.f.)
SE for comparing depths within a sampling time: 0.013 (3 d.f.)

4.4.4 Nitrate Adsorption

Nitrate adsorption was considerably higher in the soil horizons below 50 cm as in the upper 50 cm but no statistics could be added to confirm this observation (Fig. 11). Nitrate adsorption in the 00-15 and 15-30 cm soil horizon were similar but adsorption in the 30-50 cm soil horizon was higher. Nitrate adsorption isotherms of the three soil horizons below 50 cm differ only slightly.
Below 50 cm more than 70% of added NO_3-N at concentrations of 4 and 10 mg kg^{-1} was adsorbed. When concentrations of 20 to 60 mg kg^{-1} were added, more than 50% was adsorbed in the soil horizons below 50 cm.
A linear relation was found between added and adsorbed NO_3-N and regression coefficients (r^2) were 0.996 and 0.999 for the 100-150 and 150-200 cm soil horizons resp.

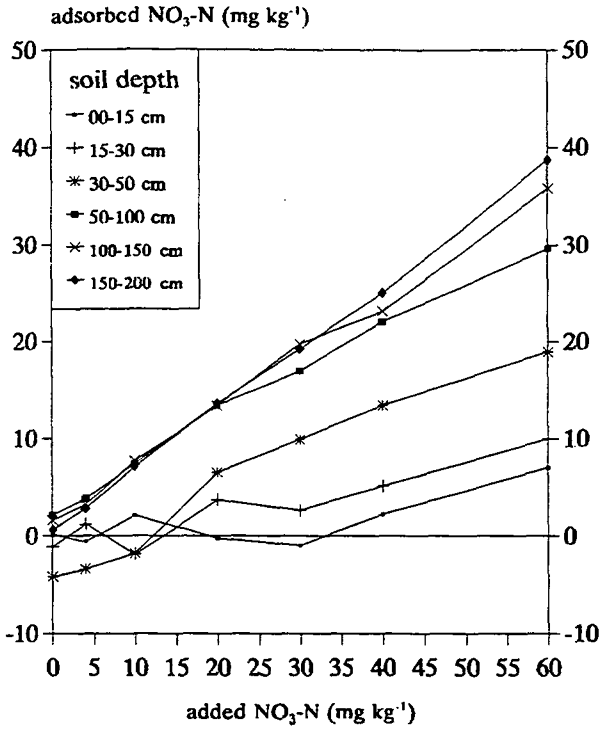

Fig. 11 Nitrate adsorption isotherms for six soil depths of Ochinga farm

4.5 Inorganic Nitrogen and WFPS Patterns under Sesbania Fallow

Analysis of variance of soil samples taken perpendicular to the sesbania hedge revealed that NH_4-N levels were affected by depth and sampling time but not by the distance of the hedge (Table 13). There was a significant distance effect on the NO_3-N levels but it was not related to soil depth or sampling time. As was seen before, NO_3-N contents were well correlated with soil depth and sampling time. Probabilities for inorganic nitrogen were similar to those for NO_3-N. Soil depth and sampling time had a significant effect on the porosity filled by water but it was not related to the distance from the hedge.

Table 13 *Analysis of variance table with probability levels for NH_4-N, NO3 -N, inorganic nitrogen and WFPS of sesbania fallow.*

sources of variation	d.f.	probability			
		NH_4-N	NO_3-N	Inorganic N	WFPS
block	3				
distance	4	0.523	0.012	0.017	0.361
residual	12				
depth	5	< 0.001	< 0.001	< 0.001	< 0.001
distance*depth	20	0.287	0.959	0.711	0.359
residual	75				
sampling time	5	< 0.001	< 0.001	< 0.001	< 0.001
distance*sampling time	20	0.403	0.587	0.212	0.944
residual	75				
depth*sampling time	25	0.053	< 0.001	0.002	< 0.001
distance*depth*sampling time	100	0.308	0.850	0.498	0.997
residual	375				
total	719				

At the beginning of December 1993, when trenches of 100 cm deep were dug around thesesbania plots to stop roots growing out of the plot, it was seen that majority of the sesbania roots were within 30 cm depth. The tap root which was found to be several meters long in another experiment near Maseno (Jama, ICRAF Maseno, pers. comm.), could not be seen. Only very few roots were found below 30 cm. One expects that the majority of the nitrogen is taken up from this first 30 cm soil layer and that when the roots are spreading no differences are found in the NO_3-N content with distance from the hedge. Despite the fact that NO_3-N levels were not affected by the interaction between distance, sampling time and soil depth, NO_3-N levels of the 00-30 cm soil horizon were plotted over time for samples taken at different distances from the hedge (Fig. 12).

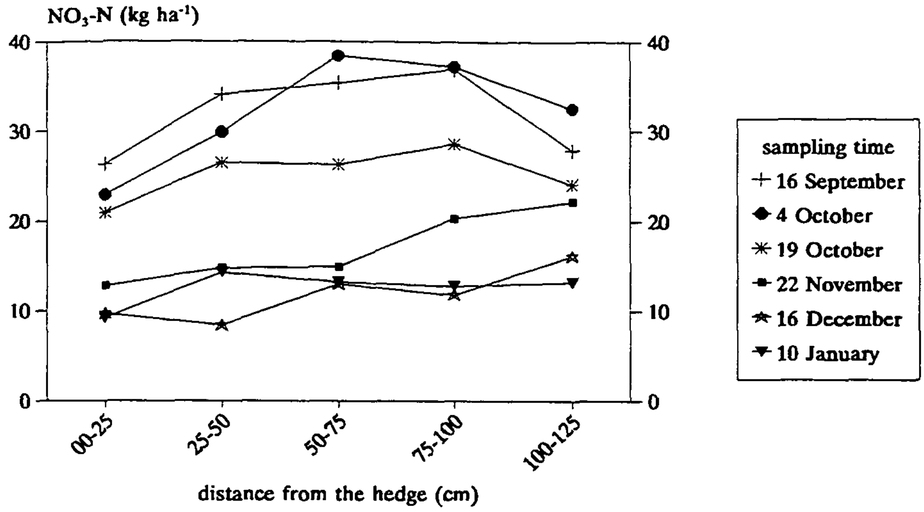

Fig. 12 NO_3-N contents of the topsoil (00-30cm) with distance from the sesbania hedge

Table 14 *Transformed NO_3-N contents in the 00-30 cm soil horizon with distance from the sesbania hedge during the period September to January (log kg ha^{-1} * 10^2)*

distance in cm:	00-25	25-50	50-75	75-100	100-125
16 Sept. 1993	142	153	155	157	145
04 Oct. 1993	136	148	159	157	151
19 Oct. 1993	132	142	142	146	138
22 Nov. 1993	111	117	117	131	135
16 Dec. 1993	99	92	112	107	121
10 Jan. 1994	97	116	112	111	112
SE for comparing distance between sampling times:					9.8 (75 d.f.)
SE for comparing distance within a sampling time:					9.9 (12 d.f.)

In September NO_3-N contents in the 00-30 cm soil horizon were at 25 cm from the hedge 26 kg ha^{-1} and at 75 cm NO_3-N contents were 35 kg ha^{-1}. However, at 125 cm from the hedge NO_3-N contents decreased to 28 kg ha^{-1} but none of the differences were significant (Table 14). With the second sampling significant differences were found between NO_3-N contents at 25 cm at 75 cm from the hedge. Also this time it appeared that in the middle of the hedges i.e. at 125 cm, levels tended to decrease although not significant.

With time, NO_3-N contents decreased at each distance from the hedge. A sharp decrease was found between the 3rd and 4th sampling time and NO_3-N contents were significantly lower except at 100 and 125 cm from the hedge.

4.6 Biomass

4.6.1 Production

Biomass was assessed in December 1993 in the sesbania, maize and weed fallow plots. Maize had produced the largest quantity of biomass followed by weed fallow and sesbania (Table 15). Biomass production under maize was 3627 kg ha^{-1} and with the weedings and thinning 4090 kg ha^{-1} were produced in the 3 months period from sowing (4th September) to biomass assessment (8th December). Though the growth of sesbania looked impressive with many trees over 3 m height in December, biomass production was only 2623 kg ha^{-1} and this was produced from April to December 1993. Of the 2623 kg ha^{-1} biomass, 1756 kg ha^{-1} was wood and 867 kg ha^{-1} were leaves. In the 3 months between September and December biomass production under weed fallow was 659 kg ha^{-1} higher than under sesbania and equalled 3282 kg ha^{-1}, but considerable variation was found between plots (see Appendix VI).

Table 15 *Biomass of sesbania, maize and weed assessed in December and biomass of weedings and thinning of maize in October and November (in kg DM ha^{-1})*

land-use system	biomass 08 Dec. '93	cv %	weeding I 06 Oct. '93	weeding II 23 Nov. '93	thinning 06 Oct. '93
sesbania	2623	39	235	61	-
maize	3627	15	177	127	159
weed fallow	3282	30	-	-	-

4.6.2 Nitrogen Uptake

To estimate nitrogen uptake (N_{uptake}) by sesbania, maize and weeds, nitrogen concentrations in the biomass were multiplied with the production as assessed in December. Nitrogen concentration in the biomass have not been analyzed yet and for the calculations use have been made of figures from the literature. For nitrogen concentrations in the weeds hardly any information could be found and use has been made from a figure of Everaarts (1992) which is based on experiments on acid, low fertility soils in Surinam. For sesbania several figures are given in the literature and they are summarized below.

Sesbania

Sesbania leaves contain on average about 38.0 g N kg^{-1} on a dry weight basis according to NFTA (1990) and the same figure is mentioned by Palm *et al.* (1988). Ghai *et al.* (1985) quoted by young (1989) report nitrogen concentrations in the leaf to vary from 24.3 to 43.6 g kg^{-1}. Shepherd *et al.* (1993) report much lower figures and found 18.0 g N kg^{-1} in the leaves antwigs and 7.3 g N kg^{-1} in the branches of *Sesbania sesban* in Western Kenya.
Total wood production was 1756 kg ha^{-1} and total leaf production was 867 kg ha^{-1}. Total N_{uptake} for the wood and leaves biomass based on the figures from the literature varied from 29 to 51 kg N ha^{-1} (Table 16). For the nitrogen concentrations in the wood, the figure of Shepherd *et al.* (1993) was taken in all 4 calculations.

Table 16 *Nitrogen uptake based on 4 different nitrogen concentrations in the sesbania leaves*

N content of the leaves in g kg^{-1}:	18.0	24.3	38.0	43.6
source:	Shepherd *et al.*, 1993	Young, 1989	NFTA, 1990	Young, 1989
leaves	16	21	33	38
wood	13	13	13	13
total	29	34	46	51

With the weedings, 296 kg biomass ha^{-1} was removed from the sesbania plots (Table 15). Everaarts (1992) found nitrogen concentrations in weeds of 81 d old of 22.9 g N kg^{-1}. If this figure is assumed for the weeds of Ochinga farm, 7 kg N ha^{-1} is taken up (0.0229 * 296). The total uptake for above ground parts of the sesbania and weeds ranges than from 36 to 58 kg N ha^{-1}.

Maize

Maize produced 3627 kg DM ha^{-1} during the period September to December. For maize leaves 30.0 g N kg^{-1} (of DM) is usually quoted (Hoeft, 1992). Stems have lower N concentrations but no figure could be found. Shepherd *et al.* (1993) report values for Western Kenya of 15.0 g N kg^{-1} in the grain and 6.0 g N kg^{-1} in maize stover and for grain production of 1 Mg ha^{-1} with a harvest index of 0.5, total N_{uptake} was 21 kg ha^{-1}. That is the amount of nitrogen removed with the harvest.
Biomass production as assessed in December was 3627 kg ha^{-1} and based on 30.0 g N kg^{-1} in the dry matter, N_{uptake} was 109 kg N ha^{-1}. With the weedings and thinning another 11 kg N ha^{-1} (0.0229 * 463) was taken up by which the total N_{uptake} for maize between September and December ranges from 32 to 120 kg ha^{-1}.

Weed fallow

During the period September to December dry matter production under weed fallow was 3282 kg ha^{-1}. If a nitrogen concentration of 22.9 g kg^{-1} is assumed for the weeds, N_{uptake} between September and December was 75 kg ha^{-1}.

The changes in inorganic nitrogen content under sesbania, maize and weed fallow were similar between September and December but the total N_{uptake} varied considerably (Table 17).

Table 17 *Range in nitrogen uptake in biomass and weedings and change in inorganic nitrogen contents (00-200 cm soil horizon) between September and December.*

	sesbania	maize	weed fallow
biomass kg ha^{-1}	2623	3627	3282
N_{uptake} range biomass kg ha^{-1}	29 to 51	21 to 109	75
biomass weedings kg ha^{-1} (+ thinning of maize)	296	463	-
N_{uptake} weedings kg ha^{-1}	7	11	-
Total N_{uptake} range kg ha^{-1}	36 to 58	32 to 120	75
Δ Sep. - Dec. kg N ha^{-1}	-77	-73	-76
+/- range kg N ha^{-1}	-41 to -19	-41 to 47	-1

Total N_{uptake} of sesbania ranged from 36 to 58 kg ha^{-1} while changes in the soil inorganic nitrogen contents were 77 kg ha^{-1}. In other words, 19 to 41 kg ha^{-1} were lost under sesbania during the period September to December. N_{uptake} of maize were variable and differences between uptake and the change in soil inorganic nitrogen contents varied accordingly. Total N_{uptake} in the weed fallow was similar to the change in inorganic nitrogen content between September and December.

5 DISCUSSION

The soils of Ochinga farm contain considerable amounts of inorganic nitrogen. In September at the beginning of the short rains, inorganic nitrogen contents in the 00-100 cm soil horizon ranged from 112 kg ha^{-1} under sesbania to 127 kg ha^{-1} under maize and bare fallow. The high inorganic nitrogen contents may explain the lack of response to N fertilizers as was found in test plots at Ochinga farm (Jama, unpublished data). The amount of inorganic nitrogen at the beginning of the short rains is about equivalent to the nitrogen uptake of a maize crop including stover with a yield of 4 Mg grain ha^{-1} (Sanchez, 1976). Maize grain yields in Western Kenya are much lower and around 1 Mg ha^{-1} which is due to the low phosphorus levels in combination with yield reducing factors as maize streak virus and striga infestation.

Nitrification

Nitrate was the major from of nitrogen in the topsoils of the 4 land-use systems as is general found in upland soils of the tropics (Grimme & Juo, 1985). In the subsoils below 100 cm, NH_4-N contents increased relative to NO_3-N which may indicate that nitrification is inhibited at those depths. In general nitrification occurs at a lower rate with increasing acidity and where aeration is limited. In the soils of Ochinga farm, pH in the subsoil is slightly higher than in the topsoil and the relative increase of NH_4-N may therefore be due to less favourable aeration rather than to acidic conditions. As a result microbial activity decreases with depth (Olsen *et al.*, 1970). The relatively slower rate of nitrification in the subsoils may, however, prevent the rapid leaching of nitrate beyond the rooting zone during the early stage of growth (Arora and Juo, 1982).

Mineralization

Inorganic nitrogen increased in the 00-200 cm soil horizon of the bare fallow with 90 kg N ha^{-1} between September and January. The increase is attributed to the surplus of mineralization over nitrogen losses. In the other land-use systems, inorganic nitrogen contents decreased during the same period which may be due to uptake as well lower mineralization rates as compared to bare fallow. A change in inorganic nitrogen contents between two moments is at its simplest the difference between internal turn-over of nitrogen (mineralization) and the balance between input and output of nitrogen:

$$\Delta N_{inorganic} = N_{mineralization} - N_{(input\ -\ output)} \qquad \text{eq. (11)}$$

Net mineralization can be considered as the difference between mineralization and immobilization. Total change in inorganic nitrogen is than the difference between net mineralization, and input (atmospheric deposition i.e. precipitation) minus output (uptake, leaching, denitrification):

$$\Delta N_{inorganic} = N_{(mineralization - immobilization)} - N_{((precipitation) - (uptake + leaching + denitrific.))} \qquad \text{eq.(12)}$$

Biological N_2 fixation (symbiotic and non-symbiotic) is not considered as an input for the soil inorganic nitrogen content. As atmospheric deposition, leaching and denitrification were not quantified in this experiment, mineralization is simply estimated from the change in soil inorganic nitrogen contents and plant uptake, as follow:

$$\Delta N_{inorganic} = N_{mineralization} - N_{uptake} \qquad \text{eq. (13)}$$

If N_{uptake} and changes in inorganic nitrogen as calculated in Table 17 are combined with eq. (13), it appears that no mineralization would have occurred as N_{uptake} equals $\Delta N_{inorganic}$ or in other words, the input and output of nitrogen are equal and the equivalent to the amount of nitrogen mineralized during the short rains of 1993 was lost under weed fallow . According to Janssen (WAU, pers. comm.) it is likely that particularly the inorganic nitrogen present at the beginning of the season is lost while nitrogen mineralized later on in the season is taken up by the plants. When the nitrogen mineralized is equal to N_{uptake} than it follows that the output by leaching and denitrification is equal to the nitrogen which is mineralized. The amount of nitrogen which is mineralized during the season is, however, not known. Semb & Robinson (1969) reported for East African soils nitrogen flushes ranging from 13 to 183 kg ha^{-1} in the 00-40 cm soil horizons. At Kawanda Research Station in Uganda (1200 m amsl, 1200 mm rain y^{-1}) which conditions are more or less comparable to Western Kenya, the difference between the amount of inorganic nitrogen before and after the rainy season in the 00-40 cm soil horizon was 56 kg ha^{-1}. Following the deductive reasoning, the 56 kg N ha^{-1} may be an indication for the amount of nitrogen which is be lost during the short rains. Under sesbania, N_{uptake} was 17 to 39 kg N ha^{-1} lower compared to weed fallow, but net changes of inorganic nitrogen were comparable to the changes under weed fallow. If mineralization rates are similar as under weed fallow than the losses of nitrogen are apparently higher. If the mineralization rates are lower due to lower moisture contents, than the losses of nitrogen under sesbania are similar or perhaps lower than the losses under weed fallow.

During the period September to January, NO_3-N accumulated in the subsoils of the bare fallow which may be due to (i) leaching, (ii) higher rates of mineralization with depth compared to the other land-use systems and (iii) the lack of nitrogen uptake. NO_3-N mineralized in the topsoil may be leached to the subsoil as there is no actively growing vegetation reducing leaching losses by transpiration of water and so reducing percolation, and absorbing nitrate from the soil solution. Due to the lack of water uptake, mineralization rates are probably enhanced in both the topsoil and subsoil resulting in more NO_3-N formation and hence higher NO_3-N.

Though the rains had ceased in December, NO_3-N contents in the 50-200 cm soil horizon increased under bare fallow. The increase is attributed to deep mineralization as there was no percolating water. Such increase was not found in the other land-use systems as moisture contents were much lower and perhaps too low for having significant mineralization rates. Moisture was conserved under bare fallow and in January WFPS of the soil horizons was 0.06 to 0.10 mL mL^{-1} higher compared to the soil horizons of other land-use systems. Besides the lack of water uptake, the higher moisture contents under bare fallow may also be caused by the reduced evaporation rates due to surface sealing of the soil. Similar reasons were mentioned by Leutenegger (1958) working with bare fallows in Tanzania.

Denitrification

Measurements of soil water-filled porosities rarely exceeded 0.7 mL mL^{-1} during the period September to January. This is probably due to the high infiltration capacities of the soils and the good ability of the subsoils to transmit water (see Appendix V). Some tentative results have shown that water soluble carbon levels in the soils of Ochinga farm were near the detection limit. Denitrification may therefore be limited in the soils of Ochinga farm as it is highly correlated with water soluble carbon (Burford & Bremner, 1975) and WFPS (Linn & Doran, 1984; Weier *et al.*, 1993). As the spatial variability of denitrification is high (Parkin, 1987; Christensen *et al.*, 1990) it may not be completely absent. Detailed studies using for example boundary-line analysis as suggested by Elliot & de Jong (1993) are required to further develop hypotheses on the occurrence of denitrification in the soils of Ochinga farm and its importance for the nitrogen balance of various land-use systems.

Leaching

Leaching was not measured directly in this experiment. The likelihood on its occurrence was estimated from changes of NO_3-N in the subsoil below 50 cm between September and January in relation to the rainfall, and the movement of NO_3-N after irrigation. Furthermore nitrate adsorption capacities provided information on the probability of leaching.

At the beginning of the season (September), the amount of NO_3-N in the 50-200 cm soil horizons of the maize, weed and bare fallow ranged from 55 to 71 kg ha^{-1}. This amount could potentially be leached as the crops had not yet rooted deeply. With the second sampling in October, NO_3-N contents in the 50-200 cm soil horizon were 29 and 23 kg ha^{-1} lower under weed fallow and bare fallow and this may have leached below 200 cm. Similar observations were made in Brazil where major amounts of inorganic N were lost during the first 60 days of a maize crop (Cahn *et al.*, 1993). Also Silvertooth *et al.* (1992) found the highest degree of leaching potential early in the season, and in Togo nitrate leaching was higher at the start of the rainy season than during the rest of the rainy period (Poss & Saragoni, 1992).

Although a decrease of NO_3-N in the 50-200 cm soil horizon was observed at the beginning of October, towards the end of October levels of NO_3-N had increased again in the sesbania, maize and weed fallow and did not change significantly hereafter. This suggests that the NO_3-N leached from the subsoil at the beginning of the rainy season, is compensated by mineralization *in situ* and/or nitrate leached from the topsoil later on in the season.

The accumulation of NO_3-N under the bare fallow (115 kg ha^{-1} in the 50-200 cm soil horizon in January) not only indicates that mineralization is enhanced but also that leaching of NO_3-N below 200 cm may be limited during the short rains. The slow rate of leaching and the accumulation of NO_3-N in the subsoil may be due to bypass-flow and the favourable soil physical properties by which water drains without leaching newly mineralized nitrate. Similar reasons were reported by Wild (1972) working with bare fallow in Northern Nigeria. Also Sanchez (1976) mentioned that leaching losses of well-aggregated clays may be limited as the nitrates mineralized inside the granules have to move through the micropores and out to the macropores before they can be susceptible to leaching.

Subsoils at Ochinga farm have a moderately acid soil reaction (pH 5.8). Since anion-exchange capacity (AEC) increases with a decrease in soil pH (Tisdale *et al.*, 1993), one would expect limited capacities of the subsoils of Ochinga farm to adsorb anions like nitrate. However, a nitrate adsorption experiment showed that more than 70% of added NO_3-N at concentrations of 4 and 10 mg kg^{-1} was adsorbed. Measured NO_3-N concentrations in the subsoil were in this range. Though the soil reaction was moderately acid, the predominant clay type is kaolinite which may explain the good capacities of the subsoils of Ochinga farm to exchange anions. According to Janssen (WAU, pers. comm.) the relative high adsorption capacities may have been caused by the extremely low P levels by which the AEC is unsaturated with P anions. Nitrate adsorption was also observed by Kinjo & Pratt (1971), Arora & Juo (1982) and Cahn *et al.* (1992) who found that leaching was retarded due to adsorption on positive charges in the B horizon.

Topsoil NO_3-N contents decreased very sharply within 48 h after irrigation with 200 mm but no likewise increase in the subsoil was found. It is likely that NO_3-N which had disappeared from the topsoil, was rapidly leached below 2 m with the 97 mm percolating water of the irrigation. Alternatively, denitrification may have caused the loss of NO_3-N but in none of the soil horizons porosity filled by water was increased over 0.7 mL mL^{-1} at which the process becomes important (Linn & Doran, 1984). Nevertheless denitrification may have occurred in some aggregates but it is uncertain whether denitrification at such level can reduce the inorganic nitrogen content with 40 kg ha^{-1} within a time-span of 48 h.

Sesbania fallow

Biomass production of sesbania after 8 months was 2.6 Mg ha^{-1} (11,110 plants ha^{-1}). In Zambia, Kwesiga and Coe (n.d.) found biomass production of *Sesbania sesban* after one year of 10.8 Mg ha^{-1} (10,000 plants ha^{-1}). NFTA (1990) reports that block planting of *Sesbania sesban* can annually produce 15 to 20 Mg ha^{-1} (dry weight) of woody biomass provided moisture is not limiting. In Western Kenya Onim *et al.* (1990) found 13.6 Mg DM ha^{-1} biomass production of *Sesbania sesban* in one year. And Nair (1993) reports 30 Mg ha^{-1} y^{-1} fuelwood yield of *Sesbania sesban.*

Sesbania biomass production in this experiment was very low (2.6 Mg ha^{-1} in 8 months) and its causes are hitherto not fully understood. It may be due to low phosphorus contents of the soil by which growth is retarded. As biomass was assessed after 8 months, it may also be that during the first period of establishment sesbania invests in below ground parts rather than above ground parts. Moisture has probably not been the limiting factor as leaf-fall was less than a few kg per hectare in the period October 1993 to January 1994.

As was seen with the trenching around the sesbania plots, the majority of the roots were concentrated in the upper 30 cm and even active nodules were found. Regarding the amount of nitrogen uptake (range: 29 to 51 kg N ha^{-1} in 8 months) and the shallow rooting pattern, not much may be expected from deep nitrogen uptake of sesbania fallow and its contribution to the nitrogen cycle in the short rains. Also Szott *et al.* (1991) stated that the ability of agroforestry systems to enhance nutrient availability on infertile soils is very limited.

For the soils of Ochinga farm containing considerable quantities of nitrogen, a nitrogen fixer like sesbania is not the most suitable species for a tree fallow. *Cassia spp.* may be more suited as it has generally a high biomass production with a large nitrogen consumption (Sanchez, ICRAF HQ, pers. comm.).

Spatial distribution of inorganic nitrogen under sesbania hedges

Analysis of variance of soil samples taken perpendicular to the hedge of sesbania indicated that distance from the hedge was not related with depth and/or sampling time for NH_4-N, NO_3-N, inorganic nitrogen or WFPS. In other words, it would not have differed in the short rains of 1993 where the soil samples were taken i.e. close to the hedge or in the middle of the rows.

Soil samples taken in hedgerow intercropping systems on other farms in Western Kenya, also revealed no clear picture of the spatial distribution of inorganic nitrogen in relation to distance from the hedge (see appendix VII). It is generally known that coefficient of variations for soil nitrate measurements are high (Arora & Juo, 1982; van Noordwijk & Wadman, 1992) and even within short distances variation of 30% can be expected in an uniform soil (Wild, 1972). If then an actively growing hedgerow component is added, variation increases likewise and large amounts of samples are needed to detect the spatial relation between the hedgerow and inorganic nitrogen. Detailed studies including shorter sampling distances as in this study in combination with quantitative root observations, may yield more insight in the matter. Geostatistical approaches may be useful in the design of such study.

6 CONCLUSION

From the foregoing some conclusions are generated based on the measurements in one season and at one location only:

During the short rains of 1993 inorganic nitrogen contents increased considerably under bare fallow. Mineralization and input of nitrogen were apparently higher than the losses which thus may have been small. If losses are indeed small under bare fallow, than it may be assumed that they are even lower with a standing crop.

From this experiment some evidence is raised that nitrogen losses are rather due to leaching than to denitrification as soil conditions favouring denitrification were not found. Future studies should therefore scope on direct measurement and quantification of leaching.

Nitrogen is not the limiting factor in the soils of Ochinga farm and losses may not seriously affect crop production. However, when the phosphorus status of the soils is improved, the crop demand for nitrogen increases likewise and the importance of nitrogen losses are directly related to the elimination of production limiting factors like P. Applying P therefore not only improves productivity but also reduces nitrogen losses.

Regarding the low biomass production of sesbania resulting in low levels of nitrogen uptake, it is concluded that sesbania is not the most suitable species for tree fallows in Western Kenya from a nutrient pumping perspective. If fallow periods with sesbania improve yields in the period after the fallow, it is not likely to have been caused by a reduction of the nitrogen losses.

From soil sampling perpendicular to sesbania hedges and the data analysis by conventional statistics, it is concluded that the spatial relation between inorganic nitrogen and the sesbania hedge is negligible.

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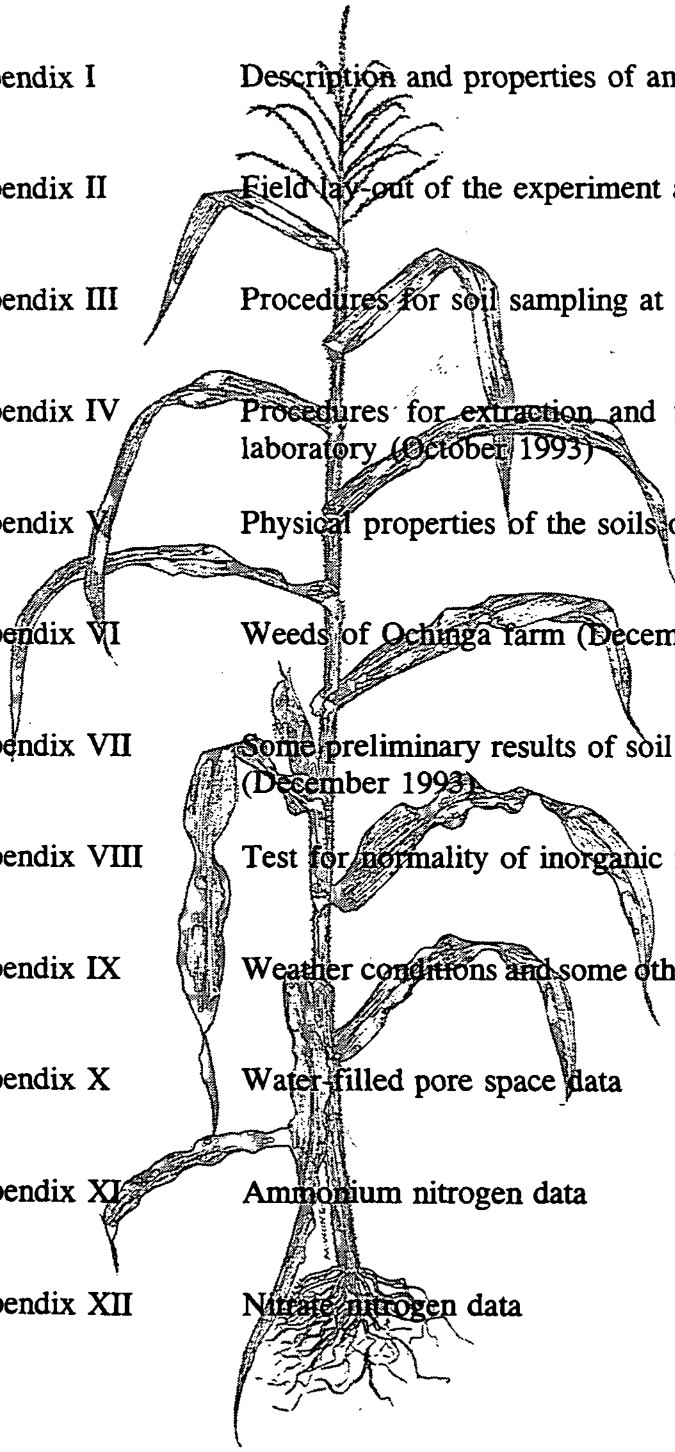
APPENDIXES

INORGANIC NITROGEN DYNAMICS UNDER DIFFERENT LAND-USE SYSTEMS ON AN OXISOL IN WESTERN KENYA



APPENDIX I DESCRIPTION AND PROPERTIES OF AN OCHINGA FARM SOIL PROFILE

Location: Ochinga Farm. Vihiga District, Emuhaya Division. Western Province. Kenya.
Coordinates: latitude 0° 06'N, longitude 34° 34'E
Pit location and description: Pit 1 was situated 50 m NNE of the shed and described by USDA-SCS-NSSC staff in July 1992. The pit was sampled for soil chemical analysis. Pit 2 was located 5 m N of the shed and sampled for soil physical characterization in October 1993 by A.E. Hartemink who also compiled this profile description.

Site description

Elevation: 1420 m above mean sea level
Physiographic position of the site: upperslope
Landform of surrounding country: undulating
slope on which profile is sited: 3-4 percent
Vegetation/Landuse: pasture in July 1992, converted to experimental fields with *Sesbania sesban*, maize and weeds.
Climate: Tropical rainy climate (Aw) with bimodal rainfall pattern; average precipitation is 1200-1400 mm.
Parent material: igneous rock of Precambrian age.
Moisture condition: moist throughout
Water table: very deep.
Depth to root limiting layer: > 200 cm.
Drainage class: well drained.

Brief description of the profile

Very deep, well drained profile with a dark reddish brown, clay topsoil over a dark reddish brown to dark red, clay subsoil. High termite activity in the profile.

Classification

Very fine, kaolinitic, isohyperthermic Kandiudalfic Eutrodox (USDA Soil Taxonomy), Rhodic Ferralsol (Revised FAO-Unesco).

Soil horizon description

00-14 cm Ap Dark reddish brown (5YR 3/2); clay; weak, coarse, subangular blocky; very friable when moist; many very fine to medium roots; common, fine to medium, tubular pores; clear and smooth boundary.

16-28 cm BA Dark reddish brown (5YR 3/3); clay; weak, medium, subangular blocky; very friable when moist; many, very fine to medium and few coarse roots; common, medium, continuous and many, very fine to fine pores; few, fine, prominent, red mottles; clear and smooth boundary.

28-51 cm	Bt1	Dark reddish brown (5YR 3/3); clay; moderate, medium, subangular blocky; very friable when moist; common, very fine to fine and few, coarse roots; many, very fine, common, fine and common medium interstitial pores; many, fine, bright, red (2.5YR 4/6) mottles; moderate, distinct clay film; many termites; gradual and wavy boundary.
51-74 cm	Bt2	Dark red (2.5YR 3/6); clay; weak, coarse, subangular blocky; common, very fine and fine roots; many, very fine and few coarse interstitial and tubular pores; very friable when moist; many, fine, prominent, red (2.5YR 4/6) mottles; moderate, distinct clay film; many termites; gradual and smooth boundary.
74-94 cm	Bt3	Dark reddish brown (2.5YR 3/4); clay; weak, coarse, subangular blocky to platy; few, very fine and fine roots; many, very fine, interstitial and tubular, few, coarse pores; very friable when moist; moderate, distinct clay film; many termites; gradual and smooth boundary.
94-120 cm	Bt4	Dark red (2.5YR 3/6); clay; weak, coarse, subangular blocky; few, very fine roots; many, very fine and fine, few coarse, interstitial pores; very friable when moist; moderate, distinct clay film; many termites; gradual and smooth boundary.
120-150cm	Bt5	Dark reddish brown (2.5YR 3/4); clay; weak, coarse, subangular blocky; few, fine and very fine roots; many, very fine and fine, few coarse, interstitial pores; very friable when moist; moderate, distinct clay film; many termites; gradual and smooth boundary.
150-177cm	Bt6	Dark red (2.5YR 3/6); clay; weak, coarse subangular blocky; few, very fine and fine roots; many, very fine and fine, interstitial and tubular, few, medium to coarse pores; very friable when moist; moderate, distinct clay film; many termites; gradual and smooth boundary.
177-200cm	Bt7	Dark red (10R 3/6); clay; weak, coarse, subangular blocky; few, very fine and fine roots; few, very fine and fine, tubular and interstitial, few medium to coarse pores; very friable when moist; moderate, distinct clay film; many termites.

Chemical properties (pit 1)

Depth cm	pH(H2O)	pH $CaCl_2$	C g kg^{-1}	N g kg^{-1}	C/N	P Bray I mg kg^{-1}
00-16	5,5	4,9	20,9	n.a.		3
16-28	5,4	4,8	17,1	n.a.		2
28-51	5,5	5,0	11,6	n.a.		0
51-74	5,6	5,2	6,6	n.a.		tr.
74-94	5,7	5,4	4,8	n.a.		0
94-120	5,8	5,4	3,6	n.a.		0
120-150	5,8	5,5	3,1	n.a.		0
150-177	5,8	5,5	3,0	n.a.		0
177-200	5,9	5,6	2,2	n.a.		tr.

n.a. = not available

Depth	Exchangeable ionic equivalents mmol(+) kg^{-1}							
cm	Ca	Mg	K	Na	CEC	BSP %	Al	ECEC
00-16	48	14	4	tr.	136	49	1	67
16-28	58	13	tr.	tr.	137	52	1	72
28-51	53	15	1	tr.	127	54	tr.	69
51-74	46	10	1	tr.	94	61	-	57
74-94	43	10	2	tr.	92	60	-	55
94-120	43	8	1	tr.	89	58	-	52
120-150	39	10	2	tr.	91	56	-	51
150-177	35	11	tr.	tr.	81	57	-	46
177-200	30	14	1	tr.	104	43	-	45

tr. = traces

Physical properties

Particle Size Distribution (pit 1)

Depth	total g kg^{-1}			silt g kg^{-1}		sand g kg^{-1}				
	clay	silt	sand	fine	coarse	v. fine	fine	medium	coarse	v. coarse
00-16	418	304	278	176	128	99	109	49	14	7
16-28	463	280	257	175	105	96	94	47	16	4
28-51	558	250	192	143	107	70	75	34	11	2
51-74	623	216	161	127	89	60	63	27	9	2
74-94	631	206	163	123	83	62	63	28	9	1
94-120	628	210	162	131	79	64	62	26	7	3
120-150	629	217	154	137	80	61	61	23	6	3
150-177	612	237	151	150	87	61	58	21	7	4
177-200	594	253	153	164	89	64	56	20	8	5

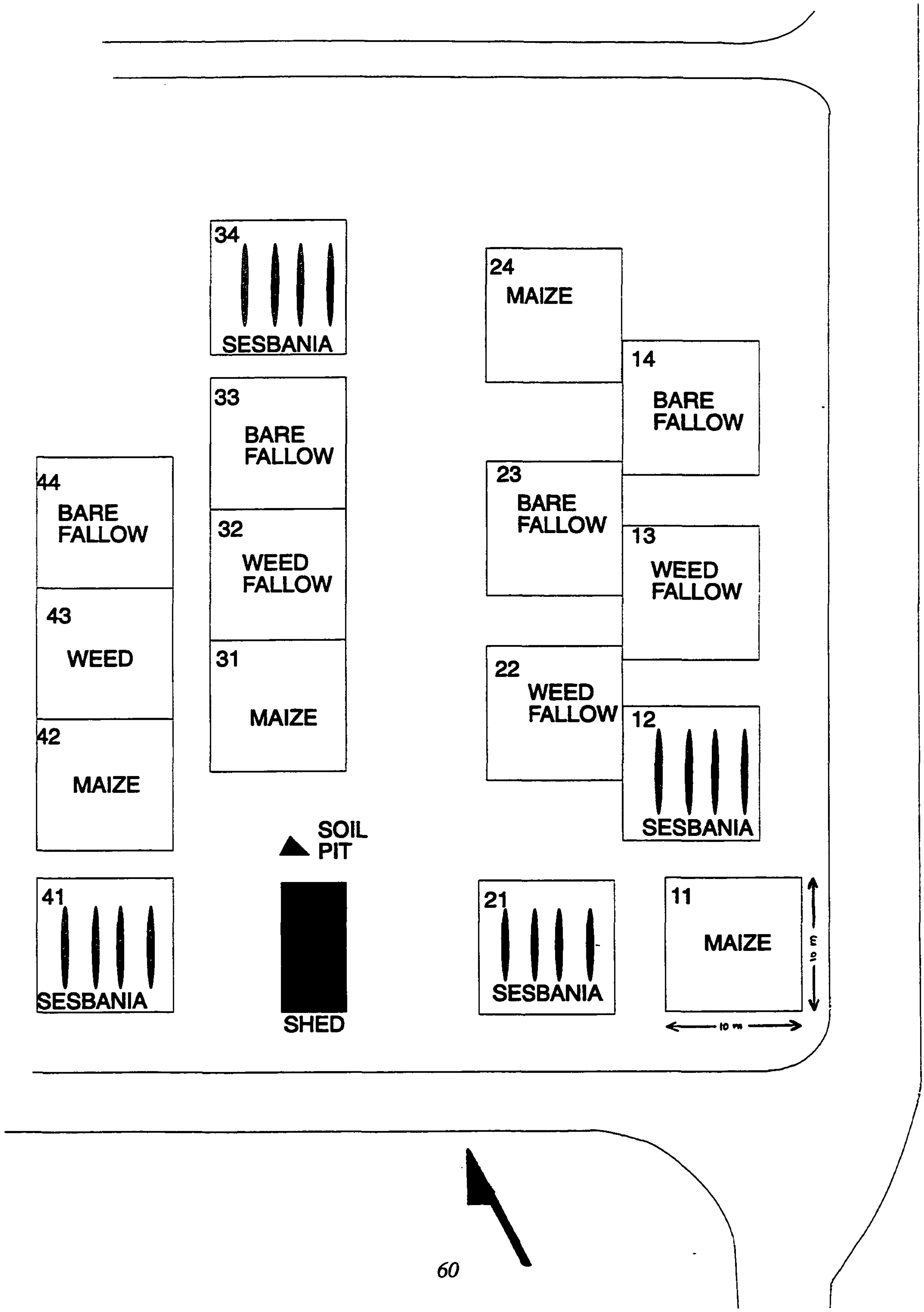
Bulk Density and Pore Volume (pit 2)

depth (cm)	bulk density Mg m^{-3}	pore volume	volumic fraction of air at *p*F	
			0.0	2.0
00-15	1.10	0.585	0.561	0.284
15-30	1.13	0.574	0.527	0.234
30-50	1.10	0.585	0.454	0.248
50-100	1.17	0.558	0.533	0.225
100-150	1.23	0.536	0.473	0.168
150-200	1.25	0.528	0.507	0.157

Moisture Fractions (pit 2)

Depth	Volume fraction of moisture at *p*F							Available moisture mm	
cm	0.0	2.0	2.3	2.5	3.7	4.2	2 - 4.2	per horizon	cummul.
00-15	0.561	0.301	0.288	0.271	0.197	0.181	0.120	18.0	18.0
15-30	0.527	0.340	0.329	0.314	0.232	0.212	0.128	19.2	37.2
30-50	0.454	0.337	0.327	0.310	0.231	0.211	0.126	25.2	62.4
50-100	0.533	0.333	0.322	0.313	0.249	0.229	0.104	52.0	114.4
100-150	0.473	0.368	0.356	0.346	0.270	0.244	0.124	62.0	176.4
150-200	0.507	0.371	0.360	0.347	0.269	0.246	0.125	62.5	238.9

APPENDIX II FIELD LAY-OUT OF THE EXPERIMENT AT OCHINGA FARM



APPENDIX III PROCEDURES FOR SOIL SAMPLING AT OCHINGA FARM (October 1993)

Experiment NM1 at Ochinga farm consists of 4 treatments with 4 replicates. Plots size is 10 * 10m although for this experiment only half of the plot is used. The treatments are briefly called: *Sesbania*, maize, weed and bare. Soil sampling is carried out for nitrate-N, ammonium-N and moisture determinations. Composite samples are taken from six depths: 00-15, 15-30, 30-50, 50-100, 100-150 and 150-200 cm.
Two distinct different sampling procedures are followed:
(i) method I is used for the maize, weed and bare plot,
(ii) method II is used for the plots with *Sesbania*.
A description of both methods is given below.

METHOD I (MAIZE, WEED BARE)

The maize plots are sampled perpendicular to the rows. The first row at either side is considered as a borderrow and not sampled. Each sample till one meter depth consists of 8 subsamples (4 * 2 pairs), below one meter each sample consists of 4 subsamples. Of the 8 sample locations 4 are taken between the rows and 4 within the rows.
A transect perpendicular to the maize rows is used for two sampling rounds as indicated below (A for round 1 and B for round 2). After two rounds, the sampling line is moved 40 cm into the plot for sampling round 3 and 4.

```
█  █  █  █  █  █  █  █  █  █  █  █  █   maize rows
   + + + +    + + + +   + + + +    + + + +   sampling location
   A A B B    A A B B   A A B B    A A B B   sampling time
```

The distance between two sample locations of a pair is 37.5 cm between the sample pairs the distance is equal to 187.5, 150 and 187.5 cm.
For the weed and bare plots the same system of sampling is used.

Sampling is carried out by an Edelman auger up to 2 metres by one team per plot. A team consist of two men, one augering and the other one with the bucket who is emptying the auger and breaking the soil and mixing it. The person with the bucket sits outside the plot to avoid unnecessary soil compaction. No walking planks are used between the rows to avoid compaction.
After the six depths are finished sampling for analysis is done in the field by pouring the soil two times over into another bucket and mixing it by hand. About 400g soil is taken and put in a plastic bag. The plastic bag is labelled and brought to the shed directly after it has been closed with sisal twine. At the same time about 50 g of soil is put in a moisture tin which is firmly closed.

The augerhole is refilled after a subsample for analysis is taken. It is done by two persons using a large funnel and a stick to compact the soil in the hole. Where the labourers have walked in the plots and compacted the topsoil a light tillage is given using a jembe. Care is taken to avoid any topsoil replacement.

OVERVIEW SAMPLING DATA MAIZE, WEED, BARE	
number of plots	: 12 (3 treatments, 4 reps)
augerings per plot	: 8
total augerings all plots	: 96
number of subsamples for one sample	: 8
number of samples per plot	: 6
number of samples per round	: 72 (6*12)

METHOD II (*Sesbania*)

For the *Sesbania* soil sampling is carried out perpendicular to the rows. The following figure shows a cross-section through the 4 *Sesbania* rows and the sample locations:

```
 1                 2                 3                 4
::::::            ::::::            ::::::            ::::::  Sesbania rows
  + + + + + + + + + + + + + + + + + + + + + + + + + + +   sample points
  1 2 3 4 5 4 3 2 1 1 2 3 4 5 4 3 2 1 1 2 3 4 5 4 3 2 1   subsample numbers
```

The distance between each of to the 27 sample points is 25 cm. All samples collected at sample point 1 are mixed into one sample which hence consists of 6 subsamples. The same is done for samples at point 2, 3 and 4. Only sample 5 consist of 3 subsamples. The sample points are marked with a coloured stick and the following codes are used: red for 1, white for 2, green for 3, black for 4 and blue for 5. Six depth are sampled for every sample point. With each sampling round the line with the sample points is moved 40 cm into plot corresponding with the distance between two *Sesbania* plants within the row. The line is placed exactly between two plants within the row.

Sampling is carried out by an Edelman auger up to 2 metres by two teams per *Sesbania* plot. Each team consist of two men, one augering and the other one with the bucket who is emptying the auger and breaking the soil and mixing it. The person with the bucket sits outside the plot to avoid unnecessary soil compaction. No walking planks are used between the rows to avoid compaction.

After the six depths are finished sampling for analysis is done in the field. It is done by pouring the soil over into another bucket and mixing it by hand. About 400g soil is taken and put in a plastic bag. The plastic bag is labelled and brought to the shed directly after it has been closed with sisal twine. At the same time about 50 g of soil is placed in a moisture tin which is firmly closed and brought to the shed.

Refilling the hole is done after a subsample has been taken for analysis. It is done by two persons using a large funnel and a stick to compact the soil in the hole. Where the labourers have walked in the plots and compacted the topsoil a light tillage is given using a jembe. Care is taken to avoid any topsoil replacement. An overview of the amount of augerings and samples collected per round is given below:

OVERVIEW SAMPLING DATA *Sesbania*

number of plots	:	4
augerings per plot	:	27
total augerings *Sesbania* plots	:	108
number of subsamples for one sample	:	6 for position 1, 2, 3 and 4
		3 for position 5
number of samples per plot	:	30 (6*5)
number of samples per round	:	120 (4*30)

NUMBERING SYSTEM OF SOIL SAMPLES

The numbering code of the soil samples consists of a letter and 2 numbers for the maize, weed and the bare plots and 3 numbers for the *Sesbania* plots. The sampling code contains the following information:

(i) sampling round i.e. sampling date which is indicated by the letter,

(ii) plot number which gives information on the location (terrace) and the treatment

(iii) soil depth indicated by a number from 1 to 6 corresponding to depths from 00-15 to 150-200cm.

In the case of *Sesbania* an extra number is added:

(iv) location which shows the position from the hedge i.e. from 1 to 5 which is corresponding to 12.5 to 112.5 cm from the middle of the hedge resp.

The letter and first number are not separated but subsequent numbers are separated by a stroke. Some examples are given below.

full code	explanation in words	letter/number
C14-1	third round	C
	terrace 1 plot 4 which is bare	14
	00-15cm depth	1
A42-4	first round	A
	terrace 4 plot 2 which is maize	42
	50-100cm depth	4
D21-5-4	fourth round	D
	terrace 2 plot 1 which is *Sesbania*	21
	100-150 cm depth	5
	87.5 cm from the middle of the row	4

TIME OF SAMPLING

Time of sampling is based on the amount of rainfall between two sampling rounds and about 100mm of rain should have been fallen. Ideally all 16 plots are sampled in one day as the chance for rain between two sampling days is considerable.

NUMBER OF SAMPLES

Per round 192 soil samples are collected (120 from the *Sesbania* plots and 72 from the maize, weed and bare plots). The samples are brought to the Maseno laboratory the same day and stored in a refrigerator at about 5 to 8°C before extraction.
Moisture tins are weighed and put into the oven the same day.

LABOUR INPUT

Sampling is done by 4 auger teams of 2 men. Furthermore there are 2 men refilling holes, and there is 1 subsampling assistant and 1 extra supervisor. In total 12 men are required to finish the sampling in about 15 hours. Labourers are paid per 5 hours of work (1 manday) so in total 36 mandays (15/5 * 12) are used for the actual sampling. Total labourcosts per sampling round are 36 * 40 = 1,440 Ksh.

Alfred Hartemink
Maseno, 23rd October 1993

APPENDIX IV PROCEDURES FOR EXTRACTION AND FILTRATION OF SOIL SAMPLES AT MASENO LABORATORY (October 1993)

Soil samples at maseno laboratory are extracted for nitrate and ammonium determination. Most samples are coming from experiment NM1 at Ochinga farm.

SUBSAMPLING

Soil samples are stored in the refrigerator at a temperature of 5 to 8°C when they are brought in from the field. Each sample weighs about 400g and contains a label with the number. The number is also written on the bag. The bags are closed with sisal twine. The bags are opened and the soil is spread out evenly over a white plastic tray of 35 * 45cm. The label is put in the right corner of the tray. A metal grill is put over the tray dividing the surface into 12 equal sized squares. Firstly a sample is taken for the moisture determination. Hereto about 20g soil of the 12 squares is put into a plastic beaker which was tared. The weight of the soil and the label number are recorded and the beaker is put on a tray after which the beakers are put in the oven for moisture determination (24h at 105°C).

Then the soil is sampled for extraction. The soil is mixed again and the grill is put back on the tray after which of 12 points little soil is taken. This is repeated till somewhere between 9.60 and 10.40 g of soil is collected in a tared 125 mL bottle. For extraction soil is usually taken of 15 points on the tray (12 before and 3 after remixing). The exact weight and the label number are recorded and the bottle is closed. Of one sample per every 23 samples a so-called duplicate sample is taken which means that the same soil on the tray is remixed and again a subsample for extraction is taken.

At last the soil is sampled for water soluble carbon. About 50 g of soil is collected randomly from the tray and put into the original plastic bag. Remaining soil is left on the tray and thrown away. The bag is closed again and the label is added. Then the bag is put again in the refrigerator and ready to be send to Machakos.

EXTRACTION

After 23 samples have been subsampled extraction starts. Exactly 100 mL of 2M KCL is added to the 125 mL bottles. The bottles are placed in a shaker with a speed of 150 for one hour. Per 23 samples 2 blanks are added i.e. a bottle with 100 mL 2M KCL with no soil. After one hour shaking the bottles are placed on the table and approximately half an hour is allowed for sedimentation of the soil in solution.

FILTRATION

The solution is filtered through Whatman filterpaper (ashless, 9cm) which are folded before washed by distilled and deionised water. Washing of the filter paper takes place while the sedimentation of the soil occurs. Hands are carefully washed before touching the filter paper.

After one polycon is half filled the filter is placed into another polycon which is also half filled. Hereafter the contents of two polycons are three times poured over and the filtrate is equally divided over the two polycons. One remains in Maseno and the other one is send to Machakos for analysis. The one remaining in Maseno has the letter R behind the number and is placed in the freezing compartment of the refrigerator.

Alfred Hartemink
Maseno, 21st October 1993

APPENDIX V

PHYSICAL PROPERTIES OF THE SOILS OF OCHINGA FARM

- WESTERN KENYA -

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ICRAF

INTERNATIONAL CENTRE FOR RESEARCH IN AGROFORESTRY

Alfred E. Hartemink
Maseno, December 1993

1 INTRODUCTION

1.1 Inducement and Objectives of the Study

Ochinga farm is located in Western Kenya about 10 km W from Maseno Agroforestry Station (Vihiga district, Emuhaya division). Field experiments for soil fertility research started in April 1993. Although numerous samples have been taken for chemical analysis, little was known sofar on the physical properties of the soils. Therefore a field survey was undertaken to determine some physical properties of the soils of Ochinga farm. The results of the survey are presented in this report. The objectives of the study were:

(i) to measure basic physical parameters for a more complete description of the experimental site.

(ii) to provide soil physical data in order to study waterbalances, leaching models and other research requiring these parameters.

This report presents not all physical parameters required to meet these objectives. Particularly soil texture, soil temperature and soil structure are important as well. However, soil temperature has been measured since May 1993 and also texture and structure were determined for the soils of Ochinga farm. These data were not available or not in a suitable format to be included in this study.

Field work took place during the week of 14 to 17 December 1993 by Alfred Hartemink, MSc-student of Wageningen Agricultural University. During fieldwork the surveyor was assisted by Tom Ochinga, the son of the farmer, Elijah Opondo of the Maseno Station laboratory and last but not least, by Ariane Hartemink-van Geijn. All are gratefully acknowledged.

1.2 Previous Work

As said, not much was know on the physical properties of the soils of Ochinga farm. Some general information was found in the soil survey report of Andriesse and van der Pouw (1985). They describe the soils near Ochinga farm as well drained, extremely deep, dark red very friable clay. Moisture storage was estimated over effective soil depth and they arrived at an AWC of over 160 mm. Infiltration was also estimated and based on soil-texture, depth and cracking properties. For the soils of Ochinga farm infiltration rates were estimated to be higher than 2.5 cm h^{-1}. The present study confirms roughly the available moisture figure but infiltration rates were found to be much higher.

2 BULK DENSITY AND PORE VOLUME

2.1 Background

Bulk density refers to the overall density of a soil (i.e. the mass of mineral soil divided by the overall volume occupied by soil, water and air). Bulk density measurements are generally made as a guide to soil compaction and porosity. Measurements are affected by the structure of the soil, i.e. its looseness or degree of compaction as well as by its swelling and shrinkage characteristics, which are dependent upon clay content and wetness (Hillel, 1982). Bulk densities are often used as indicators of problems of root penetration and soil aeration in different soil horizons. Besides for these reasons, bulk density measurements at Ochinga farm were also required for calculation of inorganic nitrogen data on a kg ha^{-1} base.

2.2 Methods

In October 1993 a soil pit was dug between plot 31 and 41 (terrace 2, see Annex I). The pit was 2 meters deep and 100 cm^3 ringsamples were taken from the following depths 00-15, 15-30, 30-50, 50-100, 100-150, 150-200 cm. These depths correspond with the sampling depths for inorganic nitrogen. Per depth 4 rings were pushed gently in the soil and remaining soil outside the rings was removed. The rings were dried for 72 hours at 105°C. Samples were also taken in December 1993 using a ring-sampler which was connected to an auger. The samples were taken between plot 23 and 24 (terrace 1) on a site which has been soaked overnight. The same number of ring-samples as in the pit were taken.
Bulk density (volumic mass) was calculated using the formula:

$$\frac{\textit{weight dry soil - ring weight}}{100} = \textit{bulk density}$$

UNITS

ring and dry soil weight	g
bulk density	Mg m^{-3}

Of each horizon the bulk density was calculated and the average was taken for the 4 rings. Based on the bulk density, the pore volume (space) of the soil was calculated assuming a particle size density of 2.65 Mg m^{-3}.

$$1 - \frac{\textit{bulk density}}{\textit{particle size density}} = \textit{pore volume}$$

UNITS

bulk density	Mg m^{-3}
particle size density	Mg m^{-3}
pore volume	fraction

The pore volume calculated with the bulk density should be equal to the volumetric water content at saturation point (i.e. *p*F 0.0).

2.3 Results

Table 1 presents the bulk density of the samples taken in the pit and with the auger. The samples taken in the pit show a clear increase of the bulk density with depth while for the samples taken with the auger an opposite trend can be noticed. The values obtained from the ring-samples taken in the pit should be preferred as the method is generally more accurate and as the outcome resembles what is usually found for bulk density measurements.

Table 1 *Bulk density and pore volume of the soils of Ochinga farm*

depth (cm)	bulk density Mg m^{-3}		pore volume		volumic fraction of air at *p*F 0.0*
	pit	auger	pit	auger	
00-15	1.10	1.24	0.585	0.532	0.561
15-30	1.13	1.26	0.574	0.525	0.527
30-50	1.10	1.13	0.585	0.575	0.454
50-100	1.17	1.07	0.558	0.596	0.533
100-150	1.23	1.07	0.536	0.596	0.473
150-200	1.25	1.04	0.528	0.608	0.507

* - see section 3.3

The bulk densities of clay, clay loam and silt loam topsoils may range between 1.00 and 1.60 Mg m^{-3} depending on their condition (Landon, 1991). The topsoils at Ochinga farm have bulk densities which classify between recently cultivated soils (0.9-1.1 Mg m^{-3}) and surface mineral soils which are not recently cultivated but not compacted (1.1-1.4 Mg m^{-3}) (Taylor *et al*. 1966). De Geus (1973) mentions that bulk densities between 1.46 to 1.63 Mg m^{-3} for silts and clays cause hindrance to root penetration. As the bulk densities in the subsoils of Ochinga farm are less than 1.3 Mg m^{-3}, no hindrance to roots is therefore expected.

Based on bulk density measurements in the pit, the soils have a pore volume of about 58% in the first 50 cm and less than 55% below 50 cm. Landon (1991) mentions that for clay soils porosities less than 50% are liable to restrict root growth due to excessive strength. These porosities are not found in the soils of Ochinga farm.

There is a discrepancy between the porosity calculated with the bulk density from the pit and based on *p*F determinations. The difference is particular noteworthy for the 30-50 cm horizon (14% difference) and for the 100-150cm horizon (13% difference). In the other horizons the difference is less pronounced although the porosity based on the moisture retention determination is systematically lower. It might be caused by the fact that the ring samples were taken while the soil was not a field capacity (FC). It is generally known that bulk densities vary with moisture content, particularly in fine textured soil (Landon, 1991). As the soils were sampled while they were having moisture contents below FC (see Annex II) the porosity may therefore have been slightly overestimated.

3 AVAILABLE WATER CAPACITY

3.1 Background

The variable amount of water contained in an unit mass or volume of soil, and the energy state of water in soil are important factors affecting the growth of plants. Numerous other soil properties and processes depend upon water content. The per mass or per volume fraction of water in the soil can be characterized in terms of soil wetness. Soil wetness is functionally related to matric (pressure) potential which characterizes the tenacity with which soil water is held by the soil matrix. The graphical representation of the relationship between soil water and matric potential is termed the soil-moisture characteristic curve (*p*F curve). There are several ways to determine soil water potential (see Anderson and Ingram, 1993). For the soils of Ochinga use has been made of ring- samples at which different pressure was applied. From this available water capacity was calculated which allows the study of soil-water relationships.

3.2 Methods

Ring samples for *p*F determination were taken of the same pit as described in section 2.2. Methods for sampling were identical as for bulk density measurements. The samples were analyzed at National Agricultural Research Laboratories (KARI) in Nairobi. Moisture content was determined at *p*F 0.0, 2.0, 2.3, 2.5, 3.7 and 4.2 (data are given in Annex III).
*p*F 0.0 is saturation point (equal to total pore space), *p*F 2.0 field-capacity (FC) and pF 4.2 resembles permanent wilting point (PWP). Available water capacity (AWC) is calculated as follows:

moisture content at FC − moisture content at PWP = AWC

The data obtained from NARL were expressed on a weight base and multiplied by the bulk density (from the pit) in order to express them on a volumetric base (Θ). Available moisture per soil horizon was calculated using the formula:

(AWC * bulk density) * thickness of horizon = available moisture

UNITS:

AWC	%w w^{-1}
bulk density	Mg m^{-3}
thickness of horizon	mm
available moisture	mm per horizon

3.3 Results

As many soil data are skewly distributed (Parkin, 1993) the *p*F data were tested for normality before they were processed. Firstly a frequency distribution was constructed (figure 1) which revealed a weakly skewed distribution.

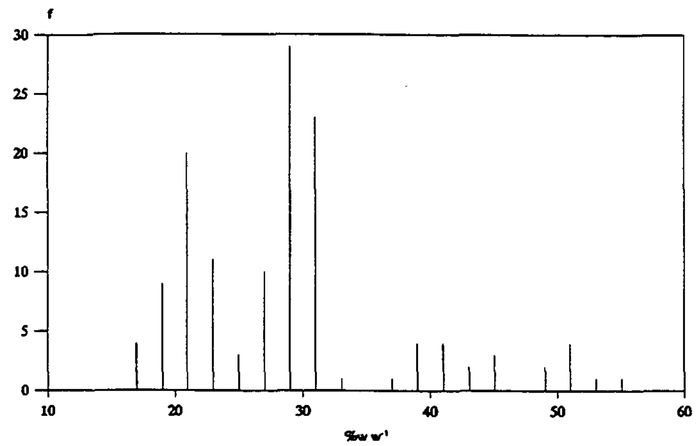

Figure 1 Frequency distibution of *p*F values
(class width 2%; figure based on 132 pF values)

Secondly, a scatter diagram was constructed to verify the relationship between the mean and the variance as is suggested by Gomez and Gomez (1984). Of each *p*F value the mean was plotted against the range (highest minus lowest value). The range increased not proportionally with the mean and transformation of data to achieve homogeneity of variance was therefore not found necessary.

The 4 *p*F-values of each soil horizon were averaged and multiplied by the bulk density to arrive at volumetric water contents (table 2).

Table 2 *Volumic fraction of moisture at pF range 0.0 to pF 4.2 and the available moisture of the soils of Ochinga farm.*

Depth	Volume fraction of moisture at *p*F							Available moisture mm	
cm	0.0	2.0	2.3	2.5	3.7	4.2	2 - 4.2	per horizon	cummul.
00-15	0.561	0.301	0.288	0.271	0.197	0.181	0.120	18.0	18.0
15-30	0.527	0.340	0.329	0.314	0.232	0.212	0.128	19.2	37.2
30-50	0.454	0.337	0.327	0.310	0.231	0.211	0.126	25.2	62.4
50-100	0.533	0.333	0.322	0.313	0.249	0.229	0.104	52.0	114.4
100-150	0.473	0.368	0.356	0.346	0.270	0.244	0.124	62.0	176.4
150-200	0.507	0.371	0.360	0.347	0.269	0.246	0.125	62.5	238.9

The available moisture content (pF 4.2-2.0) differs little with depth and is around 12%. Exception is the 50 to 100 cm horizon which has about 2% less AWC than the other horizons. The soils of Ochinga farm have about 115 mm readily available water in first meter which corresponds to a medium textured soil (FAO, 1977). Landon (1991) gives as an indication for stone free tropical soils with clayey textures 100 to 150 mm m^{-1} available water depending on soil properties such as organic matter content, structure, bulk density, clay mineralogy etc.

Soil moisture characteristics curves are presented in figure 2.

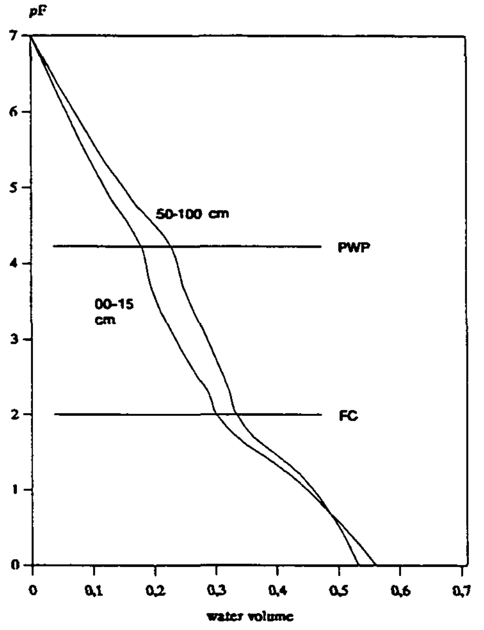

Figure 2 pF-curve of the topsoil (00-15 cm) and subsoil (50-100 cm) of Ochinga farm

The curves resemble a typical clay to loam curve with slight decrease in water volume at low pF values and a relative high portion of non-available water (i.e. water volume > pF 4.2). There is about 2% difference in AWC between the two soil horizons while the difference in non-available water is nearly 5%. In the very high suction range (i.e. > pF 5) the predominant mechanism of water retention is absorption rather than capillary, and hence the retention capacity becomes more of a textural than a soil structural attribute. This may explain the observed difference in the high suction range between the top- and subsoil of figure 2.

A profile diagram showing the ratio between water, pore-space and soil particles is presented in figure 2. The figure is based on volumetric ratios derived from the moisture retention curves. The diagram shows that air-filled pores are considerably less around 40 cm depth which could cause that saturation is occurring more rapidly as in the other soil horizons.

As has been seen in figure 2 the percentage of non-available water is steadily increasing with depth possibly caused by textural changes with depth.

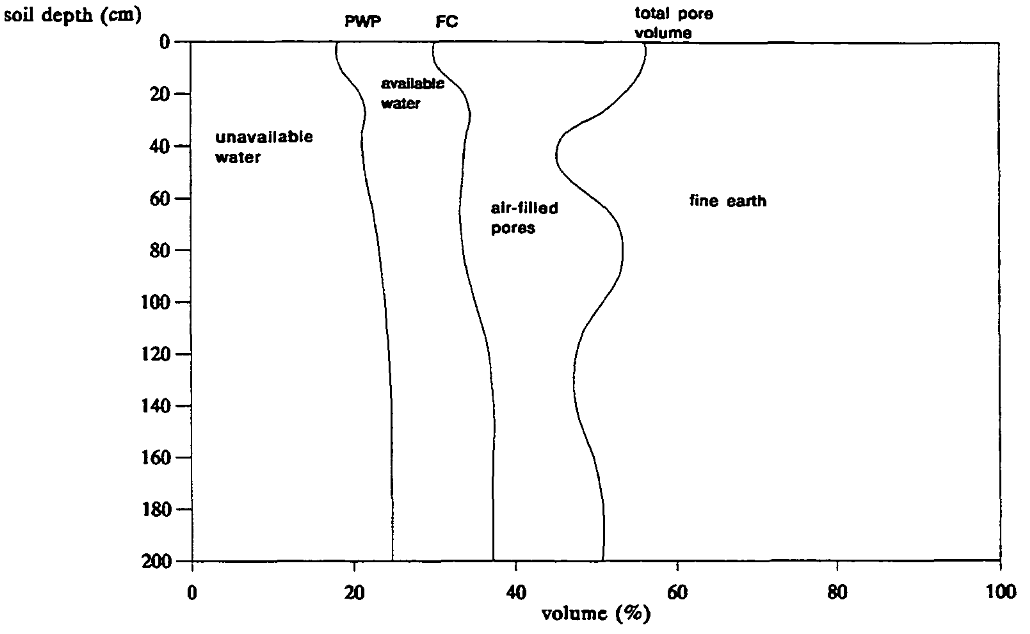

Figure 3 Profile diagram of the soils of Ochinga farm

4 HYDRAULIC CONDUCTIVITY

4.1 Background

The hydraulic conductivity (or permeability) of a soil, K, in cm h^{-1} or m day^{-1} defines the volume of water which will pass through unit cross-sectional area of a soil in unit time, given a unit difference in water potential. It refers to the subsurface movement water both vertically and horizontal.

In general K is of interest as a guide to water movement in soils and as a basis for drainage and/or irrigation designs. For Ochinga farm K was determined for soil-water relationship studies and in particular for leaching studies. Two methods are commonly used: hydraulic conductivity measurements below the water-table (saturated soils) and above the water-table (unsaturated soils).

4.2 Methods

At Ochinga farm K was determined above the water table at three locations following the inverse auger-hole method. A hole was augered (r=3.25 cm) to 100 cm deep on a site where the day before infiltration measurement was carried out (see section 5.2). The measurements were made between plot 21 and 22, between 23 and 24 and the third measurement was made 5 m NE of plot 44 (see Annex I).

Before the test was conducted the gravimetric water content of the soil was determined (24 h at 105 °C). The auger-hole was filled for about 50 cm of water and a floater with a reading stick was put into the hole. Readings were made for about 50 minutes at regular intervals. All readings are given in Annex IV.

Water was obtained from the Esava stream which flows 100 m NW from Ochinga farm. The water contained suspended and probably also dissolved soil material at a rate of about 30g 100^{-L}.

For the calculation of K firstly the tangent of the line relating the level of water in the augerhole with time was calculated:

$$\tan \alpha = \frac{h(t_0) - h(t_n)}{h(t_n)} * \frac{1}{t_n}$$

UNITS

$h(t_0)$, $h(t_n)$	cm
t_0, t_n	second

Whereby $h(t_0)$ is the interception of the y-axis at t_0 and $h(t_n)$ is the height of the water level at the last reading (t_n). K is calculated using 1.15 as a constant and r (radius) of the auger-hole (for full derivation of the formula see: Landon page 226-229, 1991).

$$K = 1.15 * \tan\alpha * r$$

UNITS

K cm s^{-1} (* 864 = m day^{-1})

r cm

4.3 Results

Before measurements were made the gravimetric water contents of the soils was determined (see table 3). Volumetric contents were calculated by multiplying the gravimetric water content with the bulk density.

Table 3 *Gravimetric (grav.) and volumetric (volum.) water content of the three soils (in %) before hydraulic conductivity measurements*

depth (cm)	auger-hole 1		auger-hole 2		auger-hole 3	
	grav.	volum.	grav.	volum.	grav.	volum.
00-15	29.2	32.1	31.3	34.4	31.3	34.4
15-30	30.2	34.1	32.1	36.3	30.5	34.5
30-50	31.8	35.0	32.3	35.5	30.1	34.0
50-100	33.8	39.5	32.2	37.7	31.8	37.2

If the volumetric water content is compared with the moisture fraction at pF 0.0 and pF 2.0 (section 3.3) than it appears that nearly all soil horizons had moisture contents below field capacity but above saturation point. The volumetric moisture content in the 15 to 30 cm horizon was in auger-hole 1 and 3 near field-capacity.
The drop in water level over time is generally plotted on semi-log paper to obtain a straight line (figure 4).

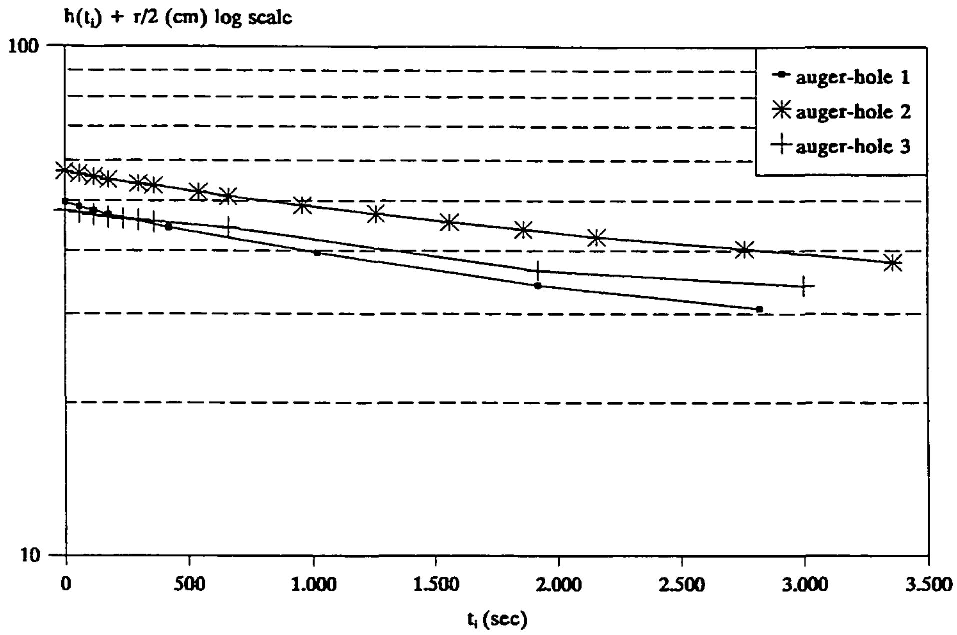

Figure 4 Relation between water level and time with inverse auger-hole method

The figure shows that the instantaneous intake rate is similar in the beginning as after 30 minutes. One generally expects a logarithmic function ($y = a*x^b$ whereby a and x > 1 and b < 0) between the intake and the time elapsed but the lines suggest a more linear relationship and high correlation coefficients were found. From the derived equations in column 2 of table 4, the tangent and K values were calculated in column 4 and 5 resp.

Table 4 *Relation between $h(t_i)$ and time (t), and calculation procedures for K in three augerholes at Ochinga farm.*

auger-hole	approx. relation	r^2	tan α	K m day^{-1}
1	$h(t_i) + r/2 = -0.00676 * t + 48.289$	0.972	$\tan\alpha = \frac{48.289-29.226}{29.226} * \frac{1}{2820} = 2.313 * 10^{-4}$	0.8
2	$h(t_i) + r/2 = -0.00581 * t + 55.678$	0.974	$\tan\alpha = \frac{55.678-36.162}{36.162} * \frac{1}{3360} = 1.606 * 10^{-4}$	0.5
3	$h(t_i) + r/2 = -0.00478 * 47.369$	0.978	$\tan\alpha = \frac{47.369-33.029}{33.029} * \frac{1}{3000} = 0.144 * 10^{-4}$	0.5

K-values obtained varied from 0.5 to 0.8 m day^{-1} for the three observations. FAO (1963) quoted by Landon (1991), considered K-values of 0.5 to 1.4 m day^{-1} as moderately fast. In 1979 FAO related texture and structure to hydraulic conductivity and found for clayey soils which are fine and medium prismatic structured K-values from 0.1 to 0.5 m day^{-1}. In coarser structured and textured soils, K-values were accordingly higher.

5 INFILTRATION CHARACTERISTICS

5.1 Background

Infiltration refers to the vertical intake (flow) of water into a soil, usually at the soil surface. It should not be confused with hydraulic conductivity or permeability, which is a measure of the ability of a soil to transmit water in all directions, horizontally as well as vertically. Rates of flow in infiltration measurements are established by the difference in water-level at predetermined time intervals. The rate of inflow diminishes with time and the experiment is terminated when the rate has become constant.

Results of infiltration measurements are generally used for irrigation studies and for run-off calculations. The latter was the main reason why it was measured at Ochinga farm.

5.2 Methods

Infiltration rate were measured using the so-called double ring method on the same sites as hydraulic conductivity measurements were made (section 4.2). About 1.5 m^2 was cleared of vegetation in a maize field. An earth bund of 20 cm was constructed and the soil was soaked with 200 L water.

For the soaking as well as for the infiltration measurements water from Esava river (near Ochinga farm) was used. The water contained about 30 g of sediments per 100 L.

The rings (height 25 cm, large ring r = 27.5 cm, small ring r = 15 cm) were pushed 10 cm in the pre-wetted soil and levelled. The rings were placed exactly between the maize rows. Water was poured carefully on the soil surface using a siphon to avoid soil disturbance.

At the first site, readings were made after the soil was soaked for 3 hours. At the second and third location the soil was soaked overnight before readings were made. Readings immediately started after the rings were filled-up with water. The water level was kept constant in the outer and inner ring at an height of about 10 to 12 cm. Readings for the first observation were made for 1.5 h after which they had to be terminated because of rain. At the 2nd and 3rd site infiltration measurements were continued for 4 and 6 h resp. till the rate was about constant. Fielddata are given in Annex V.

5.3 Results

Before infiltration measurements were made the moisture content of the soil was determined (table 5). The moisture content were about similar at the three sites.

Table 5 *Gravimetric (grav.) and volumetric (volum.) water content of the three soils (in %) before infiltration measurements*

depth (cm)	site 1		site 2		site 3	
	grav.	volum.	grav.	volum.	grav.	volum.
00-15	23.7	26.1	23.5	25.8	24.0	26.4
15-30	23.6	26.7	24.0	27.1	23.3	26.3
30-50	28.1	30.9	26.0	28.6	24.7	27.2
50-100	31.4	36.7	28.3	33.1	26.4	30.9
100-150	31.1	38.3	30.3	37.3	28.5	35.1
150-200	30.6	38.3	30.4	38.0	28.7	35.9

The top 50 cm had volumetric water contents between field capacity and wilting point before infiltration measurements were made. The subsoils below 50 cm had moisture contents close to field capacity.
The intake of water over time is presented in figure 5.

Infiltration at constant rates varied from about 8 cm h^{-1} at site 1 to 18 cm h^{-1} at site 3 (figure 5). Basic infiltration rates were however much higher and during the first ten minutes rates were over 30 cm h^{-1} at all three sites.
Variability in infiltration rate measurements are generally high (Landon, 1991). Possible causes for the differences are lack of adequate pre-wetting (site 1), trapping of air under the cylinder, soil disturbance effects and soil variability (cracks etc).
Also the water quality has a large influence on the infiltration pattern. Suspended and dissolved material in the water like was used at Ochinga farm, may seal a soil surface and hence reduce the infiltration rate. As infiltration rates were found to be high (see hereafter), the sediments in the water did probably have no effect.

Landon (1991) quotes infiltration categories used by BAI and values over 12.5 cm h^{-1} are classified as rapid to very rapid. Sanchez (1976) quoting Lugo-Lopez *et al.* (1968) gives as minimum and maximum infiltration rates for Ultisols 7.4 and 23.6 cm h^{-1}. The high rates for these soils reflect their good structure according to Sanchez. The values found at Ochinga farm very well fall within this range.

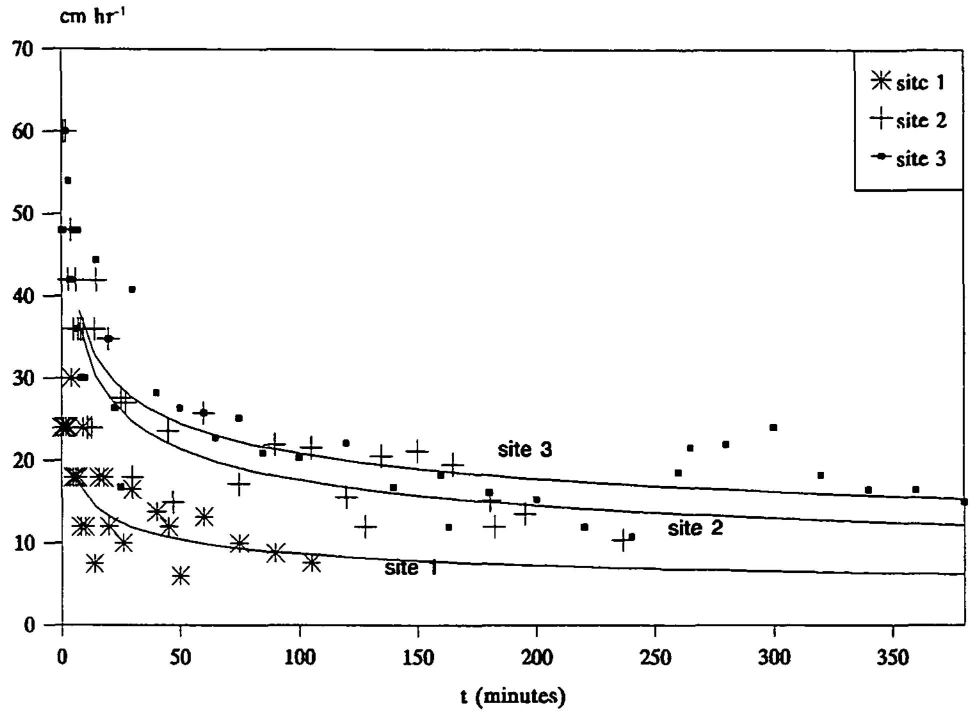

Figure 5 Infiltration pattern of the soils of Ochinga farm

From this high infiltration rates one probably does not expect runoff. Contrary to the high infiltration rates, runoff has been observed at Ochinga farm, particular in the bare-fallow plots. A possible explanation for this discrepancy might be that the infiltration measurements were made in maize plots which were apparently better structured than the soils of the bare-fallow plots. Secondly, the erosivity of the rain is far less in fields with a soil cover as in bare-fallow plots where splash erosion followed by sealing of the surface is the main cause for runoff. Also Sanchez (1976) mentions that soil cover is the predominant factor affecting runoff. From examples in West Africa it appeared that the ratio between runoff occurring at bare soil and cultivated land varied roughly with a factor 20.

6 CONCLUSIONS

The soils of Ochinga farm have bulk densities of about 1.1 in the upper 50 cm and above 1.2 Mg m^{-3} in deeper subsoils. These bulk densities are common for agricultural soils and do not hinder root growth.

The pore volume of the soils based on the bulk density and assumed particle size density of 2.65 Mg m^{-3} is about 58% in the upper 50 cm and decreases with depth to about 52 %. The pore volumes are considered favourable and do generally not restrict root growth. Pore volume based on volumic fraction at *p*F 0.0 is in all horizons lower than when calculated based on bulk density, but it is considerably lower in the 30-50 and 100-150 cm soil horizon. Possible explanation might be that the soils were not near an optimum moisture value at time of sampling for bulk density.

Based on the profile diagram of the soils, air-filled pores were found to be much lower in the 30-50 cm soil horizon. It may result in relatively early saturation levels inducing denitrification.

The soils have about 60 mm of available water in the first 50 cm and 115 mm in the first meter. This implies that at a evapotranspiration rate of 4 mm day^{-1}, it takes 12 to 28 days to deplete the soil water in the 00-50 and 00-100 cm horizons resp. The top soil (00-15 cm) stores only 18 mm of water. Drought stress during the early establishment of a maize crop when it is shallow rooted, may therefore be observed within a few days after the drought commenced. At later stage when the crop has rooted more extensively to about 50 cm depth, drought stress may be observed within 2 weeks after the last rains.

For deep-rooting perennial crops like *Sesbania sesban* drought stress is less likely to occur and the amount of readily available water is about 240 mm for the first 200 cm.

Hydraulic conductivity varied from 0.5 to 0.8 m day^{-1} which is generally regarded as moderately fast. It implies that leaching losses may also occur at this speed provided nutrients are not captured.

Constant infiltration rates were found to vary from 8 to 18 cm h^{-1} which is high. The first ten minutes, however, rates were higher than 30 cm h^{-1} which indicates that even at rainfall intensities over 300 mm h^{-1} the water is still able to infiltrate and no runoff occurs. This holds as long as the topsoil structure is strong enough to withstand the impact of the falling raindrops. It has been observed at Ochinga farm that the topsoils are vulnerable to splash erosion due to their weak structure. This causes breaking of soil particles in fine fragments which seals of the surface resulting in reduced infiltration rates. Therefore, the infiltration rates measured with the double-ring may overestimate the capacity of the soils to infiltrate water.

The combination of the high infiltration rates with the moderately fast hydraulic conductivities of the soils, is of importance for the possibilities of leaching losses at Ochinga farm.

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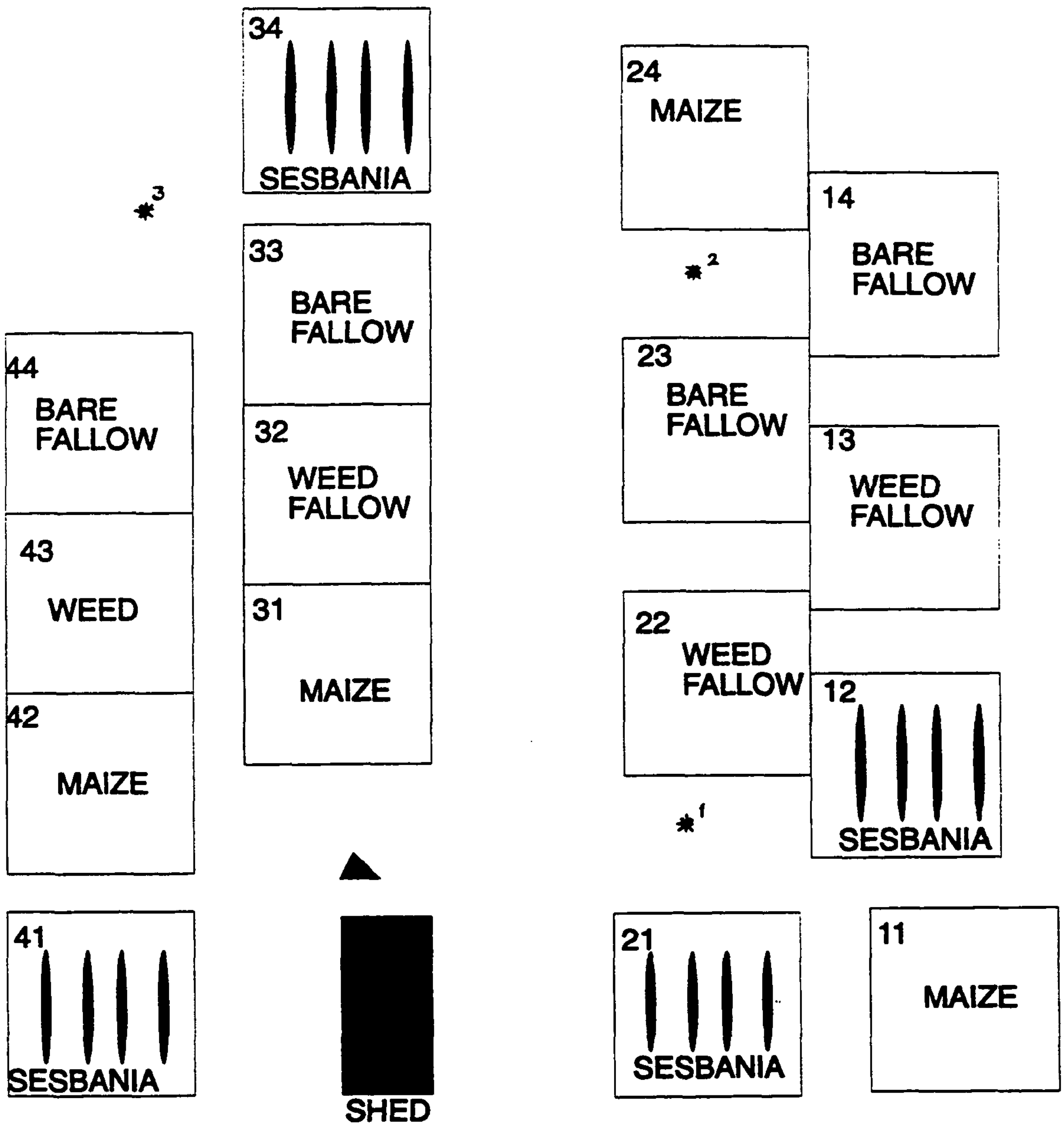
ANNEX I Location map Ochinga farm



▲ soil pit for bulk density and pF determinations

$*^{2}$ site where infiltration rate and hydraulic conductivities were determined

ANNEX II Bulk density data (pit samples)

depth cm	ring weight	wet weight	dry weight	moist%	BD Mg/m3	average BD per depth
00-15	110.97	245.27	218.18	25.27	1.07	1.10
00-15	103.34	242.26	213.22	26.43	1.10	
00-15	100.53	234.21	209.65	22.51	1.09	
00-15	94.68	235.54	208.06	24.24	1.13	
15-30	105.71	253.89	220.78	28.77	1.15	1.13
15-30	106.32	254.76	219.8	30.81	1.13	
15-30	103.62	239.26	208.53	29.29	1.05	
15-30	106.33	257.26	224.01	28.25	1.18	
30-50	99.6	232.99	202.98	29.03	1.03	1.10
30-50	103.66	249.31	216.14	29.49	1.12	
30-50	106.63	248.56	215.71	30.12	1.09	
30-50	99.83	248.66	215.35	28.83	1.16	
50-100	104.43	253.94	218.68	30.86	1.14	1.17
50-100	101.68	253.66	220.34	28.08	1.19	
50-100	98.6	250.3	216.64	28.52	1.18	
100-150	108.02	263.54	228.71	28.86	1.21	1.23
100-150	97.54	252.8	216.95	30.02	1.19	
100-150	105.27	265.01	227.94	30.22	1.23	
100-150	106.09	271.51	235.93	27.40	1.30	
150-200	106.11	263.11	228.93	27.83	1.23	1.25
150-200	100.38	259.69	224.81	28.03	1.24	
150-200	97.95	247.28	214.12	28.54	1.16	
150-200	105.38	279.48	242.19	27.26	1.37	

ANNEX II Bulk density data (auger samples)

depth cm	ring weight	dry weight	BD Mg/m3	average BD per depth
00-15	110.97	229.28	1.18	1.24
00-15	103.34	229.25	1.26	
00-15	100.53	225.30	1.25	
00-15	94.68	221.66	1.27	
15-30	105.71	228.37	1.23	1.26
15-30	106.32	231.61	1.25	
15-30	103.62	232.28	1.29	
15-30	106.33	234.61	1.28	
30-50	99.60	221.43	1.22	1.13
30-50	103.66	222.43	1.19	
30-50	106.63	212.52	1.06	
30-50	99.83	207.23	1.07	
50-100	104.43	220.95	1.17	1.07
50-100	95.88	203.61	1.08	
50-100	101.68	205.19	1.04	
50-100	98.60	199.72	1.01	
100-150	108.02	220.50	1.12	1.07
100-150	105.27	213.67	1.08	
100-150	106.09	207.24	1.01	
150-200	106.11	214.79	1.09	1.04
150-200	100.38	204.20	1.04	
150-200	105.38	205.12	1.00	

ANNEX III *p*F data (%w w^{-1})

*p*F values:	0.0	2.0	2.3	2.5	3.7	4.2
00-15	48.6	26.7	25.6	24.2	17.9	16.3
	50.7	27.6	26.4	25.0	17.8	16.5
	54.0	28.4	27.1	25.3	18.1	16.6
	50.7	26.9	25.6	24.0	17.8	16.4
mean	51.0	27.4	26.2	24.6	17.9	16.5
15-30	41.0	30.4	29.6	28.6	21.0	19.0
	50.0	30.5	29.4	28.0	20.5	18.9
	50.8	29.4	28.5	27.1	20.4	18.6
	44.7	29.9	28.9	27.6	20.1	18.4
mean	46.6	30.1	29.1	27.8	20.5	18.7
30-50	45.0	31.7	30.6	28.6	21.1	19.4
	40.3	30.2	29.3	28.0	21.0	19.1
	41.7	30.6	29.7	28.3	21.1	19.3
	38.0	30.1	29.3	28.0	20.7	19.0
mean	41.3	30.7	29.7	28.2	21.0	19.2
50-100	38.8	30.2	29.1	28.2	21.4	19.6
	42.9	27.5	26.6	25.8	21.4	19.8
	52.9	28.5	27.8	27.2	21.5	19.8
	47.5	27.5	26.6	25.7	20.9	19.2
mean	45.5	28.4	27.5	26.7	21.3	19.6
100-150	36.0	29.5	28.6	27.8	21.9	19.9
	39.3	30.3	29.4	28.4	21.9	19.8
	40.0	29.9	28.9	28.1	22.1	19.9
mean	38.4	29.9	29.0	28.1	22.0	19.9
150-200	44.7	30.2	29.3	28.3	21.9	19.9
	38.3	29.7	28.9	27.8	21.3	19.6
	38.7	29.1	28.3	27.1	21.3	19.6
mean	40.6	29.7	28.8	27.7	21.5	19.7
max	54.0	31.7	30.6	28.6	22.1	19.9
min	36.0	26.7	25.6	24.0	17.8	16.3
range	18.0	5.0	5.0	4.6	4.3	3.6
grand mean	44.3	29.3	28.3	27.1	20.6	18.8

ANNEX IV Hydraulic conductivity data

site 1 15/12/1993

interval	cum. time	reading cm		h'(ti) cm	h(ti) cm	(hti+r/2) cm
0	0	29.5	81.5	52.0	48.0	49.6
60	60	28.5	81.5	53.0	47.0	48.6
60	120	27.7	81.5	53.8	46.2	47.8
60	180	26.9	81.5	54.6	45.4	47.0
240	420	24.3	81.5	57.2	42.8	44.4
600	1020	19.5	81.5	62.0	38.0	39.6
900	1920	14.1	81.5	67.4	32.6	34.2
900	2820	10.6	81.5	70.9	29.1	30.7

site 2 16/12/1993

interval	cum. time	reading cm		h'(ti) cm	h(ti) cm	(hti+r/2) cm
0		35.4	79.9	44.5	55.5	57.1
60	60	34.8	79.9	45.1	54.9	56.5
60	120	34	79.9	45.9	54.1	55.7
60	180	33.3	79.9	46.6	53.4	55.0
120	300	32.3	79.9	47.6	52.4	54.0
60	360	31.8	79.9	48.1	51.9	53.5
180	540	30.3	79.9	49.6	50.4	52.0
120	660	29.3	79.9	50.6	49.4	51.0
300	960	27.2	79.9	52.7	47.3	48.9
300	1260	25.5	79.9	54.4	45.6	47.2
300	1560	23.7	79.9	56.2	43.8	45.4
300	1860	22.3	79.9	57.6	42.4	44.0
300	2160	20.8	79.9	59.1	40.9	42.5
600	2760	18.6	79.9	61.3	38.7	40.3
600	3360	16.2	79.9	63.7	36.3	37.9

site 3 17/12/1993

interval	cum. time	reading cm		h'(ti) cm	h(ti) cm	(hti+r/2) cm
0		26.1	79.9	53.8	46.2	47.8
60	60	25.7	79.9	54.2	45.8	47.4
60	120	25.2	79.9	54.7	45.3	46.9
60	180	24.7	79.9	55.2	44.8	46.4
60	240	24.4	79.9	55.5	44.5	46.1
60	300	24.2	79.9	55.7	44.3	45.9
60	360	23.8	79.9	56.1	43.9	45.5
240	600	22.7	79.9	57.2	42.8	44.4
1320	1920	14.8	79.9	65.1	34.9	36.5
1080	3000	12.4	79.9	67.5	32.5	34.1
1200	4200	9.9	79.9	70	30.0	31.6
1200	5400	8	79.9	71.9	28.1	29.7

ANNEX V Infiltration rate data

14/12/1993

	time interval	cum. time	reading cm	intake	infiltration cm/h
	0	0	3.5	-	-
	1	1	3.9	0.4	24.0
	1	2	4.3	0.4	24.0
	1	3	4.7	0.4	24.0
	1	4	5.2	0.5	30.0
	1	5	5.5	0.3	18.0
	1	6	5.8	0.3	18.0
	1	7	6.1	0.3	18.0
	1	8	6.3	0.2	12.0
	1	9	6.7	0.4	24.0
	1	10	6.9	0.2	12.0
water added			3.7		
	4	14	4.2	0.5	7.5
	2	16	4.8	0.6	18.0
	2	18	5.4	0.6	18.0
	3	20	6.0	0.6	12.0
water added			0.9		
	6	26	1.9	1.0	10.0
	4	30	3.0	1.1	16.5
	10	40	5.3	2.3	13.8
	5	45	6.3	1.0	12.0
water added			1.5		
	5	50	2.0	0.5	6.0
	10	60	4.2	2.2	13.2
water added			1.5		
	15	75	4.0	2.5	10.0
	15	90	6.2	2.2	8.8
	15	105	8.1	1.9	7.6

measuring stopped because of heavy rain

ANNEX V - continued -

	CUM. time	READING	INTAKE	cm/h
0	0	2.4	-	-
1	1	3.4	1.0	60.0
1	2	4.4	1.0	60.0
1	3	5.1	0.7	42.0
1	4	5.9	0.8	48.0
1	5	6.5	0.6	36.0
1	6	7.2	0.7	42.0
1	7	7.8	0.6	36.0
1	8	8.4	0.6	36.0
1	9	9.0	0.6	36.0
1	10	9.6	0.6	36.0
1	11	10.0	0.4	24.0
water added	12	2.3		
2	13	3.1	0.8	24.0
1	14	3.7	0.6	36.0
1	15	4.4	0.7	42.0
5	20	7.3	2.9	34.8
5	25	9.6	2.3	27.6
2	27	10.5	0.9	27.0
water add	28	3.2		
3	30	4.1	0.9	18.0
15	45	10	5.9	23.6
2	47	10.5	0.5	15.0
water add	48	2.5		
13	60	8.1	5.6	25.8
15	75	12.4	4.3	17.2
water add	76.5	2.4		
15	90	7.9	5.5	22.0
water add	91	1.3		
15	105	6.7	5.4	21.6
15	120	10.6	3.9	15.6
8	128	12.2	1.6	12.0
water add	129.5	0.4		
7	135	2.8	2.4	20.6
15	150	8.1	5.3	21.2
water add	151	0.8		
15	165	5.7	4.9	19.6
15	180	9.5	3.8	15.2
2	182	9.9	0.4	12.0
water add	183	2.9		
15	195	6.3	3.4	13.6
41	236	13.4	7.1	10.4

ANNEX V - continued -

16/12/1993 INTER.	CUM. time	READING	INTAKE	cm/h
0	0	2.7	-	-
1	1	3.5	0.8	48.0
1	2	4.5	1.0	60.0
1	3	5.4	0.9	54.0
1	4	6.1	0.7	42.0
1	5	6.9	0.8	48.0
1	6	7.5	0.6	36.0
1	7	8.3	0.8	48.0
1	8	8.8	0.5	30.0
water added		1.9		
2	10	2.9	1.0	30.0
5	15	6.6	3.7	44.4
5	20	9.5	2.9	34.8
2.5	22.5	10.6	1.1	26.4
water added		1.9		
2.5	25	2.6	0.7	16.8
5	30	6	3.4	40.8
10	40	10.7	4.7	28.2
water added		4.1		
10	50	8.5	4.4	26.4
water added		2.1		
10	60	6.4	4.3	25.8
5	65	8.3	1.9	22.8
water added		2.0		
10	75	6.2	4.2	25.2
10	85	9.7	3.5	21.0
water added		2.6		
15	100	7.7	5.1	20.4
water added		0.8		
20	120	8.2	7.4	22.2
water added		2.5		
20	140	8.1	5.6	16.8
water added		1.2		
20	160	7.3	6.1	18.3
3	163	7.9	0.6	12.0
water added		0.9		
17	180	5.5	4.6	16.2
water added		0.3		
20	200	5.4	5.1	15.3
20	220	9.4	4.0	12.0
water added		2.8		
20	240	6.4	3.6	10.8

ANNEX V - continued -

16/12/1993

INTERVAL	CUM. time	READING	INTAKE	cm/h
water added		1.4		
20	260	7.6	6.2	18.6
5	265	9.4	1.8	21.6
water added		1.2		
15	280	6.7	5.5	22.0
water added		1.3		
20	300	9.3	8.0	24.0
water added		1.9		
20	320	8	6.1	18.3
water added		1.8		
20	340	7.3	5.5	16.5
water added		2.7		
20	360	8.2	5.5	16.5
water added		2		
20	380	7	5.0	15.0

APPENDIX VI

WEEDS OF OCHINGA FARM

- WESTERN KENYA -

TABLE OF CONTENTS

ICRAF

INTERNATIONAL CENTRE FOR RESEARCH IN AGROFORESTRY

Alfred Hartemink
Ariane Hartemink-van Geijn

Maseno, December 1993

1 INTRODUCTION

1.1 Inducement and Objectives of the Study

Soil fertility research at Ochinga farm started in April 1993. In one of the experiments a weed-fallow is amongst the treatments and since September 1993 weeds were allowed to grow freely in 4 plots of 10 * 10 m. In an early stage it was observed that there were differences in quantitative weed growth, in number of species and in species distribution between the 4 plots. Sheer curiosity and the lack of any idea for the differences formed the base for a brief study with the following objectives:

(i) to identify the majority of the weeds in the weed-fallow plots of Ochinga farm

(ii) to investigate possible causes for observed differences between the plots.

The study took place on 15 and 17 December 1993 by Alfred and Ariane Hartemink, both non-botanists but with a fair amount of interest and some experience in identifying wild plants.
Weed biomass was assessed by Bashir Jama in November 1993.

1.2 Study Approach

Weeds were identified using basically 4 books (see Literature on page 15). The weeds were grouped into families. None of the books had determination tables and therefore not all weeds could be identified. The unidentified weeds are grouped under the heading *Others* (Chapter 2). Weeds which could not be identified with great certainty carry an asterisk behind their name.
After the weeds were identified in the 4 plots, the distribution of weeds over the plots was determined. In 1 m^2 all species were counted and this was repeated three times in each plot. The countings per square meter were made along a diagonal line through the plots. Grasses could not be counted individually and an estimate of the cover (in %) has therefore been made. Furthermore the number of species per plot were determined.
Weed biomass was determined clearing 0.5 m^2 and this was repeated 4 times per plot. The weeds were dried till constant weight at 60 °C.

Inorganic nitrogen samples were taken in October 1993 of six depths in each plot. The samples were extracted with 2*M* KCl and analyzed for ammonium and nitrate.

2 DESCRIPTION OF SPECIES

2.1 Acanthaceae

Latin name *Thunbergia alata*
English name Black-eyed Susan
Kiswahili name Kijako-gura
The plant is found up to an altitude of 2740 m in bushland, usually in partial shade. A climbing or trailing plant; leaves are slightly haired and triangular to lanceolate or ovate. The flowers, c. 4 cm across, often borne in considerable numbers, are usually orange. They have a purple centre and tube which is very dark in colour leading to the common English name.

2.2 Amaranthaceae

Latin name *Althernanthera pungens*
English name Khaki weed
A low growing perennial with branches spreading from the tap root to a length of 30 to 60 cm and rooting at the nodes. The stems are hairy and the leaves are arranged in opposite pairs of unequal size. Leave size is 2 cm broad and 4 cm long. The inconspicuous, straw coloured flowers are clustered in the axils of the leaves. Individuals flowers are compressed and their structure difficult to make out. The fruits adhere to the skin of man an animals.

2.3 Compositeae

Latin name *Ageratum conyzoides*
English name goat weed
Kiswahili name kimavi cha kuku
Luo name oluoro chieng
The *Ageratum conyzoides* is wide spread from 0-2400 m in East Africa, especially in higher rainfall areas. This annual herb with an erect hairy stem, has opposite (sometimes alternate near to the top of the plant) ovate, up to 8 cm long and 5 cm wide, hairy leaves. They have a characteristic smell when they are crushed. The pale blue or white flowerheads, up to 6 mm in diameter are attractive clustered. Fruits are black, ribbed or angled.

Latin name *Anisoppapus africanus*

Common weed in dry upland areas of East Africa and found at altitudes at 1500 to 2100 m. A perennial plant with ascending stems and broadly ovate leaves. The yellow, star-like flowers (1 cm across) are slightly cupped and stood at the end of long flexible stalks.

Latin name *Aspillia mossambicensis**

Aspillia mossambicensis is common all over East Africa at 5-2130 m except in the driest areas. If not controlled by burning it grows to a large size and may scramble over neighbouring bushes. It is a much branched herb or shrub with rough, lancelot-ovate, opposite leaves. Its yellow flower heads, 2 cm across, are solitary or grouped in loose terminal cymes.

Latin name *Bidens pilosa*
English name Yellow-flowered blackjack
Kiswahili name kichoma mguu
Luo name nyanyiek-mon, onyiego

Bidens pilosa is a annual herb which is one of the common weeds in the region. An erect, branched, annual herb growing to about 60 cm high with opposite leaves, white flowers and a 4 angled stem. Flowerheads are about 1 cm across, born on long stalks and arranged in loose branches. Fruits are black and 5-10 mm long and bear 2-3 bristles. They produce large quantities of seed, which can germinate immediately after being shed.

Latin name *Crassocephalum rubens**

This annual weed is common in the area and occurs mostly on cultivated land. The stem is soft, erect and branched and growing up to 1 m. Leaves are alternate, the upper ones with basal lobes which clasp the stem. The flowers are red to purple on long stalks. The flower stalks are 10 to 20 cm long with flowerhead of 10 to 15 mm in diameter

Latin name *Gutenbergia cordifolia*
Luo name Rabuor

Annual herb, common in the highlands as a weed of arable crops, grassland and waste ground. The stem is erect and can be up to 1.5 m high. It is branched and covered with silvery hair. Leaves are opposite to alternate and up to 7 cm long and 3.5 cm wide. They are also covered with silvery hairs on both sides. The base of the leaves clasps the stem. The purple flower heads 6-8 mm in diameter, are born on stalks up to 13 mm long, loose and much branched.

Latin name *Tagetes minuta*
English name Mexican marigold or tall khaki weed
Luo name ang'we, anyach, nyanjaga, nyanjagra

An abundant and troublesome weed in upland farming areas, wide spread at altitudes between 760-2200 m. It is an erect, strong smelling annual which is often robust but it is very variable in habit with pinnate leaves having elliptic, serrate leaflets. Its creamy-yellow flower heads, ± 5 mm across, are grouped in terminal corymbs (like umbrellas).

2.4 Convolvulaceae

Latin name *Dichondra repens*
English name kidney weed

Dichondra is distributed widely at altitudes between 900 and 2500 m and found both in grasslands and cultivated areas. The weed is perennial and creeping along the ground with stems up to 60 cm long with roots at the nodes. The simple leaves are arranged alternately. They have rounded, kidney-shaped blades up to 4 cm across, borne on an upright stalk up to 5 cm long. The flowers are small and inconspicuous, white or greenish in colour.

2.5 Euphorbiaceae

Latin name *Euphorbia* sp.
English name asthma weed, blue weed

This weed could not be identified at a higher level. It is a typical euphorbiaceae as it has milky sap, opposite leaves and inconspicuous greenish flowers. The plants had a reddish tinge.

2.6 Gramineae

Various species of the gramineae family were found at Ochinga farm but they could not be identified with certainty. Possible species are *Digitaria abyssinica* and *Eleusine* sp.

2.7 Labiateae

Latin name *Leonitis nepetifolia*
Kiswahili name Mlisha kungu

Leonitis species are indigenous plants of East Africa at altitudes above about 1000 m. *Leonitis nepetifolia* is an erect, branched annual herb growing to 1.5 m high, with a four-angled stem. The paired leaves are up to 8-10 cm long with a stalk of 2-3 cm long and a coarsely toothed blade. The upper leaves in the axils of which the flowers arise, are long and narrow. The dense circular masses of reddish flowers are 5-6 cm across. Individual flowers are about 2 cm long.

2.8 Malvaceae

Latin name *Hibiscus* sp.

There are numerous hibiscus species in Kenya. The hibiscus found at Ochinga was very common and had light green, ovate leaves of 6 cm diameter and a slightly woody stem. The plants were about 40 cm high. Flowers are simple, 2 to 3 cm in diameter and pink.

2.9 Papilionaceae

Latin name *Crotalaria* sp.
English name rattlepod

There are nearly 200 species of crotalaria in East Africa and the one found at Ochinga farm could not be identified at a higher level. Crotalaria is an annual or short-lived perennial herb with alternate leaves consisting of 3 leaflets with entire margins. The flowers are stalked and borne in an erect elongated, unbranched terminal inflorescence. The flower was yellow.

2.10 Polygonaceae

Latin name *Fallopia convolvulus**
English name black windweed

Annual, climbing herb, occurring in the highlands as a locally serious weed of cereals. The stem is slender, trailing on the ground or twining around plants, 20-250 cm long and green or greenish brown. The leaves are alternate, 4-6 cm long and arrow-shaped. Flowers are inconspicuous at stalks of about 2 mm and green white in colour.

2.11 Rubiaceae

Latin name *Richardia brasiliensis*

Richardia has been recorded from the coast up to 2000 m. It is a tap-rooted annual or short lived perennial herb with spreading branches up to 40 cm long. The branches bear opposite pairs of leaves and terminal heads of small white flowers subtended by 2 pairs of leaves. Leaf size is about 6 * 2.5 cm.

2.12 Verbenaceae

Latin name *Stachytarpheta jamaicensis*

Stachytarpheta is found up to 1500 m but more common at the coast. It is an annual herb, woody at the base and up to 1 m high. Leaves are ovate to oblong and about 5 * 2.5 cm and toothed. Flowers are royal blue and sunk in deep depressions in the axiles, spike is up to 30 cm long.

2.13 Others

There were 4 weed species who could not be identified at all. Although from some species a guess could be made on the family to which they belong it was found to be much too speculation and they are therefore not included in this study.

Furthermore seedlings from *Sesbania sesban* and some small *Persea americana* (guave) trees were found in some plots.

3 WEED DISTRIBUTION

3.1 Plot 13

Weeds had not covered the soils completely in this plot and there were some patches of less than 0.5 m² with no weeds at all. Hibiscus was nicely distributed over the entire plot. Species found and countings per m² are given in table 1; two species could not be identified.

Table 1 *Weed species and countings per m² in plot 13*

family	species	present	countings per m²		
		y/n	1	2	3
Acanthaceae	*Thunbergia alata*	y	0	0	1
Ameranthaceae	*Alternanthera pungens*	y	0	0	0
Compositeae	*Ageratum conyzoides*	y	0	0	1
	Anisoppapus africanus	y	0	0	0
	*Aspilia mossambicensis**	y	1	1	0
	Bidens pilosa	y	1	0	1
	*Crassocephalum repens**	n			
	Gutenbergia cordifolia	n			
	Tagetes minuta	y	0	0	0
Convolvulaceae	*Dichondra repens*	y	2	4	5
Euphorbiaceae	*Euphorbia* sp.	y	0	0	0
Gramineae	*Eleusine, Digitaria?*	y	50%	20%	20%
Labiateae	*Leonitis nepetifolia*	y	0	0	0
Malvaceae	*Hibiscus* sp.	y	10	11	1
Papilionaceae	*Crotalaria* sp.	y	0	1	0
Polygonaceae	*Fallopia convolvulus**	y	0	0	0
Rubiaceae	*Richardia brasiliensis*	y	2	1	0
Verbenaceae	*Stachytarpheta jamaicensis*	y	0	0	0
Others			0	1	1

* - uncertain

About 18 species were identified in plot 13 of nearly all families. Of the countings per m² it appeared that mostly hibiscus was found and to a lesser extent *Dichondra repens*. Grasses covered about one quarter to half of the plot.

3.2 Plot 22

Hibiscus and aspilia were distributed at about equidistances. At the lower part of the plot which is periodically ponded, grasses were dominant. The species present and countings per m^2 are given in table 2. In total 19 species were recognized.

Table 2 *Weed species and countings per m^2 in plot 22*

family	species	present	countings per m^2		
		y/n	1	2	3
Acanthaceae	*Thunbergia alata*	y	0	0	1
Ameranthaceae	*Alternanthera pungens*	y	0	0	0
Compositeae	*Ageratum conyzoides*	y	1	0	0
	Anisoppapus africanus	y	0	0	0
	*Aspilia mossambicensis**	y	0	0	0
	Bidens pilosa	y	0	0	0
	*Crassocephalum repens**	n			
	Gutenbergia cordifolia	y	0	1	1
	Tagetes minuta	y	0	0	0
Convolvulaceae	*Dichondra repens*	y	6	10	25
Euphorbiaceae	*Euphorbia* sp.	y	0	0	0
Gramineae	*Eleusine, Digitaria?*	y	70%	50%	10%
Labiateae	*Leonitis nepetifolia*	y	0	0	0
Malvaceae	*Hibiscus* sp.	y	14	10	1
Papilionaceae	*Crotalaria* sp.	y	0	0	1
Polygonaceae	*Fallopia convolvulus**	y	0	0	0
Rubiaceae	*Richardia brasiliensis*	y	7	1	5
Verbenaceae	*Stachytarpheta jamaicensis*	y	0	0	0
Others			1	0	1

* - uncertain

3.3 Plot 32

Hibiscus was very nicely distributed over the plot. In fact, the observed pattern induced this study. Furthermore many grasses were found in the plot as can be seen from table 3. In total only 9 species were found in this plot.

Table 3 *Weed species and countings per m² in plot 32*

family	species	present	countings per m²		
		y/n	1	2	3
Acanthaceae	*Thunbergia alata*	n			
Ameranthaceae	*Alternanthera pungens*	n			
Compositeae	*Ageratum conyzoides*	y	0	0	1
	Anisoppapus africanus	y	0	0	0
	*Aspilia mossambicensis**	y	1	0	0
	Bidens pilosa	n			
	*Crassocephalum repens**	n			
	Gutenbergia cordifolia	n			
	Tagetes minuta	n			
Convolvulaceae	*Dichondra repens*	y	6	5	5
Euphorbiaceae	*Euphorbia* sp.	n			
Gramineae	*Eleusine, Digitaria?*	y	70%	80%	65%
Labiateae	*Leonitis nepetifolia*	y	0	0	0
Malvaceae	*Hibiscus* sp.	y	8	10	12
Papilionaceae	*Crotalaria* sp.	n			
Polygonaceae	*Fallopia convolvulus**	n			
Rubiaceae	*Richardia brasiliensis*	y	1	0	0
Verbenaceae	*Stachytarpheta jamaicensis*	n			
Others			1	0	0

* - uncertain

3.4 Plot 43

The plot is characterized by many large *Aspilia mossambicensis* which are fairly well distributed over the plot. At the lower part of the plot, where water is accumulating during heavy rains, grasses tend to grow more prolific. Species and their countings can be seen in table 4. In total 16 species were recognized in plot 43

Table 4 *Weed species and countings per m² in plot 43*

family	species	present	countings per m²		
		y/n	1	2	3
Acanthaceae	*Thunbergia alata*	n			
Ameranthaceae	*Alternanthera pungens*	y	0	0	0
Compositeae	*Ageratum conyzoides*	y	0	0	2
	Anisoppapus africanus	y	1	0	3
	*Aspilia mossambicensis**	y	1	1	0
	Bidens pilosa	y	0	0	0
	*Crassocephalum repens**	y	0	0	0
	Gutenbergia cordifolia	n			
	Tagetes minuta	n			
Convolvulaceae	*Dichondra repens*	y	2	4	5
Euphorbiaceae	*Euphorbia* sp.	n			
Gramineae	*Eleusine, Digitaria?*	y	40%	60%	20%
Labiateae	*Leonitis nepetifolia*	y	0	0	0
Malvaceae	*Hibiscus* sp.	y	4	1	7
Papilionaceae	*Crotalaria* sp.	n			
Polygonaceae	*Fallopia convolvulus**	y	0	0	0
Rubiaceae	*Richardia brasiliensis*	y	3	3	1
Verbenaceae	*Stachytarpheta jamaicensis*	y	0	0	0
Others			2	1	0

* - uncertain

4 WEED BIOMASS AND SOIL NITROGEN CONTENTS

4.1 Weed Biomass

Biomass was harvested in November 1993 of 4 * 0.5 m^2 in each of the plots. Dry matter content and total biomass in kg ha^{-1} is presented in table 5.

Table 5 Biomass (in kg dm ha^{-1}) and dry matter content of the weeds in 4 plots

plot number	biomass kg ha^{-1}	dry matter %
13	4900	22
22	2600	17
32	2400	16
42	3200	19

Between 2400 and 4900 kg dm ha^{-1} was produced in the weed-fallow plots during the period September to November (± 11 weeks). Assumed dry matter accumulation is linear over time, than the dry matter accumulation corresponds to a daily production of about 30 to 65 kg dm ha^{-1} day^{-1}.

4.2 Inorganic nitrogen contents of the soil

Nitrate and ammonium content of the soils are presented in table 6. The results are of samples taken in October 1993.
Nitrate is the major form of nitrogen and 5 to 10 times more nitrate is found than ammonium. Total inorganic nitrogen contents (nitrate-N + ammonium-N) is varying from 30 to 40 kg ha^{-1} in the 00-15 cm soil horizon and from 65 to 85 kg ha^{-1} in the 00-50 cm soil horizon.

Table 6 *Ammonium and nitrate content of the 00-15 cm and 00-50 cm soil horizon of the weed plots at Ochinga farm.*

plot	00-15 cm			00-50 cm		
number	NH_4-N	NO_3-N	total	NH_4-N	NO_3-N	total
13	4.8	35.7	40.5	17.3	67.4	84.7
22	1.5	28.0	29.5	13.1	65.0	78.1
32	3.0	32.3	35.3	17.2	69.7	86.9
42	3.6	26.8	30.4	13.5	52.1	65.6

5 DISCUSSION

In total 23 species were found in the weed-fallow plots of Ochinga farm. This excludes the different gramineae species which could not be identified with confidence. In total 12 families were present with Compositeae as the largest family with 7 species. None of the plots contained all the species although distinct differences exists between the plots. Plot 13, 22 and 42 contained 18, 19 and 16 species resp. while plot 32 contained 9 species only. How to explain this pattern? From the weed countings it appeared that plot 13, 22 and 42 were covered with grasses for around 35% while plot 32 had a grass-cover which was nearly twice so high. Apparently this dense grass-cover suppresses growth of other species. Than the question arises why plot 32 had a higher grass-cover. It may of course be pure coincidence but it may also have to do with the crop history of the land. Thirdly it may be due to the nutrient status of the soils. It is generally known that soils with a high nutrient status lodge few plant species only (so-called hit and run types) while under poor and acidic soil conditions, a relatively larger number of plant species can be found. Plot 32 had indeed the highest inorganic nitrogen content in the 00-50 cm soil horizon and that may explain the relatively low number of species. However, plot 13 had nearly as much soil inorganic nitrogen but double the amounts of species.

Though few observations only, it appeared that the dry matter content of the weeds is proportional to the total biomass (see table 5). In other words an increase in weed biomass tends to result in a increase in the dry matter content. It might be that plots with a higher dry matter production have plants with relatively more dead leaves. Secondly, it was found that the lowest dry matter contents (16 %) of the weeds was found in the plots with the most grasses (70% cover). As grasses have generally low lignin and cellulose content, it may explain the low dm content.

In 11 weeks dry matter production was 2400 kg ha^{-1} in plot 32 and 4900 kg ha^{-1} in plot 13. If the weeds would grow the whole year through, than the rate of dry matter production would be between 11 and 23 t dm ha^{-1} y^{-1}. Let assume that weeds in Western Kenya grow for 8 months only, than the annual dry matter production would be somewhere between 7 and 15 t dm ha^{-1} which is still a considerable production.

The highest dry matter production was found in plot 13 which had also the highest inorganic nitrogen content in the 00-15 soil horizon and 18 species. But the lowest dry matter production was found in plot 32 which had the highest nitrogen contents in the 00-50 cm soil layer and 9 species only. Relating inorganic nitrogen content of the soil with dry matter production is probably overruled by the dominance of certain species. And although the dominance of certain species is likely to be related to the inorganic nitrogen status of the soil, it could not be deduced from this study.

It was tentatively calculated dry matter productions of the weed plots was varying between 30 to 65 kg ha^{-1} day^{-1}. If about 2% of the dry matter produced consist of nitrogen, the nitrogen uptake varies from 0.6 to 1.3 kg N ha^{-1} day^{-1}. Assumed the soil has about 2% org. C, the C/N ratio is 10 and mineralization rates are 4%, than daily mineralization in the 00-30 cm soil horizon becomes: $(1/10 * 2\% * 4\% * ((0.15 * 1.10 * 10^4 * 10^3) + (0.15 * 1.13 * 10^4 * 10^3)))/365 = 0.75$ kg N ha^{-1} day^{-1}. Theoretically speaking, the uptake of nitrogen by the weeds keeps pace with the rate of mineralization in the top 30 cm layer. Mineralization occurring below this depth is lower (less o.m.) but probably more susceptible to be lost from the system as in some plots the weeds obtain sufficient nitrogen from mineralization in the 00-30 cm soil horizon.

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APPENDIX VII

SOME PRELIMINARY RESULTS OF SOIL SAMPLING IN HEDGEROW INTERCROPPING SYSTEMS

- WESTERN KENYA -

TABLE OF CONTENTS

ICRAF

INTERNATIONAL CENTRE FOR RESEARCH IN AGROFORESTRY

Alfred E. Hartemink

Maseno, December 1993

1 INTRODUCTION

Planting trees on farm boundaries is a common practise in the highlands of western Kenya (Ouko, 1993). In most districts farms have a size of 1 to 2 ha (Ndufa *et al.*, 1992) and trees are not cultivated in separate plots. Not much is known, however, about the horizontal effect of a boundary row of trees or a hedgerow on the inorganic nitrogen content of the soil. The horizontal influence of the hedgerows on the inorganic nitrogen content in the soil might be due to the root distribution (Escamilla *et al.*, 1991), hence nutrient uptake, as well as through difference in moisture conditions affecting important soil-chemical processes like mineralization and denitrification. Therefore, a randomized taken soil sample in a plot with hedgerows might not be representative for the entire plot. The problem has been recognized in forested areas where it was difficult to secure a representative sample (Pritchett, 1979). It has been first mentioned by Jamison (1942) as he found that certain soil properties varied systematically with distance from orange trees in Florida. Zinke (1962) reported spatial variability with relation to the location of the trees. The general pattern is that individual plants are the centre from which soil properties may vary in a predictable manner (Zinke, 1962). The purpose of this study was to gain some insight in the spatial distribution of inorganic nitrogen with distance from a hedgerow and to contribute to the discussion on sampling techniques in hedgerow intercropping systems.

2 SAMPLING SITES

Sampling sites were selected in three districts of western Kenya which both differed in altitude and rainfall regime. Selection criteria for the sites were formulated as follows:

(i) a hedgerow of one of the following species: *Calliandra calothyrsus, Cassia siamea or spectabilis, Sesbania sesban* or *Luecaena leucocephala*.

(ii) about 10 m of land adjacent to the hedgerow where no trees or other hedges are growing.

(iii) uniform deep soils preferably cropped with maize.

Six farms were visited, but only three farms were selected for the experiment. A detailed description of the three farms is given the following sections.

2.1 Lucya farm

The farm is located about 8 km from Kiboswa (Kisumu District, Winam division). Only the rainfall data of 1991 could be traced and the monthly distribution is presented in figure 1. Rainfall appeared to be weekly bimodal in 1991 with a pronounced rainy season from March to May. The yearly total in 1991 was 1424 mm of rain.

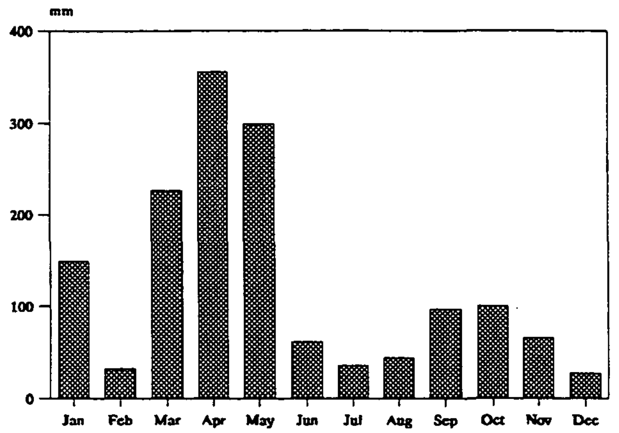

Figure 1. Monthly Rainfall Distribution for Lucya Farm
(data of 1991 only)

The sampling site was located on flat to slightly undulating ridge. Soil depth was only 50 to 70 cm. Below this depth (partly) rotten bedrock was found and it is expected that this seriously reduces effective rooting depth and the available water capacity of the soils. According to Andriesse and van der Pouw (1985) the soils near Lucya farm are well drained, shallow to moderately deep, dark yellowish brown to reddish brown sandy clay loams to gravelly sandy clay. The soils can be classified as ferralic and dystric cambisols and orthic acrisols. Fertility of the soils was appraised low with a CEC of less than 16 cmol kg^{-1}, a base saturation lower than 50% and less than 1.5% organic matter (Andriesse and van der Pouw, 1985).

Soils were sampled near a *Leucaena leucocephala* hedgerow which was planted in November 1990. A few weeks before the soil samples were taken, the leucaena suffered from psyllids and hardly any green leaves were left. With the rains which fell prior to the sampling, the leucaena had much improved and looked fairly recovered.

The site had been cropped with maize during the previous season. The major part of the land was planted with potatoes at the time of sampling.

2.2 Nyabeda farm

Nyabeda farm is located about 20 km west of Maseno (Vihiga district, Emuhaya division). Rainfall data have been obtained from Yala for the years 1991 and 1992. The two year average is 1796 mm of rain which is well distributed over the months (figure 2).

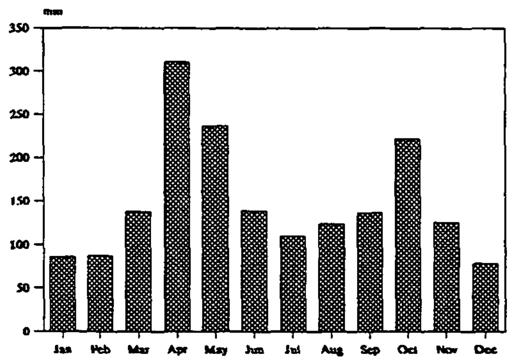

Figure 2. Monthly Rainfall Distribution for Nyabeda Farm
(average of 1991 and 1992)

The site was located on a flat to nearly flat plateau. The soils of Nyabeda farm are well drained, extremely deep, dark red with very friable clay (Andriesse and van der Pouw, 1985). They classify as rhodic ferralsol with a low fertility.

Samples were taken near a hedgerow of *Cassia spectabilis* which was planted in april 1993. The plants were still small and had an height of less than 75 cm. A few weeks before the soil samples were taken maize was planted which had about 4 leaves folded.

2.3 Ebukanga farm

The farm is located 1 km from Ebukanga primary school (Siaya district, Yala division). Rainfall figures have been taken from a nearby station for the years 1991 and 1992. The average per month was calculated and plotted (figure 3).

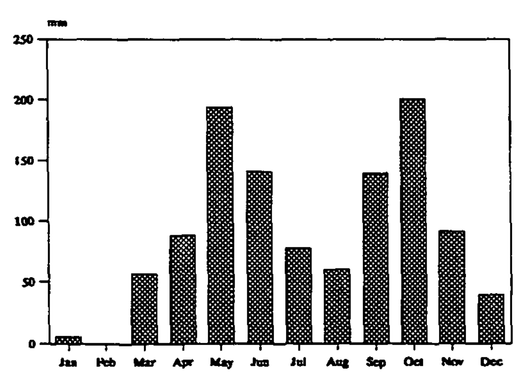

Figure 3. Monthly Rainfall Distribution for Ebukanga farm
(average of 1991 and 1992)

The rainfall pattern appears to bimodal. May and October are the wettest month and based on a two year average have nearly 200 mm of rain. December to february are dry months with hardly any rain at all. The two year average is about 1066 mm of rain which is lower than one would anticipate for the area. Andriesse and van der Pouw (1985) described the area around Ebukanga school as the middle level uplands with an undulating to rolling landforms. The soils are described well drained, very deep with dark reddish brown friable clays. They were classified as ferralo-orthic acrisol.

The farmer had made two terraces and planted *Calliandra calothyrsus* and *Cassia siamea* on the terrace borders. The trees were planted in November 1991. Soil samples were taken on the terrace with cassia as hedgerow. The cassia had an height of about 1.80m and were pruned for the first 0.8m from the ground.

3 MATERIALS AND METHODS

Samples were taken perpendicular to the hedgerows along a line of 5 metres at 0.25 cm intervals (transect). Two depths were sampled using an Edelman auger. At Nyabeda and Ebukanga farm samples were taken of 00-15 and 100-125 cm. At Lucya farm the sampled depths were 00-15 and 30-50. Two transects were sampled at Ebukanga and Lucya farm. The transects were spaced two metres apart. At Nyabeda one transect was sampled. The soil samples were taken in October 1993.

Soil samples were extracted with 2N KCl. Nitrate was determined by cadmium reduction and subsequent colorimetric determination of nitrite. Ammonium was analyzed by colorimetric determination. Inorganic nitrogen was calculated as the sum of nitrate and ammonium. The values were calculated into kg ha^{-1} using bulk densities of 1.10 Mg m^{-3} for the 00-15 and 30-50 cm layers and 1.23 Mg m^{-3} for the 100-125 cm layer.

4 RESULTS

4.1 General

Average inorganic nitrogen contents of the soils of the three farms varied widely both in the topsoil as in the subsoil (table 1). The soils of Nyabeda farm have on average the highest ammonium and nitrate content. The difference with the other farms is particular noteworthy for nitrate. Ammonium contents are similar in the topsoils of Nyabeda and Ebukanga farm and in the subsoil of Lucya and Nyabeda farm.

Table 1. *Average inorganic nitrogen contents of the top- and subsoil (kg ha^{-1}).*

	topsoil				subsoil			
	NH_4-N	NO_3-N	total	CV%	NH_4-N	NO_3-N	total	CV%
Lucya	3.5	10.8	14.3	57	4.4	6.3	10.7	36
Nyabeda	1.8	24.4	26.2	34	4.9	18.2	23.1	66
Ebukanga	1.8	15.6	17.4	31	2.2	4.5	6.7	91

For Lucya farm the amount of total nitrogen found in the topsoil varied from 8.4 to 20.6 kg ha^{-1} and from 5.9 to 16.5 kg ha^{-1} in the subsoil. The variation at Nyabeda farm was found to be 11.2 to 41.4 kg ha^{-1} in the topsoil and from 4.8 to 76.2 kg ha^{-1} in the subsoil while the nitrogen contents at Ebukanga farm varied from 6.3 to 29.7 kg ha^{-1} in the topsoil and from 1.9 to 32.1 kg ha^{-1} in the subsoil.

As there was large variability at short distances, the nitrate and ammonium content of the 4 sample points in the first meter from the centre of the hedge was averaged. The same was done for the 4 points in the second, third, fourth and fifth meter by which the transect was cut into 5 observation points (table 2). At Lucya and Nyabeda farm the outcome of the two transects were averaged.

Table 2 *NH_4-N and NO_3-N contents in the top- and subsoil at 50, 150, 250, 350 and 450 cm from the centre of the hedgerows*

	Lucya		Nyabeda		Ebukanga	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
topsoil						
50cm	3.6	8.0	2.8	20.3	1.0	13.9
150cm	4.1	11.9	1.1	23.6	1.0	16.1
250cm	3.3	13.3	1.5	24.8	1.9	12.2
350cm	3.1	8.2	1.6	25.7	3.1	16.6
450cm	3.7	11.4	2.0	27.7	2.0	18.8
subsoil						
50cm	4.4	4.1	3.9	20.8	1.2	2.9
150cm	4.6	5.3	4.5	11.0	1.5	3.8
250cm	4.2	5.8	10.0	13.0	2.5	2.5
350cm	4.2	7.8	3.7	13.4	1.3	3.7
450cm	4.8	7.2	2.2	32.9	4.4	9.6

For all three farms nitrate is the major form of nitrogen in the topsoil. About 10 to 15 times more nitrate than ammonium is found in the topsoils of Nyabeda and Ebukanga farm. At Lucya farm the ratio of nitrate to ammonium is about 3 to 4. Also in the subsoil nitrate is the major form of nitrogen. The highest nitrate contents in the subsoil were found at Nyabeda farm. Contents at Lucya and Ebukanga farm are much lower and do not differ widely from the ammonium contents. There is no clear relation between the ammonium content in the top- and subsoil with distance from the hedge. Nitrate contents, however, tend to increase in both the topsoil and the subsoil with distance from the centre of the hedge. This relation is almost linear in the topsoils of Nyabeda farm and in the subsoils of Lucya farm.

4.2 Lucya farm

A sharp increase can be noticed for the inorganic nitrogen content in the topsoil till about 3 m from the centre of the leucaena hedge (figure 1).

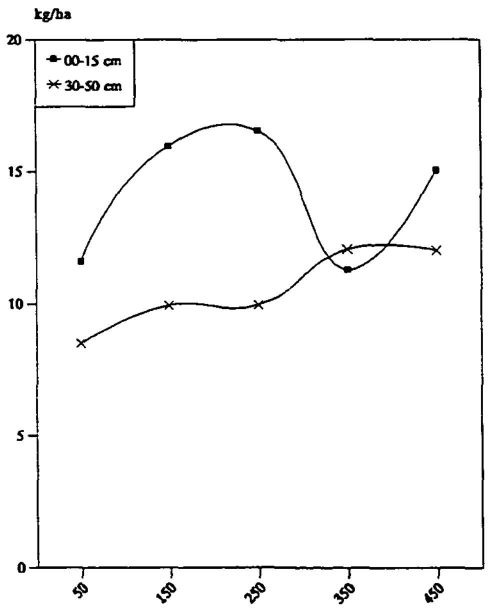

Figure 1 Inorganic nitrogen content with distance from a *Leuceana leucocephala* hedge at Lucya farm

At about 3.5 m the nitrogen content of the topsoil is lower than in the subsoil but increases again further away from the hedge. Inorganic nitrogen contents in the subsoil show a steady increase with distance and the relation is almost linear (r = 0.947).

4.3 Nyabeda farm

There is a proportional relation between the inorganic nitrogen content in the topsoil and the distance from centre of the hedge (r = 0.993). For the subsoil, however, a very irregular patterns can be recognized (figure 2).
Inorganic nitrogen contents are higher in the subsoil within the first meter of the hedge and in the fifth meter.

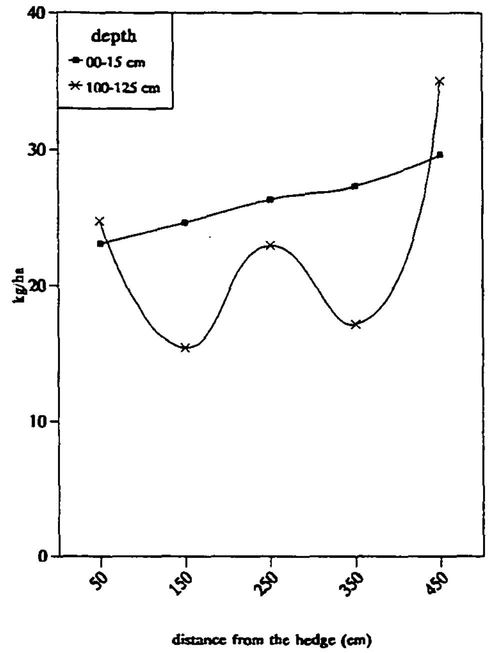

Figure 2. Inorganic nitrogen contents with distance from a *Cassia spectabilis* hedge at Nyabeda farm

4.4 Ebukanga farm

The nitrogen contents in the soils of Ebukanga farm are much higher in the upper 15 cm as in the 100-125 cm layer regardless at which distance from the hedge (figure 3).
Inorganic nitrogen contents in the topsoils show a wavy pattern with distance from the hedge (r = 0.775). Subsoil contents remain about constant till the fourth meter; hereafter a very sharp increase follows.

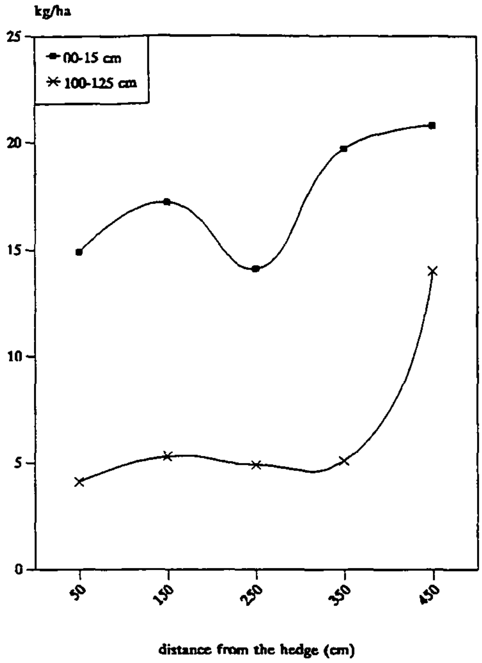

Figure 3. Inorganic nitrogen content with distance from a *Cassia siamea* hedge at Ebukanga farm

5 DISCUSSION

There tends to be an increase in soil inorganic nitrogen content with distance from the centre of a hedgerow. High correlations were found for the topsoils in two farms. However, the overall pattern for the top- and subsoil differed per farm and it may be explained by differences in the rooting pattern of the different species. Differences between farms may also be due to the age of the trees. Climatic and soil properties of the three sampling sites is probably another source of variation.

Mongi *et al.* (1979) stressed the need for accurate sampling and to the standardization of research methods in agroforestry so that results are comparable. Also Bowen and Nambiar (1984) mention that more attention needs to be given to sampling requirements in forested ecosystems. The present studies confirms this requirement when it comes to sampling procedures in hedgerow intercropping systems. More research is therefore needed to reveal the spatial distribution of inorganic nitrogen. Although one may eventually arrive at '*how*' to sample hedgerow intercropping systems, '*why*' is still another cup of tea.

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APPENDIX VIII TEST FOR NORMALITY OF INORGANIC NITROGEN DATA

(November 1993)

INTRODUCTION

Soil variables often exhibit frequency distributions that are positively skewed (Parkin, 1993). When this situation exists, the assumption of normality associated with statistical procedures is violated. For skewed distributed data the population mean and median have different values and transfer is than most appropriate. Transformation cannot be used directly for zero values and when some of the values are less than 10. It is therefore desirable to have a transformation which act like the square root for small values and like the logarithmic for large values (Steel and Torrie, 1980). Addition of 1 to each number prior to taking logarithms has the desired effect. That is, log(X+1) behaves like the square root transformation for numbers up to 10 and differs little from logX thereafter.

In this paper three different ways of testing data for normality are investigated. Data were derived from experiment NM1 at Ochinga Farm.

TEST FOR NORMALITY

The following was undertaken to test whether the inorganic nitrogen data were normally distributed:

(i) histogram or frequency distribution,

(ii) scatter diagram showing relation between range and mean,

(iii) ANOVA with untransformed and transformed data.

(i) Frequency distribution

For the first 666 ammonium and 498 nitrate analysis a frequency distribution has been calculated which shows clearly a skewed distribution (Fig. 1).

The median of the ammonium data was 0.33 with a mean of 0.38. For the nitrate this was resp. 0.39 and 0.49.

Transforming the data resulted in more normal distribution although the data were still slightly skewed. Transformation of the ammonium data was more successful than for nitrate. After the transformation the mean of the ammonium data was 0.137 with a median of 0.124. For nitrogen transformation resulted in a mean of 0.163 and a median of 0.143.

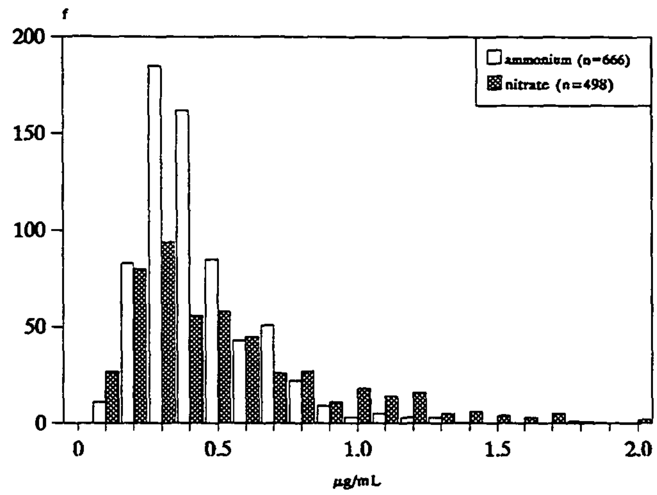

Figure 1. Frequency distribution of ammonium and nitrate data

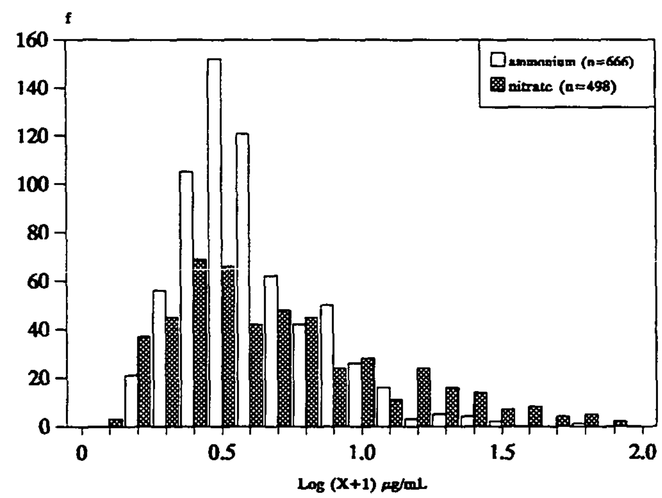

Figure 2. Frequency distribution of transformed ammonium and nitrate data

(ii) Scatter diagram

Gomez and Gomez (1984) recommend the construction of a scatter-diagram to verify the relationship between the mean and the variance. Hereto the mean of every treatment is plotted against the range (highest minus lowest value within a treatment). If the range increases proportionally with the mean the data should be transformed. The success of the logarithmic transformation in achieving the desired homogeneity of variance, can be verified by plotting the transformed mean and range. The scatter-diagram should show no relationship between the range and mean. For every treatment the mean and the range were calculated for each depth, and plotted (Fig. 3).

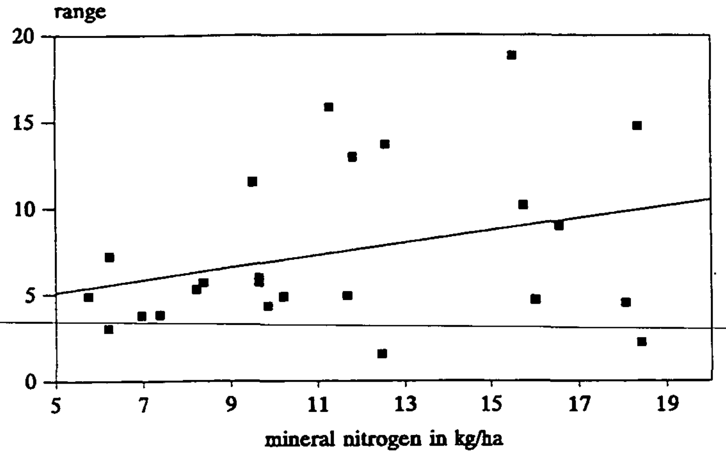

Figure 3. Relationship between the range and the treatment mean data per depth before logarithmic transformation

The original data show little relation between the range and mean ($r=0.309$). Transformation of the mean and range results in a better homogeneity of variance and brings the correlation coefficients further down to 0.265. Although no apparent relationship between the range and mean is noticed the relation is also not fully absent.
The horizontal line in figure 4 presents the mean.

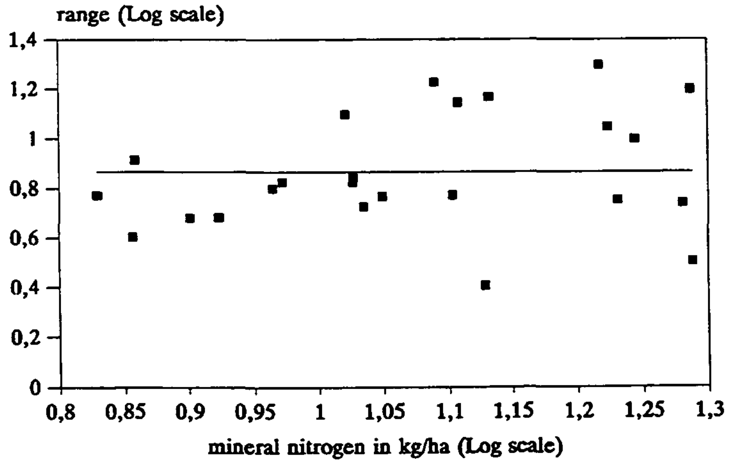

Figure 4. Relationship between the range and the treatment mean data per depth after logarithmic transformation

(iii) Plotting residuals

Residuals of the analysis of variance were plotted against fitted values. In this context, the residuals are the deviations of observations from expected or predicted values. The variance of the residuals must be constant and they should be approximately normally distributed. If the plotted point can be roughly contained within two parallel lines, equally spaced about the line through zero for residuals, then it is likely that the residuals are normally distributed (Lane et al., 1987). A pattern whereby residuals vary with the fitted values implies an inconstant magnitude of errors. The plot of residual look like an outward opening funnel or megaphone (Montgomery, 1988).

ANOVA clearly revealed that the residuals were not normally distributed and transformation of data resulted in plotted values that did not reveal any obvious pattern (figure 5b).

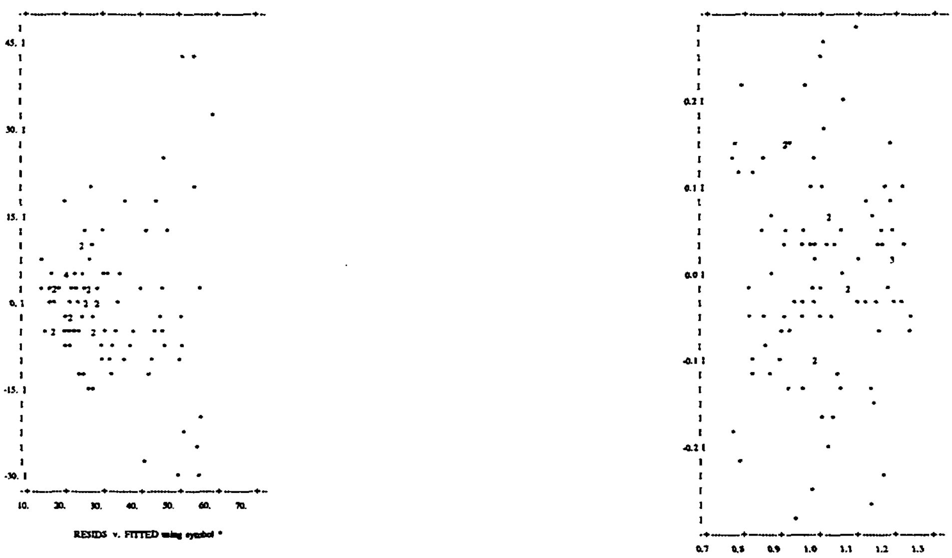

Figure 5 Plot of residuals against fitted values; (a) untransformed data, (b) transformed data (GENSTAT output file).

CONCLUSIONS

- Inorganic nitrogen data of NM1 showed in all three test skewed dsitributions.
- Transformation of ammonium and nitrate data by logarithms results in a more normal distribution of the data. Although 660 and 500 data were used for the ammonium and nitrate distribution resp., frequency distributions of transformed data were still slightly skewed.
- Plotting the untransformed mean and the range of mineral nitrogen data per depth showed a weak relation between the to parameters. Transforming the data resulted in an even weaker relation although the relation was not completely absent.
- Plotting the residuals versus the fitted values showed clear differences between transformed and untransformed data.
- Plotting the residuals yielded the best results when testing whether the transformation of data has been successful.
- Transformation of lognormally distributed data does not always result in a normal distributions in case a scatter diagram or frequency distribution is used. The sample size may be crucial point in this respect.

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Alfred E. Hartemink

Maseno, 30th November 1993

APPENDIX IX WEATHER CONDITIONS AND SOME OTHER OBSERVATIONS AT THE TIME OF SAMPLING EXPERIMENT NM1

FIRST ROUND, 16 AND 18 SEPTEMBER 1993

Weather

August has been a reasonably wet month with 120 mm of rain. It was fairly well spread over the month. The first two weeks of September had 60 mm of rain. Two days after a shower of 25mm the first sampling round at Ochinga was started.

Soils

The soils were reasonably moist possibly due to the shower two days before the sampling.
The soils have an increase in clay content with depth due to an illuviation of clay. The increase was estimated to exceed 20%. Augering to 2 metres depth is not hampered by bedrock or other root restricting layers. Due to the clay increase with depth and the strong soil structure below 75 cm augering is not an easy task.

Crops

It was noticed that *Sesbania* plant were slightly hanging over in one particular direction. It probably has to do with the prevailing wind direction although the farmer mentioned another prevailing wind direction than was concluded looking at the *Sesbania*. The *Sesbania* had an average height of 90 cm though variation was large. Maize which was sown 14 days before the first sampling round and was well established. Most plants had 2 to 3 leaves.

SECOND ROUND, 4 AND 5 OCTOBER 1993

Weather

September had 124 mm of rain which is about equal to the amount of rain in August.
There was 64 mm of rain since the first sampling round which is about two-third of the target amount of rain.
Six days before the second sampling round started there was 31 mm of rain followed by 3 mm the next day.
Then there were 5 days with no rain at all.
About 4.5 mm of rain fell in the afternoon of 4 October when more than half of the 16 plots were sampled.

Soils

The topsoils appeared to be a drier than the previous round. Some light erosion was observed in the bare fallow treatment. Sealing and crusting was observed although not to a large extent.
A soil pit up to 2 meters of depth was dug on 3rd October close to the shed. The profile confirmed what already has been observed with the augerings: a textural increase with depth and a strong structure below 75 cm. The topsoil is more than 20 cm and has a dark reddish brown colour (not measured). The AB horizon extends up to 40 cm after which 3 Bt's can be recognized. There is a high termite activity throughout the profile (*Macrothermes spp.?*). The termite activity causes a high degree of homogenization in the profile. Termite nests up to 30 cm diameter in size were found below 175 cm of depth. Though the profile was not described in detail and no chemical analysis data are known, it appears to be a favourable soil for crop production. Physical soil properties are favourable but the structure of the topsoil is probably a bit weak.

Crops

Three *Sesbania* plants were flowering in the fourth terrace. According to Barack Owuor this can be explained by the large variation in genotypes of *Sesbania sesban*.

Maize plants unfolded their 5th leaf and looked healthy. Very few plants (less than 1 out 100) showed purple colouring of the stem possibly due to P-deficiency. No parallel streak has yet been observed.

Weeds had grown quite a bit though not considerably. Weeds in the weed fallow treatment had not covered the soil surface.

At the end of the second round weeding was carried out in all but the weed fallow treatments. Also the maize was thinned to a density of about 53,000 plants per ha. The amount of dry matter removed per plot is given below (data are of 4 plots).

	weeds in g $plot^{-1}$*			maize in g $plot^{-1}$*		
treatment	mean	minimum	maximum	mean	minimum	maximum
Sesbania	2325	1535	3829	1592	1390	1846
maize	1170	1108	2370			

* dividing by 10 gives the amount in kg ha^{-1}

Although few data only, it looks like that weed growth is more prolific under *Sesbania* as under maize. It might have to do with competition for water and nutrients which is less under *Sesbania*.

The *Sesbania* had an average height of 1.25m though variation was large. No particular pattern could be recognized within or between plots.

THIRD ROUND, 19 AND 20 OCTOBER 1993

Weather

The period prior to the third round of soil sampling was characterized by daily rain. It looked like the short rains are on. Most rain precipitates towards the end of the day due to the raising of clouds of Lake Victoria? At the beginning of the period there were light showers of 4 to 7 mm per day but towards the end a heavy shower of 48 mm occurred followed by 18 mm the next day. The heavy shower was accompanied by hail and did quite a bit of damage to the maize crop. The *Sesbania* looked unaffected possibly as it folds the leaves when it rains. Two days after the heavy rain and hailstorm, soil sampling started. Unfortunately nearly 10 mm of rain fell in the night of 19 to 20 October. It fell in approximately 1.5 hour and when sampling started at the 20th October at 6.45am, the topsoils were quite wet.

In total 107 mm of rain fell since the second sampling round which is about the target amount between two sampling rounds.

Soils

The heavy rain prior to the sampling had resulted in considerable erosion which was not observed before at Ochinga farm. The erosion was particular noticed at the bare fallow plots. Some patches at the lower part of the terrace were clearly ponded during some hours after the rain. The ponding was observed in both terraces.

An explanation for the observations might be the following: The heavy rain and hail resulted in fine fragmentation of the soil particles (splash erosion) which could then be take in suspension by the running water. At the lower part of the terrace the water is stopped from running. Here sedimentation of the fine particles takes place and seals of the surface which reduces infiltration rates. When the soils dries a fine crust is formed with some small cracks of a few cm deep. With the next rains more fine soil material is added to the lower parts and the hazard for ponding increases.

Besides the evidence of fine material being washed downslope, it was observed in the maize plots that some plants were bended. Closer investigation showed accumulation of soil material (1 to 3 cm!) at the foot of the plant and the plants apparently bowed by the force of the soil wash. It might have occurred in combination with the hail.

The vulnerability of the soils for erosion may be explained by the following combination of factors:

(i) poor structure of the topsoil due to frequent tillage (planting, weeding),

(ii) absence of a soil cover.

Although not much evidence is collected for the following factors, it may contribute as well to the erosion as observed at Ochinga farm:

(iii)texture or particle size distribution of the soils favouring sealing and crusting,

(iv) erosivity of the rains i.e. high intensity.

There are some ways to avoid and overcome the effects of erosion. The bare fallow plots were covered with a sheet of gunnybags at 25th October. It is expected that the coverage will particularly avoid the splash erosion but it may also stop the water from running downslope. This is however not an option for the other three treatments. With time, however, *Sesbania*, maize and weeds will grow and reduce the erosivity of the rain. To overcome the effect of erosion it is necessary to break open the crusts at the lower part of the terrace to improve filtration. Weedgrowth, though attractive from a soil cover point of view, is not feasible because of the objectives of the experiment.

Crops

Sesbania beetles were observed in the first *Sesbania* plot. All plots were sprayed with Diazonin at 21st October. According to Bashir Jama this pest particularly occurs under wet conditions.

Maize plants had about 10 leaves unfolded. Some very few maize plants suffered from parallel streak and about the same number of plants showed symptoms associated with P-deficiency as was seen in the second sampling round.

FOURTH ROUND, 22 AND 23 NOVEMBER 1993

Weather

About 145 mm of rain has been falling in the month of October which is 20 mm more than in September and August. There was a dry period of nearly three weeks from 20th October to 10th November in which only 15 mm precipitated. The amount of rain since the last sampling at 19th and 20th October was 126 mm. On 10th and 11th November two heavy showers of about 30 mm of rain fell and although it was intention to sample directly hereafter, water and refrigerator space problems at the Maseno laboratory did not allow this. Between this heavy showers and the actual sampling dates only 9 mm of rain fell.

Soils

The soils were dry in the toppart but still felt moist below 80 cm. There is now reasonable consensus amongst the auger-men what the 'hard' depths are to auger. It may be summarized as follows: the topsoil is easy but the

layer from 20 to 40 cm depth is difficult to auger. Also from 80 to 120 cm it is difficult whereafter augering is relatively easy again. How to explain this pattern? One is easily attempted to call the difficulties just below the topsoil a ploughpan but looking at the rate of mechanization at Ochinga farm that is not quite realistic. When measuring the bulk densities it was found that the 15 to 30 cm layer had a slightly higher density as the toplayer and the 30 to 50 cm layer (1.13 for the 15-30cm layer and 1.10 for the 00-15 and 30-50cm layer). So it might be that there is a relative higher clay content in the 15-30cm layer than in the 30-50cm layer. Clay replacement may be higher from the 30-50cm layer than from the 15-30 cm layer as the latter has a higher organic matter content and therefore a stronger clay-humus complex.
The reason why the layer at 80 to 120 cm is difficult to auger is probably caused by the sheer illuviation of clay and/or sesquioxides which increases the bulk densities. The highest bulk densities, however, were found below 150 cm (1.25 Mg m^{-3}) but as the soil at those depth is relatively moist it may explain why it is not so difficult to auger.
It was observed that some soils were cracking on sites were we had previously sampled. It is likely to be the result of structural deformation though a very light tillage was given after the last sampling. The cracks certainly encourage by-pass flow and affect our leaching hypotheses. Fortunately the new samples are taken in parts of the plots were no compaction or other recent human influence has occurred.
The gunny bag sheets which cover the bare-fallow treatment, do not avoid weed growth. They may on the other hand reduce run-off and hence increase infiltration but this still needs to be proven. Furthermore it was observed that the soil under this plastic mulch is more moist than without. Also temperature might be influenced and therefore thermometers have been installed under and adjacent to the gunny bag cover. Conflictingly enough the temperatures under the gunny bag cover were found higher than without cover.

Crops

The maize crop had suffered badly from the drought in October and early November and many of the lower leaves had died. The drought had affected the smaller plants more than the larger plants possibly as they had deeper rooting system. Around Ochinga farm it was observed that some farmers just cut the maize plants and feed it to their cattle. Apparently they do not expect any yield and also for our experimental plots it is doubtful whether any cobs will be formed. Most maize plants were tasselling and about 100 to 175 cm in height. Large variations in the stand was observed though most plants had folded their 10th leaf. There was relatively little P-deficiency observed.
Sesbania looked unaffected by the drought and very little dead leaves were collected in the litter traps. The rows nearly close and the plants still hang over in one particular direction. The stand of sesbania is very irregular. As a test crop for nitrogen capture it would perhaps have been better to have a more uniform crop. Beetles had returned and spraying was done on 24th November.
Around the sesbania plots trenching to 1 m depth was carried out to avoid roots growing into adjacent plots. It took place from the 23rd November onwards.
Weeds nearly cover the soils in the weed-fallow plots. A very nicely pattern of weed species was found in the weed-fallow treatment. Some species occur on nearly equi-distances (niche-differentiation). There is little difference within a plot but quite a difference in soil cover and species between plots. At the lower part of the terraces where more water is accumulating after heavy rain, weed growth is more prolific possibly due to higher available water capacity for the shallow rooting weeds.
Weeding of sesbania and maize plots was done at 23rd November.

Alfred E. Hartemink
Maseno, 26th November 1993

APPENDIX X WATER-FILLED PORE SPACE DATA (%)

			DATE:	16 SEPT 1993	4 OCT 1993	19 OCT 1993	22 NOV 1993	16 DEC 1993	10 JAN 1994
PLOT NO.	LAND USE SYSTEM	DEPTH (cm)	POSITION (SESBANIA ONLY)	WFPS%	WFPS%	WFPS%	WFPS%	WFPS%	WFPS%
12	SESBANIA	00-15	12.5 CM	45.9	43.1	48.3	41.8	42.2	37.6
		15-30	FROM THE	51.1	49.1	56.0	43.9	52.2	45.2
		30-50	HEDGE	57.3	54.1	49.7	48.1	46.9	46.6
		50-100		64.5	65.1	61.9	55.8	54.5	51.3
		100-150		68.4	68.3	73.2	63.1	58.0	59.8
		150-200		67.2	68.9	65.8	63.7	59.7	55.6
12	SESBANIA	00-15	37.5 CM	57.0	45.9	45.6	38.0	48.6	37.9
		15-30	FROM THE	54.4	49.1	52.0	47.6	47.1	44.6
		30-50	HEDGE	56.3	55.5	53.8	48.5	45.3	46.9
		50-100		69.6	64.9	63.1	56.8	52.4	52.8
		100-150		67.0	70.5	69.9	59.2	59.0	58.9
		150-200		67.5	65.6	66.2	63.3	57.4	55.9
12	SESBANIA	00-15	62.5 CM	46.8	45.2	46.6	39.2	43.6	39.1
		15-30	FROM THE	53.1	52.5	47.9	45.2	45.3	42.5
		30-50	HEDGE	57.7	53.9	53.5	46.9	44.0	44.3
		50-100		66.5	65.4	65.0	55.2	49.8	41.8
		100-150		70.8	70.4	70.9	61.0	60.3	59.1
		150-200		66.9	68.9	66.8	60.7	57.5	57.3
12	SESBANIA	00-15	87.5 CM	48.6	47.6	46.1	37.7	41.8	42.0
		15-30	FROM THE	47.2	53.8	52.0	43.4	44.5	42.2
		30-50	HEDGE	56.9	55.7	53.2	46.4	45.7	43.6
		50-100		66.7	65.6	63.3	55.4	53.5	53.1
		100-150		68.2	69.2	66.3	62.7	62.4	57.4
		150-200		66.4	66.5	68.5	67.5	58.2	56.3
12	SESBANIA	00-15	112.5	48.6	45.8	46.2	36.9	39.5	40.2
		15-30	FROM THE	54.6	57.2	50.8	43.0	45.8	44.5
		30-50	HEDGE	58.5	56.9	54.3	45.2	44.7	47.1
		50-100		66.1	67.5	66.1	56.1	53.9	53.7
		100-150		70.7	71.3	70.1	63.8	61.3	58.1
		150-200		67.6	67.8	70.5	65.0	59.7	58.0
21	SESBANIA	00-15	12.5 CM	50.8	39.8	47.2	37.3	42.4	43.9
		15-30	FROM THE	54.4	44.2	48.0	44.5	46.2	43.4
		30-50	HEDGE	51.6	48.9	48.9	46.2	46.6	43.5
		50-100		59.4	57.0	57.3	54.1	55.2	52.4
		100-150		64.0	63.9	59.5	59.1	58.8	55.6
		150-200		66.2	63.1	60.1	58.9	56.3	55.7

WATER-FILLED PORE SPACE DATA IN % (CONT.)

21	SESBANIA	00-15	37.5 CM	50.1	39.8	46.2	35.5	40.5	36.7
		15-30	FROM THE	52.2	46.3	51.2	40.9	50.0	41.7
		30-50	HEDGE	53.0	45.7	50.1	45.6	48.1	42.4
		50-100		59.3	61.2	56.6	52.7	54.4	52.1
		100-150		64.1	61.2	61.7	59.4	59.6	54.2
		150-200		66.3	64.0	68.4	58.6	56.7	55.7
21	SESBANIA	00-15	62.5 CM	48.2	38.7	42.9	34.2	48.7	38.7
		15-30	FROM THE	53.9	42.8	48.5	39.4	41.0	42.5
		30-50	HEDGE	54.5	48.5	48.0	44.1	48.1	43.5
		50-100		61.3	55.1	58.8	51.0	55.6	50.5
		100-150		65.2	64.9	65.1	60.2	55.3	54.5
		150-200		64.3	64.2	62.6	60.2	53.1	55.2
21	SESBANIA	00-15	87.5 CM	50.4	38.5	43.7	34.8	38.5	35.8
		15-30	FROM THE	54.8	40.6	46.5	40.1	42.8	42.1
		30-50	HEDGE	53.0	47.4	50.4	42.1	42.4	45.7
		50-100		57.6	56.7	59.7	49.8	53.3	48.7
		100-150		63.3	63.6	65.3	57.4	54.7	55.2
		150-200		64.3	66.5	64.7	60.4	57.1	55.5
21	SESBANIA	00-15	112.5	50.3	41.8	43.5	35.4	39.2	26.1
		15-30	FROM THE	57.1	41.8	62.1	42.3	43.6	42.2
		30-50	HEDGE	53.5	54.0	48.3	45.8	45.1	44.1
		50-100		60.1	59.9	60.2	50.9	53.4	50.8
		100-150		63.8	64.4	65.7	58.2	55.4	55.5
		150-200		66.4	67.7	65.6	64.9	56.9	54.6
34	SESBANIA	00-15	12.5 CM	44.9	44.8	53.0	38.7	42.8	31.4
		15-30	FROM THE	49.4	49.3	59.7	46.0	47.4	36.6
		30-50	HEDGE	51.3	50.2	57.7	47.8	47.3	43.1
		50-100		59.3	61.4	58.7	57.0	51.6	49.7
		100-150		65.1	64.5	66.2	63.4	57.8	57.2
		150-200		61.9	65.1	65.9	62.7	58.8	59.8
34	SESBANIA	00-15	37.5 CM	48.5	44.3	51.3	39.8	45.4	30.0
		15-30	FROM THE	51.9	51.1	53.9	43.8	48.0	43.7
		30-50	HEDGE	52.9	53.7	52.1	47.1	46.4	42.1
		50-100		60.2	58.0	60.6	54.6	51.6	49.3
		100-150		66.9	65.7	67.0	63.5	62.8	66.6
		150-200		65.3	64.7	65.2	60.8	59.6	58.0
34	SESBANIA	00-15	62.5 CM	46.1	42.9	51.7	38.3	45.4	42.1
		15-30	FROM THE	55.0	51.8	53.9	46.6	47.4	43.5
		30-50	HEDGE	53.3	54.4	55.3	48.1	46.9	44.8
		50-100		60.8	58.6	61.5	57.1	49.8	51.0
		100-150		56.9	66.0	67.7	64.2	59.4	57.4
		150-200		66.8	65.6	65.3	66.1	61.4	57.7

WATER-FILLED PORE SPACE DATA IN % (CONT.)

34	SESBANIA	00-15	87.5 CM	50.0	42.3	52.6	36.4	45.7	36.8
		15-30	FROM THE	50.9	51.9	53.9	40.8	46.6	42.2
		30-50	HEDGE	54.4	54.1	52.8	44.0	47.1	43.8
		50-100		60.6	60.9	60.0	53.5	50.2	51.3
		100-150		65.2	67.5	67.3	62.9	62.5	56.4
		150-200		65.8	65.0	66.7	64.0	61.1	56.6
34	SESBANIA	00-15	112.5	46.6	45.0	51.9	35.4	42.9	38.9
		15-30	FROM THE	54.9	52.1	53.2	43.2	47.4	43.8
		30-50	HEDGE	55.3	54.5	53.1	45.1	45.7	43.7
		50-100		60.9	62.5	62.0	52.9	55.8	50.4
		100-150		67.0	66.4	67.5	63.9	57.8	53.2
		150-200		67.5	66.4	66.3	65.3	63.9	55.7
34	SESBANIA	00-15	12.5 CM	52.4	42.5	48.9	40.0	54.6	34.9
		15-30	FROM THE	55.3	48.2	53.8	44.6	53.6	39.4
		30-50	HEDGE	52.5	48.5	50.7	46.7	58.4	44.6
		50-100		60.6	58.7	58.5	55.8	53.8	51.9
		100-150		67.8	67.7	65.9	65.5	73.8	56.5
		150-200		66.6	65.6	67.6	65.4	55.3	55.0
41	SESBANIA	00-15	37.5 CM	52.9	43.1	48.1	38.0	51.2	44.3
		15-30	FROM THE	57.2	50.4	53.5	44.9	48.0	43.6
		30-50	HEDGE	57.3	51.7	52.5	46.2	54.4	45.1
		50-100		63.1	61.8	61.3	55.8	53.6	50.7
		100-150		68.6	63.2	67.9	65.8	57.1	52.2
		150-200		67.3	66.0	69.0	64.6	63.8	55.4
41	SESBANIA	00-15	62.5 CM	52.9	42.3	47.4	34.7	52.5	33.4
		15-30	FROM THE	58.4	48.7	53.7	44.4	52.6	41.1
		30-50	HEDGE	57.2	55.3	52.8	46.8	54.2	45.4
		50-100		62.5	63.2	63.2	56.9	69.0	50.6
		100-150		69.8	67.5	69.9	65.8	68.0	55.7
		150-200		67.8	65.7	67.2	65.7	41.1	54.4
41	SESBANIA	00-15	87.5 CM	52.1	44.3	48.3	39.3	52.9	34.1
		15-30	FROM THE	56.6	52.8	53.5	43.0	53.1	38.8
		30-50	HEDGE	56.4	57.9	52.7	47.8	54.5	45.1
		50-100		60.2	60.7	63.1	63.4	51.0	50.2
		100-150		66.1	68.6	68.6	65.8	56.9	55.9
		150-200		68.4	64.3	67.6	62.7	62.7	57.3
41	SESBANIA	00-15	112.5	50.8	38.9	47.5	37.3	50.9	33.5
		15-30	FROM THE	56.9	46.4	53.4	44.2	57.8	40.3
		30-50	HEDGE	56.4	54.4	54.4	46.0	54.6	44.1
		50-100		63.4	64.8	62.9	56.8	51.4	50.6
		100-150		68.1	69.0	69.3	66.2	57.4	55.1
		150-200		67.6	65.6	66.3	67.0	58.3	57.6

WATER-FILLED PORE SPACE DATA IN % (CONT.)

11	MAIZE	00-15	56.6	42.8	57.3	37.0	50.5	37.7
		15-30	57.5	52.2	55.4	42.4	46.2	43.8
		30-50	54.5	55.8	58.8	50.5	50.1	44.6
		50-100	63.9	61.2	66.4	63.8	52.4	54.9
		100-150	66.3	69.2	73.0	70.6	66.0	66.2
		150-200	65.8	69.4	73.4	69.9	69.5	65.3
24	MAIZE	00-15	53.8	46.4	59.2	38.1	54.5	43.9
		15-30	55.9	53.0	60.1	41.3	49.6	45.2
		30-50	56.5	56.2	57.4	46.5	55.0	43.7
		50-100	61.6	41.5	65.3	57.2	60.5	58.1
		100-150	68.3	71.1	70.6	70.1	64.1	65.4
		150-200	67.8	68.6	70.1	72.3	67.7	66.6
31	MAIZE	00-15	51.3	42.6	48.5	36.8	47.4	31.1
		15-30	57.1	47.8	53.5	39.9	45.6	37.3
		30-50	55.4	55.3	55.4	47.9	43.7	41.6
		50-100	62.7	59.7	62.6	58.4	63.4	50.8
		100-150	66.7	64.2	65.2	67.3	64.1	61.6
		150-200	65.3	62.6	66.7	63.7	65.0	62.6
42	MAIZE	00-15	57.3	43.9	49.3	38.7	52.7	34.7
		15-30	60.1	51.6	57.2	43.7	51.9	36.2
		30-50	56.0	56.1	57.5	51.8	46.7	42.1
		50-100	61.2	64.2	64.4	62.0	54.0	51.7
		100-150	66.5	68.8	68.2	66.6	66.1	62.0
		150-200	66.3	65.5	67.7	65.6	65.7	63.9
13	WEED	00-15	49.9	45.5	49.6	46.7	57.3	39.3
	FALLOW	15-30	54.0	50.1	53.0	52.0	61.7	45.4
		30-50	57.7	56.6	57.8	55.1	60.3	40.7
		50-100	63.9	64.6	64.3	64.5	59.4	56.8
		100-150	69.6	68.1	70.3	71.2	68.2	60.4
		150-200	67.5	70.0	66.8	70.5	61.2	63.3
22	WEED	00-15	53.4	48.0	49.9	38.1	47.1	29.3
	FALLOW	15-30	60.6	53.1	56.3	45.8	49.7	37.0
		30-50	56.7	57.9	58.2	52.4	46.9	38.7
		50-100	63.3	67.6	66.6	64.5	60.9	49.0
		100-150	68.8	71.4	72.5	70.0	65.8	58.0
		150-200	66.9	62.4	66.1	70.8	71.4	63.3
32	WEED	00-15	55.4	45.3	50.0	37.2	48.9	34.3
	FALLOW	15-30	58.2	52.5	55.1	41.7	48.1	38.6
		30-50	57.0	56.3	57.0	48.7	47.2	43.5
		50-100	64.2	62.8	65.1	60.2	59.1	55.0
		100-150	68.2	62.5	69.7	67.7	68.2	63.7
		150-200	67.7	65.5	65.6	65.5	67.1	65.4

WATER-FILLED PORE SPACE DATA IN % (CONT.)

43	WEED FALLOW	00-15	56.5	44.9	51.0	36.0	48.2	30.0
		15-30	59.3	52.0	55.2	39.0	45.7	34.2
		30-50	56.6	53.3	54.4	46.5	45.3	39.1
		50-100	61.1	62.3	64.3	59.2	49.8	50.4
		100-150	69.4	67.3	68.1	67.2	62.9	60.7
		150-200	66.7	66.6	68.5	65.6	66.9	63.4
14	BARE FALLOW	00-15	49.4	51.6	57.0	49.6	49.3	45.2
		15-30	55.4	56.3	60.1	55.6	52.3	48.6
		30-50	56.4	54.8	59.7	57.9	54.5	49.7
		50-100	63.6	61.6	69.4	63.3	61.9	63.4
		100-150	68.7	66.0	70.6	75.4	70.5	67.9
		150-200	65.6	66.4	69.4	66.4	70.2	68.3
23	BARE FALLOW	00-15	54.3	48.6	48.9	51.5	56.0	47.8
		15-30	61.4	57.3	55.8	58.2	60.9	51.1
		30-50	57.2	56.4	56.0	59.8	55.3	51.6
		50-100	62.0	62.5	62.7	66.8	63.6	63.5
		100-150	65.9	70.2	71.7	72.2	69.7	69.9
		150-200	66.7	65.4	67.4	72.6	68.0	65.7
33	BARE FALLOW	00-15	49.6	48.1	50.1	48.3	52.2	38.6
		15-30	56.7	52.7	55.6	54.3	56.9	46.3
		30-50	57.1	56.0	56.8	55.3	56.1	44.4
		50-100	61.7	63.1	62.0	60.1	62.7	59.4
		100-150	66.9	66.4	68.7	69.3	66.4	67.0
		150-200	66.0	64.1	66.8	70.7	68.7	66.2
44	BARE FALLOW	00-15	56.0	44.7	55.9	46.7	57.3	39.5
		15-30	60.0	48.9	58.2	52.0	61.7	43.4
		30-50	56.8	56.1	57.3	55.1	60.3	50.3
		50-100	63.0	59.8	67.1	64.5	59.4	60.4
		100-150	65.9	70.4	64.2	71.2	68.2	67.8
		150-200	66.0	67.1	71.2	70.5	61.2	67.2

APPENDIX XI AMMONIUM NITROGEN DATA

PLOT NO.	LAND USE SYSTEM	DEPTH (cm)	DATE: / POSITION (SESBANIA ONLY)	16 SEPT 1993 NH4-N mg/kg	4 OCT 1993 NH4-N mg/kg	19 OCT 1993 NH4-N mg/kg	22 NOV 1993 NH4-N mg/kg	16 DEC 1993 NH4-N mg/kg	10 JAN 1994 NH4-N mg/kg
12	SESBANIA	00-15	12.5 CM	4.82	1.66	4.36	8.24	1.84	2.94
		15-30	FROM THE	7.06	1.32	6.23	5.21	2.98	4.02
		30-50	HEDGE	0.22	2.74	3.81	3.08	3.77	1.66
		50-100		5.76	1.12	3.93	2.77	1.37	3.30
		100-150		2.18	1.78	2.41	1.32	0.86	0.92
		150-200		0.48	0.32	1.71	1.07	0.85	1.02
12	SESBANIA	00-15	37.5 CM	1.27	0.93	0.78	6.61	2.82	4.66
		15-30	FROM THE	0.98	2.75	4.75	4.02	1.84	4.25
		30-50	HEDGE	1.97	2.44	3.52	2.97	2.64	2.93
		50-100		2.52	0.19	2.43	0.96	3.24	3.19
		100-150		6.33	0.59	2.52	1.71	1.00	1.42
		150-200		0.35	0.18	1.56	2.39	1.35	2.91
12	SESBANIA	00-15	62.5 CM	4.20	0.43	1.27	0.00	0.59	2.72
		15-30	FROM THE	2.57	2.59	3.18	3.90	2.70	2.60
		30-50	HEDGE	2.29	2.02	3.91	4.35	4.14	2.03
		50-100		1.31	0.00	2.40	1.73	0.35	2.55
		100-150		4.89	0.19	1.61	3.66	0.99	1.68
		150-200		0.09	2.39	2.52	0.44	0.60	1.79
12	SESBANIA	00-15	87.5 CM	2.73	1.82	2.14	4.17	3.44	2.73
		15-30	FROM THE	2.68	2.64	2.15	3.65	1.32	3.21
		30-50	HEDGE	6.81	2.95	2.37	3.35	4.10	2.97
		50-100		5.30	5.46	0.40	1.73	3.31	0.79
		100-150		3.70	7.10	1.20	1.73	2.43	2.80
		150-200		6.59	0.06	1.97	1.35	0.22	1.64
12	SESBANIA	00-15	112.5	3.15	5.35	3.53	2.75	2.90	1.71
		15-30	FROM THE	1.63	8.53	4.51	3.23	3.84	3.34
		30-50	HEDGE	4.26	1.00	3.45	2.96	2.26	2.80
		50-100		2.42	0.45	2.40	2.49	1.89	2.45
		100-150		0.09	5.10	2.24	2.83	2.91	1.54
		150-200		5.59	0.83	1.95	2.64	2.65	1.80
21	SESBANIA	00-15	12.5 CM	1.36	0.54	1.78	2.49	0.00	3.30
		15-30	FROM THE	4.88	2.74	3.07	4.09	1.84	3.97
		30-50	HEDGE	7.07	2.74	3.75	4.64	2.14	0.65
		50-100		6.95	0.94	0.64	2.10	1.63	2.06
		100-150		5.01	0.70	2.75	5.79	1.77	0.78
		150-200		2.23	0.00	0.00	2.40	4.63	2.15

AMMONIUM-NITROGEN DATA IN mg/kg (CONT.)

21	SESBANIA	00-15	37.5 CM	0.00	3.72	0.00	4.03	0.58	2.59
		15-30	FROM THE	4.81	1.56	0.64	4.72	4.76	4.65
		30-50	HEDGE	6.28	1.55	4.04	2.84	1.48	3.14
		50-100		1.00	0.58	1.18	2.47	1.87	2.04
		100-150		4.70	1.33	1.68	1.58	0.60	3.66
		150-200		6.36	0.00	2.54	1.69	1.99	2.93
21	SESBANIA	00-15	62.5 CM	2.26	0.77	0.26	3.41	2.20	2.60
		15-30	FROM THE	6.37	3.23	7.29	3.22	4.30	4.48
		30-50	HEDGE	5.20	3.08	2.71	4.28	2.39	3.28
		50-100		1.03	1.09	2.63	2.20	1.12	1.80
		100-150		1.81	1.10	2.58	3.95	1.82	2.28
		150-200		4.29	1.52	0.77	1.45	0.21	2.25
21	SESBANIA	00-15	87.5 CM	1.66	0.77	3.30	3.86	2.05	4.54
		15-30	FROM THE	2.07	2.51	3.02	5.75	4.92	3.21
		30-50	HEDGE	6.72	2.66	2.82	5.28	4.37	3.14
		50-100		12.58	3.04	0.91	2.93	2.26	2.68
		100-150		5.49	0.99	0.90	1.76	0.72	3.03
		150-200		4.55	1.96	0.64	0.56	0.47	1.55
21	SESBANIA	00-15	112.5	7.69	3.80	0.12	2.57	1.93	2.57
		15-30	FROM THE	2.76	3.06	2.54	2.38	4.64	4.03
		30-50	HEDGE	5.88	5.68	2.44	4.07	1.73	3.03
		50-100		0.00	4.94	0.78	2.08	2.38	1.92
		100-150		4.53	0.19	2.97	0.94	0.72	1.03
		150-200		4.74	1.88	0.13	3.50	0.46	1.91
34	SESBANIA	00-15	12.5 CM	1.51	0.00	1.18	5.65	1.70	3.81
		15-30	FROM THE	3.16	4.05	2.73	4.14	0.97	4.29
		30-50	HEDGE	4.91	1.09	3.23	3.48	2.26	4.38
		50-100		4.56	5.73	0.53	2.24	1.37	0.66
		100-150		3.36	2.01	2.75	1.36	0.86	2.31
		150-200		7.02	0.00	1.16	2.38	1.11	1.08
34	SESBANIA	00-15	37.5 CM	4.78	0.44	0.53	5.12	0.46	3.78
		15-30	FROM THE	2.32	3.17	3.40	4.10	2.85	3.64
		30-50	HEDGE	1.03	1.98	3.64	3.85	2.88	3.72
		50-100		2.67	1.72	2.80	3.76	1.24	0.65
		100-150		1.15	2.20	1.96	2.61	0.00	2.49
		150-200		0.89	0.00	0.66	1.57	2.37	0.78
34	SESBANIA	00-15	62.5 CM	7.01	1.44	0.64	2.97	1.22	3.86
		15-30	FROM THE	2.79	0.83	3.07	6.18	3.36	3.14
		30-50	HEDGE	10.53	2.83	1.67	2.45	2.87	2.90
		50-100		2.89	5.22	2.13	3.13	1.22	2.54
		100-150		2.19	5.54	0.00	2.49	3.08	1.68
		150-200		8.67	4.42	1.57	1.22	2.02	1.04

AMMONIUM-NITROGEN DATA IN mg/kg (CONT.)

34	SESBANIA	00-15	87.5 CM	3.79	3.71	0.90	3.16	3.34	2.42
		15-30	FROM THE	3.20	1.11	3.96	3.77	1.84	3.09
		30-50	HEDGE	6.16	5.11	2.85	5.12	0.84	1.91
		50-100		2.84	0.06	0.52	3.72	2.24	2.80
		100-150		5.12	8.46	1.46	1.97	1.13	1.41
		150-200		4.89	7.65	0.00	1.87	2.67	1.66
34	SESBANIA	00-15	112.5	13.18	1.19	2.32	3.14	0.96	2.95
		15-30	FROM THE	3.31	3.99	3.08	3.83	2.86	3.54
		30-50	HEDGE	1.01	1.64	2.26	3.18	1.99	3.03
		50-100		6.24	2.29	0.64	1.71	3.58	2.55
		100-150		4.46	1.09	0.00	2.30	1.10	1.66
		150-200		6.80	1.23	1.04	3.82	1.63	4.43
34	SESBANIA	00-15	12.5 CM	8.69	1.41	2.08	2.74	0.75	4.30
		15-30	FROM THE	4.00	2.49	3.69	3.63	4.72	2.48
		30-50	HEDGE	2.40	2.17	1.54	2.59	2.76	3.51
		50-100		11.25	2.00	0.53	3.51	1.38	1.54
		100-150		1.37	2.00	0.13	0.96	0.90	0.00
		150-200		3.10	0.00	3.16	1.61	1.38	2.41
41	SESBANIA	00-15	37.5 CM	1.02	1.65	1.03	2.20	1.40	3.24
		15-30	FROM THE	4.17	5.67	2.18	5.00	3.30	4.99
		30-50	HEDGE	5.77	1.56	1.04	3.46	2.68	4.02
		50-100		1.43	2.80	0.66	2.28	1.14	2.18
		100-150		3.11	1.70	0.00	1.49	1.25	1.41
		150-200		3.86	3.71	0.00	1.73	1.38	1.89
41	SESBANIA	00-15	62.5 CM	8.19	1.04	0.90	3.06	2.16	2.05
		15-30	FROM THE	4.22	1.06	4.66	3.50	3.63	2.67
		30-50	HEDGE	2.11	3.18	2.28	3.23	2.09	3.65
		50-100		0.36	5.96	2.95	1.71	2.00	1.67
		100-150		1.98	2.59	2.75	2.16	1.28	1.53
		150-200		5.45	1.90	1.18	1.88	1.50	3.38
41	SESBANIA	00-15	87.5 CM	0.87	0.67	2.99	3.80	5.89	3.11
		15-30	FROM THE	11.53	4.54	4.70	3.80	3.39	3.89
		30-50	HEDGE	4.49	0.60	3.26	4.55	2.66	2.62
		50-100		12.42	1.12	0.00	2.52	0.00	2.16
		100-150		0.22	2.60	2.25	1.37	0.73	2.29
		150-200		2.05	1.11	1.71	1.49	0.69	1.28
41	SESBANIA	00-15	112.5	2.06	1.01	0.38	2.44	1.77	3.10
		15-30	FROM THE	3.35	1.68	2.88	3.85	4.16	3.56
		30-50	HEDGE	1.89	2.26	3.26	3.21	3.31	3.92
		50-100		2.59	0.86	3.16	1.59	0.35	2.94
		100-150		1.69	1.55	2.22	3.06	0.47	2.29
		150-200		3.95	1.99	3.41	2.52	1.36	1.42

11	MAIZE	00-15	3.06	6.71	2.19	4.63	1.52	3.54
		15-30	10.41	1.88	4.20	5.56	2.20	3.64
		30-50	3.45	2.49	2.88	4.38	2.80	3.81
		50-100	6.89	1.76	3.18	1.66	1.11	2.19
		100-150	2.42	3.97	2.40	0.86	2.06	5.27
		150-200	3.08	1.63	2.00	0.32	0.62	1.45
24	MAIZE	00-15	2.12	1.17	1.07	3.27	2.84	3.38
		15-30	4.30	2.28	1.48	4.38	2.66	3.77
		30-50	3.35	1.81	1.76	3.40	1.12	2.90
		50-100	4.79	1.52	2.65	4.56	2.31	1.95
		100-150	1.29	0.00	2.15	3.79	2.82	1.07
		150-200	1.80	1.46	1.06	3.23	3.39	2.50
31	MAIZE	00-15	4.69	2.37	6.66	2.92	2.01	3.89
		15-30	6.15	3.25	5.19	4.02	2.09	3.96
		30-50	5.46	2.67	3.00	5.30	3.58	3.92
		50-100	3.60	0.00	2.64	2.66	2.53	2.05
		100-150	4.27	0.84	2.37	0.71	0.22	2.34
		150-200	6.41	0.81	1.67	1.23	0.00	4.03
42	MAIZE	00-15	6.50	2.31	0.91	2.37	2.57	2.99
		15-30	4.60	2.49	1.83	1.89	2.15	5.68
		30-50	2.95	2.65	3.59	4.30	3.01	3.90
		50-100	2.94	0.06	2.94	1.24	0.00	1.54
		100-150	0.36	1.67	0.39	2.28	2.31	0.93
		150-200	0.66	1.48	0.14	1.23	1.24	1.31
13	WEED	00-15	2.88	1.58	2.92	2.75	1.13	1.66
	FALLOW	15-30	3.11	2.37	2.97	2.61	4.10	2.90
		30-50	6.79	4.44	3.41	4.35	2.89	2.38
		50-100	2.57	1.24	2.09	1.09	2.58	1.58
		100-150	2.23	2.57	1.73	1.25	1.42	1.31
		150-200	1.73	1.77	0.65	1.75	3.73	0.00
22	WEED	00-15	0.72	2.36	0.91	3.09	2.63	1.55
	FALLOW	15-30	1.39	2.32	1.72	2.15	3.59	2.79
		30-50	2.60	1.88	3.94	5.83	1.88	2.83
		50-100	4.13	1.93	2.28	4.60	0.49	4.66
		100-150	11.75	1.40	3.33	2.17	0.87	1.57
		150-200	1.02	1.86	2.37	3.08	0.50	0.41
32	WEED	00-15	5.27	0.18	1.82	4.04	1.12	4.92
	FALLOW	15-30	3.16	2.07	3.37	4.72	2.63	7.60
		30-50	4.40	1.86	3.84	3.66	2.51	3.78
		50-100	1.45	0.71	1.19	5.02	1.66	4.38
		100-150	5.90	0.57	2.65	1.50	1.41	3.28
		150-200	2.92	0.06	1.29	1.75	0.09	3.55

AMMONIUM-NITROGEN DATA IN mg/kg (CONT.)

43	WEED	00-15		1.27	0.80	2.19	5.22	0.98	4.50
	FALLOW	15-30		10.36	2.35	3.40	1.64	1.59	4.36
		30-50		5.10	2.64	1.86	4.12	3.01	3.85
		50-100		1.95	1.38	2.62	3.04	1.38	2.18
		100-150		3.97	2.80	2.09	0.97	0.22	1.57
		150-200		4.01	1.48	0.79	2.00	1.92	1.31
14	BARE	00-15		0.21	4.06	0.13	0.69	2.29	1.28
	FALLOW	15-30		4.90	2.52	1.87	4.23	2.04	2.76
		30-50		1.83	2.16	0.81	3.11	2.45	2.73
		50-100		4.60	5.43	2.75	3.12	0.36	0.97
		100-150		5.30	4.11	0.00	3.42	3.27	2.27
		150-200		2.24	0.69	0.91	1.64	2.59	0.95
23	BARE	00-15		4.72	1.21	3.41	3.23	2.86	3.85
	FALLOW	15-30		4.87	2.30	5.48	3.13	2.93	4.25
		30-50		2.85	2.09	4.07	3.80	2.08	2.09
		50-100		2.13	0.73	2.81	2.33	1.69	2.43
		100-150		10.39	1.80	3.26	4.48	1.91	7.33
		150-200		3.72	0.85	2.37	2.16	0.89	1.86
33	BARE	00-15		7.71	0.97	1.67	3.42	1.63	0.99
	FALLOW	15-30		4.21	3.07	2.98	8.23	2.45	3.04
		30-50		1.15	3.04	3.05	4.25	0.89	4.15
		50-100		5.53	6.39	3.34	4.21	0.00	1.73
		100-150		2.27	2.04	2.26	1.13	1.42	1.61
		150-200		5.03	1.33	1.98	1.77	0.48	0.81
44	BARE	00-15		2.00	1.69	1.06	1.32	1.43	3.07
	FALLOW	15-30		7.30	5.61	3.66	4.49	1.02	4.36
		30-50		2.88	0.73	0.93	2.98	3.04	3.22
		50-100		5.58	0.97	2.95	1.91	0.00	2.65
		100-150		2.62	1.38	0.54	3.01	1.43	3.45
		150-200		2.91	1.89	1.98	2.97	0.49	3.95

AMMONIUM NITROGEN DATA IN kg/ha

			DATE:	16 SEPT 1993	4 OCT 1993	19 OCT 1993	22 NOV 1993	16 DEC 1993	10 JAN 1994
PLOT NO.	LAND USE SYSTEM	DEPTH (cm)	POSITION (SESBANIA ONLY)	NH4-N kg/ha	NH4-N kg/ha	NH4-N kg/ha	NH4-N kg/ha	NH4-N kg/ha	NH4-N kg/ha
12	SESBANIA	00-15	12.5 CM	8.0	2.7	7.2	13.6	3.0	4.8
		15-30	FROM THE	12.0	2.2	10.6	8.8	5.1	6.8
		30-50	HEDGE	0.5	6.0	8.4	6.8	8.3	3.7
		50-100		33.7	6.5	23.0	16.2	8.0	19.3
		100-150		13.4	10.9	14.8	8.1	5.3	5.7
		150-200		3.0	2.0	10.7	6.7	5.3	6.4

AMMONIUM-NITROGEN DATA IN kg/ha (CONT.)

12	SESBANIA	00-15	37.5 CM	2.1	1.5	5.7	10.9	4.7	7.7
		15-30	FROM THE	1.7	4.7	8.1	6.8	3.1	7.2
		30-50	HEDGE	4.3	5.4	7.7	6.5	5.8	6.4
		50-100		14.8	1.1	14.2	5.6	18.9	18.7
		100-150		39.0	3.6	15.5	10.5	6.1	8.7
		150-200		2.2	1.1	9.7	14.9	8.5	18.2
12	SESBANIA	00-15	62.5 CM	6.9	0.7	2.1	0.0	1.0	4.5
		15-30	FROM THE	4.3	4.4	5.4	6.6	4.6	4.4
		30-50	HEDGE	5.0	4.4	8.6	9.6	9.1	4.5
		50-100		7.6	0.0	0.0	10.1	2.0	14.9
		100-150		30.1	1.2	9.9	22.5	6.1	10.4
		150-200		0.6	14.9	15.7	2.7	3.7	11.2
12	SESBANIA	00-15	87.5 CM	4.5	3.0	3.5	6.9	5.7	4.5
		15-30	FROM THE	4.5	4.5	3.6	6.2	2.2	5.4
		30-50	HEDGE	15.0	6.5	5.2	7.4	9.0	6.5
		50-100		31.0	31.9	2.3	10.1	19.3	4.6
		100-150		22.8	43.6	7.4	10.7	14.9	17.2
		150-200		66.2	0.4	12.3	8.4	1.3	10.3
12	SESBANIA	00-15	112.5	5.2	8.8	5.8	4.5	4.8	2.8
		15-30	FROM THE	2.8	14.5	7.6	5.5	6.5	5.7
		30-50	HEDGE	9.4	2.2	7.6	6.5	5.0	6.2
		50-100		14.1	2.7	14.0	14.5	11.0	14.3
		100-150		0.5	31.4	13.8	17.4	17.9	9.5
		150-200		35.0	5.2	12.2	16.5	16.5	11.2
21	SESBANIA	00-15	12.5 CM	2.2	0.9	2.9	4.1	2.3	5.4
		15-30	FROM THE	8.3	4.6	5.2	6.9	3.1	6.7
		30-50	HEDGE	15.5	6.0	8.2	10.2	4.7	1.4
		50-100		40.6	5.5	3.7	12.3	9.5	12.1
		100-150		30.8	4.3	16.9	35.6	10.9	4.8
		150-200		13.9	0.0		15.0	29.0	13.4
21	SESBANIA	00-15	37.5 CM	0.0	6.1	0.0	6.7	1.0	4.3
		15-30	FROM THE	8.2	2.7	1.1	8.0	8.1	7.9
		30-50	HEDGE	13.8	3.4	8.9	6.2	3.3	6.9
		50-100		5.8	3.4	6.9	14.4	10.9	11.9
		100-150		28.9	8.2	10.3	9.7	3.7	22.5
		150-200		39.8	0.0	15.9	10.6	12.4	18.3
21	SESBANIA	00-15	62.5 CM	3.7	1.3	0.4	5.6	3.6	4.3
		15-30	FROM THE	10.8	5.5	12.4	5.5	7.3	7.6
		30-50	HEDGE	11.4	6.8	6.0	9.4	5.3	7.2
		50-100		6.0	6.4	15.4	12.9	6.6	10.5
		100-150		11.1	6.8	15.9	24.3	11.2	14.0
		150-200		26.8	9.5	4.8	9.1	1.3	14.1

AMMONIUM-NITROGEN DATA IN kg/ha (CONT.)

21	SESBANIA	00-15	87.5 CM	2.7	1.3	5.4	6.4	3.4	7.5
		15-30	FROM THE	3.5	4.3	5.1	9.7	8.3	5.4
		30-50	HEDGE	14.8	5.9	6.2	11.6	9.6	6.9
		50-100		73.6	17.8	5.3	17.1	13.2	15.7
		100-150		33.8	6.1	5.5	10.8	4.4	18.7
		150-200		28.4	12.2	4.0	3.5	2.9	9.7
21	SESBANIA	00-15	112.5	12.7	6.3	0.2	4.2	3.2	4.2
		15-30	FROM THE	4.7	5.2	4.3	4.0	7.9	6.8
		30-50	HEDGE	12.9	12.5	5.4	9.0	3.8	6.7
		50-100		0.0	28.9	4.6	12.1	13.9	11.2
		100-150		27.8	1.1	18.3	5.8	4.4	6.3
		150-200		29.6	11.8	0.8	21.8	2.9	11.9
34	SESBANIA	00-15	12.5 CM	2.5	0.0	1.9	9.3	2.8	6.3
		15-30	FROM THE	5.4	6.9	4.6	7.0	1.6	7.3
		30-50	HEDGE	10.8	2.4	7.1	7.7	5.0	9.6
		50-100		26.7	33.5	3.1	13.1	8.0	3.8
		100-150		20.7	12.3	16.9	8.4	5.3	14.2
		150-200		43.9	0.0	7.3	14.9	6.9	6.7
34	SESBANIA	00-15	37.5 CM	7.9	0.7	0.9	8.4	0.8	6.2
		15-30	FROM THE	3.9	5.4	5.8	7.0	4.8	6.2
		30-50	HEDGE	2.3	4.4	8.0	8.5	6.3	8.2
		50-100		15.6	10.0	16.4	22.0	7.2	3.8
		100-150		7.1	13.6	12.1	16.1	5.8	15.3
		150-200		5.6	0.0	4.1	9.8	14.8	4.9
34	SESBANIA	00-15	62.5 CM	11.6	2.4	1.1	4.9	2.0	6.4
		15-30	FROM THE	4.7	1.4	5.2	10.5	5.7	5.3
		30-50	HEDGE	23.2	6.2	3.7	5.4	6.3	6.4
		50-100		16.9	30.5	12.5	18.3	7.2	14.9
		100-150		13.5	34.1		15.3	19.0	10.4
		150-200		54.2	27.6	9.8	7.6	12.6	6.5
34	SESBANIA	00-15	87.5 CM	6.2	6.1	1.5	5.2	5.5	4.0
		15-30	FROM THE	5.4	1.9	6.7	6.4	3.1	5.2
		30-50	HEDGE	13.5	11.2	6.3	11.3	1.8	4.2
		50-100		16.6	0.3	3.1	21.8	13.1	16.4
		100-150		31.5	52.0	9.0	12.1	6.9	8.7
		150-200		30.6	47.8	0.0	11.7	16.7	10.4
34	SESBANIA	00-15	112.5	21.8	2.0	3.8	5.2	1.6	4.9
		15-30	FROM THE	5.6	6.8	5.2	6.5	4.8	6.0
		30-50	HEDGE	2.2	3.6	5.0	7.0	4.4	6.7
		50-100		36.5	13.4	3.8	10.0	21.0	14.9
		100-150		27.4	6.7		14.1	6.8	10.2
		150-200		43.0	7.7	6.5	23.9	10.2	27.7

34	SESBANIA	00-15	12.5 CM	14.3	2.3	3.4	4.5	1.2	7.1
		15-30	FROM THE	6.8	4.2	6.2	6.1	8.0	4.2
		30-50	HEDGE	5.3	4.8	3.4	5.7	6.1	7.7
		50-100		65.8	11.7	3.1	20.6	8.1	9.0
		100-150		8.4	12.3	0.8	5.9	5.5	0.0
		150-200		19.4	0.0	19.7	10.1	8.6	15.1
41	SESBANIA	00-15	37.5 CM	1.7	2.7	1.7	3.6	2.3	5.3
		15-30	FROM THE	7.1	9.6	3.7	8.5	5.6	8.5
		30-50	HEDGE	12.7	3.4	2.3	7.6	5.9	8.8
		50-100		8.4	16.4	3.9	13.3	6.6	12.7
		100-150		19.1	10.5	0.0	9.2	7.7	8.7
		150-200		24.2	23.2	0.0	10.8	8.7	11.8
41	SESBANIA	00-15	62.5 CM	13.5	1.7	1.5	5.0	3.6	3.4
		15-30	FROM THE	7.1	1.8	7.9	5.9	6.2	4.5
		30-50	HEDGE	4.6	7.0	5.0	7.1	4.6	8.0
		50-100		2.1	34.9	17.2	10.0	11.7	9.8
		100-150		12.2	15.9	16.9	13.3	7.9	9.4
		150-200		34.1	11.9	7.4	11.7	9.3	21.1
41	SESBANIA	00-15	87.5 CM	1.4	1.1	4.9	6.3	9.7	5.1
		15-30	FROM THE	19.5	7.7	8.0	6.4	5.7	6.6
		30-50	HEDGE	9.9	1.3	7.2	10.0	5.9	5.8
		50-100		72.7	6.6	0.0	14.8	0.0	12.6
		100-150		1.4	16.0	13.8	8.4	4.5	14.1
		150-200		12.8	6.9	10.7	9.3	4.3	8.0
41	SESBANIA	00-15	112.5	3.4	1.7	0.6	4.0	2.9	5.1
		15-30	FROM THE	5.7	2.8	4.9	6.5	7.1	6.0
		30-50	HEDGE	4.2	5.0	7.2	7.1	7.3	8.6
		50-100		15.1	5.0	18.5	9.3	2.0	17.2
		100-150		10.4	9.5	13.7	18.8	2.9	14.1
		150-200		24.7	12.4	21.3	15.7	8.5	8.9
11	MAIZE	00-15		5.0	11.1	3.6	7.6	2.5	5.8
		15-30		17.6	3.2	7.1	9.4	3.7	6.2
		30-50		7.6	5.5	6.3	9.6	6.2	8.4
		50-100		40.3	10.3	18.6	9.7	6.5	12.8
		100-150		14.9	24.4	14.8	5.3	12.7	32.4
		150-200		19.2	10.2	12.5	2.0	3.9	9.0
24	MAIZE	00-15		3.5	1.9	1.8	5.4	4.7	5.6
		15-30		7.3	3.9	2.5	7.4	4.5	6.4
		30-50		7.4	4.0	3.9	7.5	2.5	6.4
		50-100		28.0	8.9	15.5	26.7	13.5	11.4
		100-150		7.9	0.0	13.2	23.3	17.3	6.6
		150-200		11.3	9.2	6.6	20.2	21.2	15.6

31	MAIZE	00-15	7.7	3.9	11.0	4.8	3.3	6.4
		15-30	10.4	5.5	8.8	6.8	3.5	6.7
		30-50	12.0	5.9	6.6	11.7	7.9	8.6
		50-100	21.1	0.0	15.4	15.6	14.8	12.0
		100-150	26.3	5.2	14.6	4.3	1.4	14.4
		150-200	40.1	5.1	10.4	7.7	0.0	25.2
42	MAIZE	00-15	10.7	3.8	1.5	3.9	4.2	4.9
		15-30	7.8	4.2	3.1	3.2	3.6	9.6
		30-50	6.5	5.8	7.9	9.5	6.6	8.6
		50-100	17.2	0.3	17.2	7.2	0.6	9.0
		100-150	2.2	10.3	2.4	14.0	14.2	5.7
		150-200	4.1	9.3	0.8	7.7	7.8	8.2
13	WEED FALLOW	00-15	4.8	2.6	4.8	4.5	1.9	2.7
		15-30	5.3	4.0	5.0	4.4	6.9	4.9
		30-50	14.9	9.8	7.5	9.6	6.4	5.2
		50-100	15.0	7.2	12.2	6.4	15.1	9.2
		100-150	13.7	15.8	10.6	7.7	8.7	8.1
		150-200	10.8	11.0	4.1	10.9	23.3	0.0
22	WEED FALLOW	00-15	1.2	3.9	1.5	5.1	4.3	2.6
		15-30	2.3	3.9	2.9	3.6	6.1	4.7
		30-50	5.7	4.1	8.7	12.8	4.1	6.2
		50-100	24.2	11.3	13.4	26.9	2.8	27.3
		100-150	72.3	8.6	20.4	13.3	5.4	9.6
		150-200	6.4	11.6	14.8	19.3	3.1	2.6
32	WEED FALLOW	00-15	8.7	0.3	3.0	6.7	1.8	8.1
		15-30	5.4	3.5	5.7	8.0	4.5	12.9
		30-50	9.7	4.1	8.5	8.0	5.5	8.3
		50-100	8.5	4.1	7.0	29.4	9.7	25.6
		100-150	36.3	3.5	16.3	9.2	8.7	20.1
		150-200	18.3	0.4	8.1	10.9	0.6	22.2
43	WEED FALLOW	00-15	2.1	1.3	3.6	8.6	1.6	7.4
		15-30	17.6	4.0	5.8	2.8	2.7	7.4
		30-50	11.2	5.8	4.1	9.1	6.6	8.5
		50-100	11.4	8.1	15.3	17.8	8.1	12.8
		100-150	24.4	17.2	12.9	6.0	1.4	9.6
		150-200	25.1	9.2	4.9	12.5	12.0	8.2
14	BARE FALLOW	00-15	0.3	6.7	0.2	1.1	3.8	2.1
		15-30	8.3	4.3	3.2	7.2	3.5	4.7
		30-50	4.0	4.8	1.8	6.8	5.4	6.0
		50-100	26.9	31.7	16.1	18.2	2.1	5.7
		100-150	32.6	25.3	0.0	21.0	20.1	13.9
		150-200	14.0	4.3	5.7	10.3	16.2	5.9

AMMONIUM-NITROGEN DATA IN kg/ha (CONT.)

23	BARE	00-15	7.8	2.0	5.6	5.3	4.7	6.4
	FALLOW	15-30	8.3	3.9	9.3	5.3	5.0	7.2
		30-50	6.3	4.6	9.0	8.4	4.6	4.6
		50-100	12.4	4.3	16.4	13.6	9.9	14.2
		100-150	63.9	11.1	20.1	27.5	11.8	45.1
		150-200	23.3	5.3	14.8	13.5	5.5	11.6
33	BARE	00-15	12.7	1.6	2.8	5.6	2.7	1.6
	FALLOW	15-30	7.1	5.2	5.0	13.9	4.2	5.1
		30-50	2.5	6.7	6.7	9.3	2.0	9.1
		50-100	32.4	37.4	19.6	24.6	0.0	10.1
		100-150	13.9	12.5	13.9	6.9	8.8	9.9
		150-200	31.4	8.3	12.4	11.1	3.0	5.0
44	BARE	00-15	3.3	2.8	1.8	2.2	2.4	5.1
	FALLOW	15-30	12.4	9.5	6.2	7.6	1.7	7.4
		30-50	6.3	1.6	2.0	6.6	6.7	7.1
		50-100	32.7	5.7	17.3	11.2	0.0	15.5
		100-150	16.1	8.5	3.3	18.5	8.8	21.2
		150-200	18.2	11.8	12.4	18.6	3.1	24.7

APPENDIX XII NITRATE NITROGEN DATA

PLOT NO.	LAND USE SYSTEM	DEPTH (cm)	DATE: POSITION (SESBANIA ONLY)	16 SEPT 1993 NO3-N mg/kg	4 OCT 1993 NO3-N mg/kg	19 OCT 1993 NO3-N mg/kg	22 NOV 1993 NO3-N mg/kg	16 DEC 1993 NO3-N mg/kg	10 JAN 1994 NO3-N mg/kg
12	SESBANIA	00-15	12.5 CM	8.69	6.41	9.10	2.06	3.51	2.91
		15-30	FROM THE	5.47	5.41	4.14	2.96	2.91	2.75
		30-50	HEDGE	1.55	2.39	2.45	2.03	1.79	1.26
		50-100		3.68	2.63	5.68	1.44	2.84	1.01
		100-150		1.04	0.64	0.25	1.79	3.23	3.19
		150-200		1.30	1.01	0.00	1.29	0.65	0.87
12	SESBANIA	00-15	37.5 CM	15.24	24.13	14.14	4.51	3.87	4.15
		15-30	FROM THE	2.80	6.40	0.00	3.74	1.65	3.48
		30-50	HEDGE	3.48	3.68	5.33	3.06	3.20	8.07
		50-100		5.67	3.85	3.77	2.86	2.66	4.81
		100-150		1.89	1.96	2.91	3.58	2.48	6.33
		150-200		2.58	1.00	1.03	1.70	1.66	1.51
12	SESBANIA	00-15	62.5 CM	17.34	14.27	17.71	6.44	6.08	4.17
		15-30	FROM THE	9.51	8.59	11.70	4.11	3.13	2.70
		30-50	HEDGE	3.84	2.85	3.37	1.78	4.45	3.01
		50-100		2.69	4.37	6.39	3.63	3.49	5.56
		100-150		3.86	1.96	4.00	2.20	2.97	1.53
		150-200		2.36	2.57	0.00	0.00	0.65	0.50
12	SESBANIA	00-15	87.5 CM	13.46	15.60	14.59	10.44	9.33	4.55
		15-30	FROM THE	14.27	6.18	6.57	3.48	0.39	5.15
		30-50	HEDGE	2.10	3.65	3.81	1.92	2.56	5.29
		50-100		4.30	4.85	4.91	2.86	2.46	0.76
		100-150		3.20	4.36	3.58	3.38	2.48	2.64
		150-200		2.33	1.90	1.30	1.57	0.00	1.50
12	SESBANIA	00-15	112.5	10.71	10.04	6.29	5.66	13.13	4.33
		15-30	FROM THE	7.06	0.00	3.25	7.59	8.15	3.31
		30-50	HEDGE	2.86	3.20	1.98	3.80	3.21	4.29
		50-100		5.73	5.25	3.86	3.47	2.20	3.69
		100-150		1.58	2.76	3.02	2.41	1.56	2.52
		150-200		1.06	1.01	2.19	2.34	1.81	2.03
21	SESBANIA	00-15	12.5 CM	8.28	7.30	4.95	4.04	1.53	3.02
		15-30	FROM THE	7.18	4.99	3.06	3.56	3.15	1.85
		30-50	HEDGE	2.28	3.18	1.80	2.94	2.71	1.12
		50-100		4.44	2.63	4.95	3.60	3.48	2.16
		100-150		3.27	3.20	2.36	2.23	3.38	1.51
		150-200		2.52	3.69	1.40	1.71	1.53	0.50

21	SESBANIA	00-15	37.5 CM	12.56	6.20	8.03	4.48	3.12	4.28
		15-30	FROM THE	6.37	2.39	4.37	2.97	2.16	2.43
		30-50	HEDGE	2.83	4.35	2.33	0.01	2.55	2.74
		50-100		3.37	3.11	3.79	5.35	3.83	2.14
		100-150		3.19	2.02	3.22	1.92	1.93	2.01
		150-200		1.91	1.69	0.50	2.28	1.67	4.17
21	SESBANIA	00-15	62.5 CM	13.82	8.48	4.46	2.89	3.25	6.51
		15-30	FROM THE	6.28	6.58	3.70	5.25	2.13	2.23
		30-50	HEDGE	3.06	2.62	3.21	3.38	2.71	1.38
		50-100		2.53	4.38	3.40	4.06	2.98	3.55
		100-150		2.37	4.02	1.93	3.16	1.50	1.51
		150-200		1.90	0.64	0.63	3.57	1.15	1.73
21	SESBANIA	00-15	87.5 CM	13.66	5.13	8.11	3.71	7.00	2.97
		15-30	FROM THE	8.31	7.83	5.40	3.53	2.00	1.10
		30-50	HEDGE	3.05	7.93	3.07	2.88	2.53	1.50
		50-100		3.58	2.84	4.42	4.27	2.45	1.52
		100-150		2.76	2.78	4.36	4.62	3.03	2.76
		150-200		1.27	2.72	0.37	1.15	5.05	0.76
21	SESBANIA	00-15	112.5	16.25	17.97	10.74	6.87	2.60	4.37
		15-30	FROM THE	4.71	8.00	4.55	7.26	1.36	1.94
		30-50	HEDGE	2.28	5.47	2.56	1.90	1.15	1.63
		50-100		4.73	4.20	3.91	4.57	2.43	3.15
		100-150		3.12	3.58	2.57	2.82	0.65	2.01
		150-200		2.45	0.00	2.06	2.05	0.89	0.88
34	SESBANIA	00-15	12.5 CM	12.26	13.62	9.81	4.52	3.87	5.80
		15-30	FROM THE	6.27	8.87	7.13	4.97	4.03	5.95
		30-50	HEDGE	7.86	9.02	5.93	3.31	4.22	4.73
		50-100		2.56	3.54	5.01	4.77	2.58	1.77
		100-150		0.81	1.02	2.35	1.58	0.79	0.76
		150-200		0.52	1.01	0.37	1.96	0.00	0.79
34	SESBANIA	00-15	37.5 CM	13.44	14.15	19.07	8.42	1.63	7.86
		15-30	FROM THE	8.70	5.17	6.65	7.50	4.66	8.36
		30-50	HEDGE	6.45	5.11	4.53	5.46	5.23	6.65
		50-100		4.77	2.40	4.12	2.44	2.44	2.76
		100-150		9.04	1.85	1.69	1.55	2.35	0.91
		150-200		0.53	10.88	0.91	1.15	2.05	0.38
34	SESBANIA	00-15	62.5 CM	16.62	13.72	11.98	6.72	6.15	2.85
		15-30	FROM THE	5.41	10.90	7.01	4.79	6.31	5.75
		30-50	HEDGE	1.82	2.62	6.17	5.70	5.08	4.87
		50-100		2.53	3.33	4.26	3.22	3.68	1.13
		100-150		1.98	0.76	1.15	1.94	1.84	1.02
		150-200		0.64	1.26	0.90	0.79	0.53	1.01

34	SESBANIA	00-15	87.5 CM	12.88	18.01	14.20	5.99	5.77	5.62
		15-30	FROM THE	9.34	18.15	6.75	9.01	3.28	5.88
		30-50	HEDGE	6.33	7.62	5.82	5.33	2.40	6.14
		50-100		4.59	6.13	4.83	0.52	2.43	3.15
		100-150		2.57	1.28	1.71	2.31	0.79	1.38
		150-200		1.51	0.88	1.43	0.92	2.59	0.88
34	SESBANIA	00-15	112.5	2.05	9.97	3.34	7.16	7.85	7.19
		15-30	FROM THE	8.50	11.79	12.29	5.39	3.42	6.53
		30-50	HEDGE	9.17	11.94	8.11	4.77	5.47	5.64
		50-100		3.47	6.16	5.40	3.08	7.78	2.40
		100-150		3.44	1.01	2.53	2.00	3.56	1.00
		150-200		2.23	1.15	1.16	0.92	0.66	0.00
34	SESBANIA	00-15	12.5 CM	9.50	4.37	8.83	5.76	2.92	1.55
		15-30	FROM THE	6.06	6.52	4.95	3.71	1.69	1.35
		30-50	HEDGE	5.39	2.45	5.39	4.08	1.23	4.73
		50-100		5.84	4.42	5.14	3.99	2.47	2.15
		100-150		2.43	1.92	0.78	1.70	4.44	2.53
		150-200		1.69	1.15	1.43	0.79	1.05	0.88
41	SESBANIA	00-15	37.5 CM	13.44	11.41	8.37	3.13	2.24	2.74
		15-30	FROM THE	9.09	9.16	6.14	3.35	1.30	3.63
		30-50	HEDGE	6.60	5.13	6.78	4.82	2.87	5.87
		50-100		6.83	6.24	7.53	4.73	3.28	2.78
		100-150		2.48	2.64	4.47	1.84	1.69	1.26
		150-200		1.16	0.89	0.79	1.69	2.35	0.12
41	SESBANIA	00-15	62.5 CM	11.45	20.75	9.92	3.74	3.38	3.82
		15-30	FROM THE	6.19	12.64	4.00	2.48	2.67	3.72
		30-50	HEDGE	5.10	6.75	6.82	3.70	2.81	1.25
		50-100		5.12	5.35	5.62	4.48	7.62	1.65
		100-150		2.29	4.37	2.08	1.72	5.30	2.14
		150-200		2.04	2.08	0.25	2.36	0.78	0.25
41	SESBANIA	00-15	87.5 CM	12.26	15.34	8.83	7.15	2.47	3.44
		15-30	FROM THE	5.51	8.54	5.96	7.39	0.78	4.23
		30-50	HEDGE	6.93	7.01	6.38	5.01	3.10	1.48
		50-100		5.97	6.64	6.01	6.78	1.95	1.51
		100-150		3.33	5.19	2.37	3.17	1.04	1.51
		150-200		1.43	1.95	0.25	3.02	1.34	1.13
41	SESBANIA	00-15	112.5	14.35	13.87	12.68	7.91	6.09	4.14
		15-30	FROM THE	5.74	11.45	6.13	5.66	3.20	1.83
		30-50	HEDGE	5.27	7.09	8.34	6.96	1.82	1.26
		50-100		6.04	0.11	7.24	4.50	2.32	1.27
		100-150		1.86	3.23	3.26	2.63	0.78	1.13
		150-200		0.92	1.78	3.40	3.26	1.04	3.17

NITRATE NITROGEN DATA IN mg/kg (CONT.)

11	MAIZE	00-15	13.35	5.41	7.21	2.91	6.49	9.70
		15-30	5.41	5.05	3.66	3.14	1.63	4.24
		30-50	5.94	3.39	5.49	3.80	3.67	6.22
		50-100	7.19	3.90	6.22	7.64	0.78	5.60
		100-150	3.74	1.93	4.26	3.77	2.77	4.07
		150-200	2.98	3.13	2.39	3.07	0.68	1.55
24	MAIZE	00-15	13.22	6.79	9.18	6.83	3.42	5.72
		15-30	13.91	12.52	9.94	3.35	2.07	4.12
		30-50	7.04	3.89	7.99	11.74	5.29	3.75
		50-100	12.41	7.91	11.26	5.27	5.77	9.60
		100-150	2.26	2.38	4.43	6.82	3.52	3.78
		150-200	1.71	0.87	1.97	1.07	2.26	1.43
31	MAIZE	00-15	10.87	10.84	13.06	7.90	9.22	6.33
		15-30	6.31	8.22	4.92	4.85	3.40	1.07
		30-50	4.06	3.24	3.76	3.39	3.63	3.90
		50-100	2.60	3.00	6.05	3.80	5.15	4.05
		100-150	2.22	1.15	2.88	2.24	2.37	2.06
		150-200	1.64	0.48	1.66	1.06	0.67	2.19
42	MAIZE	00-15	12.94	6.48	9.71	3.43	5.63	9.37
		15-30	4.64	7.40	6.25	5.17	3.24	9.66
		30-50	3.52	2.96	3.30	4.65	3.32	6.54
		50-100	2.58	1.82	3.19	3.96	5.27	4.42
		100-150	2.15	2.39	1.04	2.61	4.32	2.34
		150-200	1.62	1.27	2.16	1.58	1.81	1.29
13	WEED FALLOW	00-15	7.11	17.79	21.68	12.18	2.61	2.64
		15-30	9.69	10.39	11.73	7.44	6.09	4.50
		30-50	5.18	7.42	5.37	4.31	5.87	4.34
		50-100	5.76	5.74	3.83	4.05	4.73	6.59
		100-150	1.87	2.75	3.17	3.60	1.87	2.96
		150-200	5.69	2.21	1.42	2.36	1.32	2.18
22	WEED FALLOW	00-15	17.38	11.88	16.96	2.45	1.92	3.88
		15-30	5.58	5.96	11.47	5.20	3.65	3.49
		30-50	8.20	4.80	8.00	7.72	1.42	2.81
		50-100	7.17	5.20	0.00	3.89	6.43	3.01
		100-150	5.22	1.86	3.56	6.89	1.84	1.80
		150-200	3.46	0.62	0.91	5.02	4.83	0.51
32	WEED FALLOW	00-15	11.58	14.95	19.58	9.32	5.42	8.60
		15-30	8.33	11.30	13.99	4.32	3.70	14.31
		30-50	3.22	4.87	6.21	3.49	2.83	7.52
		50-100	4.75	0.63	4.22	3.94	4.60	3.71
		100-150	2.56	1.53	3.16	3.70	1.73	1.56
		150-200	1.47	2.16	0.00	1.71	2.11	0.52

NITRATE NITROGEN DATA IN mg/kg (CONT.)

43	WEED	00-15	13.92	13.34	16.24	6.98	10.94	6.83
	FALLOW	15-30	13.29	9.26	8.23	8.44	4.77	9.03
		30-50	6.98	5.80	5.17	5.10	7.63	4.81
		50-100	5.18	3.41	8.50	4.56	8.54	4.19
		100-150	3.23	2.59	1.16	5.01	5.48	3.86
		150-200	1.95	0.50	1.44	2.61	2.89	1.80
14	BARE	00-15	8.44	18.84	24.52	19.36	31.16	35.62
	FALLOW	15-30	9.88	12.30	16.18	20.53	28.16	24.24
		30-50	5.89	9.97	11.04	13.04	22.31	14.27
		50-100	1.28	2.20	3.98	2.68	12.89	6.01
		100-150	4.29	0.79	3.12	3.11	4.65	17.40
		150-200	1.89	1.00	0.00	2.92	1.99	2.24
23	BARE	00-15	17.23	7.27	18.87	20.08	22.29	28.20
	FALLOW	15-30	9.05	10.27	13.03	22.74	18.08	22.14
		30-50	4.20	7.02	6.69	13.40	8.22	12.66
		50-100	5.15	4.03	5.07	9.24	8.29	8.53
		100-150	2.18	1.58	3.79	4.97	3.53	5.98
		150-200	0.90	1.17	1.43	1.99	3.72	4.33
33	BARE	00-15	14.34	11.43	23.69	24.37	24.62	24.61
	FALLOW	15-30	7.72	9.41	10.60	20.00	17.31	16.06
		30-50	4.11	7.01	6.36	15.75	7.97	11.73
		50-100	4.77	1.43	5.07	6.98	3.88	10.33
		100-150	0.94	0.77	0.52	2.43	1.35	3.03
		150-200	1.51	1.28	0.91	1.73	2.62	1.82
44	BARE	00-15	12.28	13.84	18.61	20.25	17.90	30.91
	FALLOW	15-30	8.75	11.59	12.40	15.34	19.09	31.36
		30-50	7.55	9.37	7.68	10.39	16.48	20.34
		50-100	11.38	3.64	17.82	6.12	10.91	11.30
		100-150	2.91	3.94	4.97	9.30	8.55	4.87
		150-200	1.60	1.42	2.50	1.61	4.80	1.44

NITRATE NITROGEN DATA IN kg/ha

			DATE:	16 SEPT 1993	4 OCT 1993	19 OCT 1993	22 NOV 1993	16 DEC 1993	10 JAN 1994
PLOT NO.	LAND USE SYSTEM	DEPTH (cm)	POSITION (SESBANIA ONLY)	NO3-N kg/ha	NO3-N kg/ha	NO3-N kg/ha	NO3-N kg/ha	NO3-N kg/ha	NO3-N kg/ha
12	SESBANIA	00-15	12.5 CM	14.3	10.6	15.0	3.4	5.8	4.8
		15-30	FROM THE	9.3	9.2	7.0	5.0	4.9	4.7
		30-50	HEDGE	3.4	5.3	5.4	4.5	3.9	2.8
		50-100		21.5	15.4	33.2	8.4	16.6	5.9
		100-150		6.4	3.9	1.6	11.0	19.9	19.6
		150-200		8.1	6.3	0.0	8.0	4.1	5.5

12	SESBANIA	00-15	37.5 CM	25.1	39.8	23.3	7.4	6.4	6.8
		15-30	FROM THE	4.7	10.8	0.0	6.3	2.8	5.9
		30-50	HEDGE	7.7	8.1	11.7	6.7	7.0	17.8
		50-100		33.1	22.5	22.0	16.7	15.6	28.1
		100-150		11.6	12.0	17.9	22.0	15.2	38.9
		150-200		16.1	6.3	6.4	10.6	10.4	9.4
12	SESBANIA	00-15	62.5 CM	28.6	23.5	29.2	10.6	10.0	6.9
		15-30	FROM THE	16.1	14.6	19.8	7.0	5.3	4.6
		30-50	HEDGE	8.5	6.3	7.4	3.9	9.8	6.6
		50-100		15.7	25.6	0.0	0.0	0.0	32.5
		100-150		23.7	12.1	24.6	13.6	18.3	9.4
		150-200		14.7	16.0	0.0	0.0	4.1	3.2
12	SESBANIA	00-15	87.5 CM	22.2	25.7	24.1	17.2	15.4	7.5
		15-30	FROM THE	24.2	10.5	11.1	5.9	0.7	8.7
		30-50	HEDGE	4.6	8.0	8.4	4.2	5.6	11.6
		50-100		25.1	28.4	28.7	16.7	14.4	4.5
		100-150		19.7	26.8	22.0	20.8	15.3	16.3
		150-200		14.5	11.9	8.1	9.8	0.0	9.3
12	SESBANIA	00-15	112.5	17.7	16.6	10.4	9.3	21.7	7.2
		15-30	FROM THE	12.0	0.0	5.5	12.9	13.8	5.6
		30-50	HEDGE	6.3	7.0	4.3	8.4	7.1	9.4
		50-100		33.5	30.7	22.6	20.3	12.9	21.6
		100-150		9.7	17.0	18.6	14.8	9.6	15.5
		150-200		6.7	6.3	13.7	14.6	11.3	12.7
21	SESBANIA	00-15	12.5 CM	13.7	12.0	8.2	6.7	2.5	5.0
		15-30	FROM THE	12.2	8.5	5.2	6.0	5.3	3.1
		30-50	HEDGE	5.0	7.0	4.0	6.5	6.0	2.5
		50-100		26.0	15.4	28.9	21.1	20.3	12.7
		100-150		20.1	19.7	14.5	13.7	20.8	9.3
		150-200		15.7	23.1	8.8	10.7	9.6	3.1
21	SESBANIA	00-15	37.5 CM	20.7	10.2	13.2	7.4	5.1	7.1
		15-30	FROM THE	10.8	4.1	7.4	5.0	3.7	4.1
		30-50	HEDGE	6.2	9.6	5.1	0.0	5.6	6.0
		50-100		19.7	18.2	22.2	31.3	22.4	12.5
		100-150		19.6	12.4	19.8	11.8	11.9	12.3
		150-200		12.0	10.5	3.1	14.3	10.4	26.0
21	SESBANIA	00-15	62.5 CM	22.8	14.0	7.4	4.8	5.4	10.7
		15-30	FROM THE	10.6	11.2	6.3	8.9	3.6	3.8
		30-50	HEDGE	6.7	5.8	7.1	7.4	6.0	3.0
		50-100		14.8	25.6	19.9	23.8	17.4	20.8
		100-150		14.6	24.7	11.8	19.4	9.3	9.3
		150-200		11.9	4.0	3.9	22.3	7.2	10.8

NITRATE NITROGEN DATA IN kg/ha (CONT.)

21	SESBANIA	00-15	87.5 CM	22.5	8.5	13.4	6.1	11.5	4.9
		15-30	FROM THE	14.1	13.3	9.1	6.0	3.4	1.9
		30-50	HEDGE	6.7	17.4	6.7	6.3	5.6	3.3
		50-100		20.9	16.6	25.9	25.0	14.3	8.9
		100-150		17.0	17.1	26.8	28.4	18.6	17.0
		150-200		7.9	17.0	2.3	7.2	31.6	4.8
21	SESBANIA	00-15	112.5	26.8	29.6	17.7	11.3	4.3	7.2
		15-30	FROM THE	8.0	13.6	7.7	12.3	2.3	3.3
		30-50	HEDGE	5.0	12.0	5.6	4.2	2.5	3.6
		50-100		27.7	24.5	22.9	26.7	14.2	18.4
		100-150		19.2	22.0	15.8	17.3	4.0	12.4
		150-200		15.3	0.0	12.9	12.8	5.6	5.5
34	SESBANIA	00-15	12.5 CM	20.2	22.5	16.2	7.5	6.4	9.6
		15-30	FROM THE	10.6	15.0	12.1	8.4	6.8	10.1
		30-50	HEDGE	17.3	19.8	13.1	7.3	9.3	10.4
		50-100		15.0	20.7	29.3	27.9	15.1	10.3
		100-150		5.0	6.3	14.4	9.7	4.8	4.7
		150-200		3.3	6.3	2.3	12.2	0.0	4.9
34	SESBANIA	00-15	37.5 CM	22.2	23.3	31.5	13.9	2.7	13.0
		15-30	FROM THE	14.7	8.8	11.3	12.7	7.9	14.2
		30-50	HEDGE	14.2	11.2	10.0	12.0	11.5	14.6
		50-100		27.9	14.1	24.1	14.3	14.3	16.2
		100-150		55.6	11.4	10.4	9.5	14.5	5.6
		150-200		3.3	68.0	5.7	7.2	12.8	2.4
34	SESBANIA	00-15	62.5 CM	27.4	22.6	19.8	11.1	10.1	4.7
		15-30	FROM THE	9.2	18.5	11.9	8.1	10.7	9.7
		30-50	HEDGE	4.0	5.8	13.6	12.5	11.2	10.7
		50-100		14.8	19.5	24.9	18.8	21.5	6.6
		100-150		12.2	4.7	7.1	11.9	11.3	6.3
		150-200		4.0	7.9	5.6	4.9	3.3	6.3
34	SESBANIA	00-15	87.5 CM	21.3	29.7	23.4	9.9	9.5	9.3
		15-30	FROM THE	15.8	30.8	11.4	15.3	5.6	10.0
		30-50	HEDGE	13.9	16.8	12.8	11.7	5.3	13.5
		50-100		26.8	35.8	28.2	3.0	14.2	18.4
		100-150		15.8	7.9	10.5	14.2	4.9	8.5
		150-200		9.4	5.5	9.0	5.8	16.2	5.5
34	SESBANIA	00-15	112.5	3.4	16.4	5.5	11.8	12.9	11.9
		15-30	FROM THE	14.4	20.0	20.8	9.1	5.8	11.1
		30-50	HEDGE	20.2	26.3	17.8	10.5	12.0	12.4
		50-100		20.3	36.0	31.6	18.0	45.5	14.0
		100-150		21.1	6.2	15.5	12.3	21.9	6.2
		150-200		13.9	7.2	7.2	5.8	4.1	0.0

NITRATE NITROGEN DATA IN kg/ha (CONT.)

34	SESBANIA	00-15	12.5 CM	15.7	7.2	14.6	9.5	4.8	2.6
		15-30	FROM THE	10.3	11.1	8.4	6.3	2.9	2.3
		30-50	HEDGE	11.8	5.4	11.9	9.0	2.7	10.4
		50-100		34.1	25.8	30.1	23.3	14.5	12.6
		100-150		14.9	11.8	4.8	10.5	27.3	15.6
		150-200		10.6	7.2	9.0	5.0	6.5	5.5
41	SESBANIA	00-15	37.5 CM	22.2	18.8	13.8	5.2	3.7	4.5
		15-30	FROM THE	15.4	15.5	10.4	5.7	2.2	6.2
		30-50	HEDGE	14.5	11.3	14.9	10.6	6.3	12.9
		50-100		40.0	36.5	44.0	27.7	19.2	16.3
		100-150		15.3	16.2	27.5	11.3	10.4	7.7
		150-200		7.3	5.6	4.9	10.5	14.7	0.8
41	SESBANIA	00-15	62.5 CM	18.9	34.2	16.4	6.2	5.6	6.3
		15-30	FROM THE	10.5	21.4	6.8	4.2	4.5	6.3
		30-50	HEDGE	11.2	14.8	15.0	8.1	6.2	2.8
		50-100		30.0	31.3	32.9	26.2	44.6	9.6
		100-150		14.1	26.9	12.8	10.6	32.6	13.2
		150-200		12.7	13.0	1.6	14.8	4.9	1.6
41	SESBANIA	00-15	87.5 CM	20.2	25.3	14.6	11.8	4.1	5.7
		15-30	FROM THE	9.3	14.5	10.1	12.5	1.3	7.2
		30-50	HEDGE	15.2	15.4	14.0	11.0	6.8	3.3
		50-100		34.9	38.8	35.1	39.7	11.4	8.8
		100-150		20.5	31.9	14.6	19.5	6.4	9.3
		150-200		8.9	12.2	1.6	18.9	8.4	7.1
41	SESBANIA	00-15	112.5	23.7	22.9	20.9	13.1	10.1	6.8
		15-30	FROM THE	9.7	19.4	10.4	9.6	5.4	3.1
		30-50	HEDGE	11.6	15.6	18.4	15.3	4.0	2.8
		50-100		35.4	0.6	42.3	26.3	13.6	7.4
		100-150		11.4	19.9	20.0	16.2	4.8	7.0
		150-200		5.8	11.1	21.2	20.4	6.5	19.8
11	MAIZE	00-15		22.0	8.9	11.9	4.8	10.7	16.0
		15-30		9.2	8.6	6.2	5.3	2.8	7.2
		30-50		13.1	7.5	12.1	8.4	8.1	13.7
		50-100		42.1	22.8	36.4	44.7	4.6	32.7
		100-150		23.0	11.9	26.2	23.2	17.1	25.0
		150-200		18.6	19.5	14.9	19.2	4.2	9.7
24	MAIZE	00-15		21.8	11.2	15.1	11.3	5.6	9.4
		15-30		23.6	21.2	16.8	5.7	3.5	7.0
		30-50		15.5	8.6	17.6	25.8	11.6	8.3
		50-100		72.6	46.3	65.9	30.8	33.7	56.2
		100-150		13.9	14.7	27.2	42.0	21.7	23.3
		150-200		10.7	5.5	12.3	6.7	14.1	9.0

31	MAIZE	00-15	17.9	17.9	21.5	13.0	15.2	10.4
		15-30	10.7	13.9	8.3	8.2	5.8	1.8
		30-50	8.9	7.1	8.3	7.5	8.0	8.6
		50-100	15.2	17.5	35.4	22.2	30.1	23.7
		100-150	13.6	7.1	17.7	13.8	14.6	12.6
		150-200	10.2	3.0	10.4	6.6	4.2	13.7
42	MAIZE	00-15	21.4	10.7	16.0	5.7	9.3	15.5
		15-30	7.9	12.5	10.6	8.8	5.5	16.4
		30-50	7.8	6.5	7.3	10.2	7.3	14.4
		50-100	15.1	10.7	18.7	23.1	30.8	25.8
		100-150	13.2	14.7	6.4	16.1	26.6	14.4
		150-200	10.1	8.0	13.5	9.9	11.3	8.0
13	WEED FALLOW	00-15	11.7	29.4	35.8	20.1	4.3	4.4
		15-30	16.4	17.6	19.9	12.6	10.3	7.6
		30-50	11.4	16.3	11.8	9.5	12.9	9.5
		50-100	33.7	33.6	22.4	23.7	27.7	38.5
		100-150	11.5	16.9	19.5	22.1	11.5	18.2
		150-200	35.6	13.8	8.9	14.8	8.2	13.6
22	WEED FALLOW	00-15	28.7	19.6	28.0	4.0	3.2	6.4
		15-30	9.5	10.1	19.4	8.8	6.2	5.9
		30-50	18.0	10.6	17.6	17.0	3.1	6.2
		50-100	42.0	30.4	0.0	22.8	37.6	17.6
		100-150	32.1	11.4	21.9	42.4	11.3	11.1
		150-200	21.6	3.9	5.7	31.4	30.2	3.2
32	WEED FALLOW	00-15	19.1	24.7	32.3	15.4	8.9	14.2
		15-30	14.1	19.1	23.7	7.3	6.3	24.3
		30-50	7.1	10.7	13.7	7.7	6.2	16.5
		50-100	27.8	3.7	24.7	23.0	26.9	21.7
		100-150	15.7	9.4	19.5	22.7	10.7	9.6
		150-200	9.2	13.5	0.0	10.7	13.2	3.3
43	WEED FALLOW	00-15	23.0	22.0	26.8	11.5	18.0	11.3
		15-30	22.5	15.7	13.9	14.3	8.1	15.3
		30-50	15.4	12.8	11.4	11.2	16.8	10.6
		50-100	30.3	20.0	49.7	26.7	50.0	24.5
		100-150	19.9	15.9	7.2	30.8	33.7	23.7
		150-200	12.2	3.1	9.0	16.3	18.1	11.3
14	BARE FALLOW	00-15	13.9	31.1	40.5	31.9	51.4	58.8
		15-30	16.7	20.8	27.4	34.8	47.7	41.1
		30-50	13.0	21.9	24.3	28.7	49.1	31.4
		50-100	7.5	12.9	23.3	15.7	75.4	35.1
		100-150	26.4	4.8	19.2	19.1	28.6	107.0
		150-200	11.8	6.2	0.0	18.3	12.5	14.0

NITRATE NITROGEN DATA IN kg/ha (CONT.)

23	BARE	00-15	28.4	12.0	31.1	33.1	36.8	46.5
	FALLOW	15-30	15.3	17.4	22.1	38.5	30.6	37.5
		30-50	9.3	15.5	14.7	29.5	18.1	27.8
		50-100	30.1	23.5	29.6	54.0	48.5	49.9
		100-150	13.4	9.7	23.3	30.6	21.7	36.8
		150-200	5.6	7.3	9.0	12.4	23.2	27.1
33	BARE	00-15	23.7	18.9	39.1	40.2	40.6	40.6
	FALLOW	15-30	13.1	15.9	18.0	33.9	29.3	27.2
		30-50	9.0	15.4	14.0	34.6	17.5	25.8
		50-100	27.9	8.4	29.7	40.8	22.7	60.4
		100-150	5.8	4.7	3.2	14.9	8.3	18.6
		150-200	9.4	8.0	5.7	10.8	16.4	11.4
44	BARE	00-15	20.3	22.8	30.7	33.4	29.5	51.0
	FALLOW	15-30	14.8	19.6	21.0	26.0	32.4	53.2
		30-50	16.6	20.6	16.9	22.9	36.3	44.7
		50-100	66.6	21.3	104.2	35.8	63.8	66.1
		100-150	17.9	24.2	30.6	57.2	52.6	30.0
		150-200	10.0	8.9	15.6	10.0	30.0	9.0

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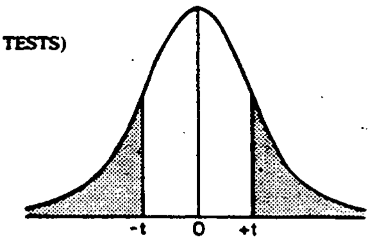
DISTRIBUTION OF t (TWO-TAILED TESTS)



Degrees of Freedom	Probability of a Larger Value, Sign Ignored								
	0.500	0.400	0.200	0.100	0.050	0.025	0.010	0.005	0.001
1	1.000	1.376	3.078	6.314	12.706	25.452	63.657		
2	0.816	1.061	1.886	2.920	4.303	6.205	9.925	14.089	31.598
3	.765	0.978	1.638	2.353	3.182	4.176	5.841	7.453	12.941
4	.741	.941	1.533	2.132	2.776	3.495	4.604	5.598	8.610
5	.727	.920	1.476	2.015	2.571	3.163	4.032	4.773	6.859
6	.718	.906	1.440	1.943	2.447	2.969	3.707	4.317	5.959
7	.711	.896	1.415	1.895	2.365	2.841	3.499	4.029	5.405
8	.706	.889	1.397	1.860	2.306	2.752	3.355	3.832	5.041
9	.703	.883	1.383	1.833	2.262	2.685	3.250	3.690	4.781
10	.700	.879	1.372	1.812	2.228	2.634	3.169	3.581	4.587
11	.697	.876	1.363	1.796	2.201	2.593	3.106	3.497	4.437
12	.695	.873	1.356	1.782	2.179	2.560	3.055	3.428	4.318
13	.694	.870	1.350	1.771	2.160	2.533	3.012	3.372	4.221
14	.692	.868	1.345	1.761	2.145	2.510	2.977	3.326	4.140
15	.691	.866	1.341	1.753	2.131	2.490	2.947	3.286	4.073
16	.690	.865	1.337	1.746	2.120	2.473	2.921	3.252	4.015
17	.689	.863	1.333	1.740	2.110	2.458	2.898	3.222	3.965
18	.688	.862	1.330	1.734	2.101	2.445	2.878	3.197	3.922
19	.688	.861	1.328	1.729	2.093	2.433	2.861	3.174	3.883
20	.687	.860	1.325	1.725	2.086	2.423	2.845	3.153	3.850
21	.686	.859	1.323	1.721	2.080	2.414	2.831	3.135	3.819
22	.686	.858	1.321	1.717	2.074	2.406	2.819	3.119	3.792
23	.685	.858	1.319	1.714	2.069	2.398	2.807	3.104	3.767
24	.685	.857	1.318	1.711	2.064	2.391	2.797	3.090	3.745
25	.684	.856	1.316	1.708	2.060	2.385	2.787	3.078	3.725
26	.684	.856	1.315	1.706	2.056	2.379	2.779	3.067	3.707
27	.684	.855	1.314	1.703	2.052	2.373	2.771	3.056	3.690
28	.683	.855	1.313	1.701	2.048	2.368	2.763	3.047	3.674
29	.683	.854	1.311	1.699	2.045	2.364	2.756	3.038	3.659
30	.683	.854	1.310	1.697	2.042	2.360	2.750	3.030	3.646
35	.682	.852	1.306	1.690	2.030	2.342	2.724	2.996	3.591
40	.681	.851	1.303	1.684	2.021	2.329	2.704	2.971	3.551
45	.680	.850	1.301	1.680	2.014	2.319	2.690	2.952	3.520
50	.680	.849	1.299	1.676	2.008	2.310	2.678	2.937	3.496
55	.679	.849	1.297	1.673	2.004	2.304	2.669	2.925	3.476
60	.679	.848	1.296	1.671	2.000	2.299	2.660	2.915	3.460
70	.678	.847	1.294	1.667	1.994	2.290	2.648	2.899	3.435
80	.678	.847	1.293	1.665	1.989	2.284	2.638	2.887	3.416
90	.678	.846	1.291	1.662	1.986	2.279	2.631	2.878	3.402
100	.677	.846	1.290	1.661	1.982	2.276	2.625	2.871	3.390
120	.677	.845	1.289	1.658	1.980	2.270	2.617	2.860	3.373
∞	.6745	.8416	1.2816	1.6448	1.9600	2.2414	2.5758	2.8070	3.2905

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LIST OF ABBREVIATIONS AND ACRONYMS

AEC	anion exchange ca[illegible]
amsl	above mean sea level
ANOVA	analysis of variance
ASA	American Society of Agronomy
C	carbon
°C	degree centigrade
Ca	calcium
CEC	cation exchange capacity
cm	centimetre
d	day
d.f.	degree of freedom
DM	dry matter
FC	field capacity
g	gram
h	hour
ha	hectare
ICRAF	International Centre for Research in Agroforestry
K	potassium
KARI	Kenya Agricultural Research Institute
KCl	potassium chloride
KEFRI	Kenya forestry Research Institute
kg	kilogram
km	kilometre
LSD	least significant difference
M	molar
m	meter
Mg	magnesium or megagram
mg	milligram
mm	millimetre
mmol(+)	millimole ionic equivalents
mL	millilitre
N	nitrogen
NFTA	Nitrogen Fixing Tree Association
NH_4-N	ammonium-nitrogen
NO_3-N	nitrate-nitrogen
NSSC	National Soil Survey Center-USA
P	phosphorus
PWP	permanent wilting point
SCS	Soil Conservation Service-USA
SD	standard deviation
SE	standard error
SSA	Sub Saharan Africa
SSSA	Soil Science Society of America
TSBF	Tropical Soil Biology and Fertility programme
USDA	United States Department of Agriculture
WAU	Wageningen Agricultural University
WFPS	water-filled pore space
y	year

INORGANIC NITROGEN DYNAMICS UNDER DIFFERENT LAND-USE SYSTEMS ON AN OXISOL IN WESTERN KENYA

MSc thesis
Alfred E. Hartemink 1994