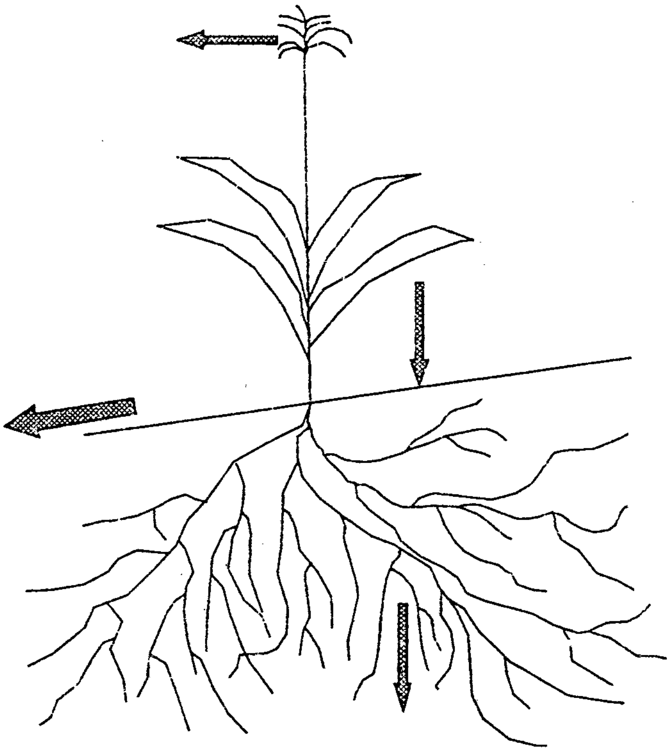
WATER, NITROGEN AND PHOSPHORUS DYNAMICS IN THREE FALLOW SYSTEMS AND MAIZE IN WESTERN KENYA



MSc thesis
Peter van Bodegom
1995

Wageningen agricultural university

Department of Soil Science and Plant Nutrition

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September 1995

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The difficulty - I could say- is not to find the solution, but to acknowledge something to be the solution, while it seems to be only in the first stage.
Ludwig Wittgenstein

ABSTRACT

Maize yields in Western Kenya are usually not higher than 1000 kgha^{-1}, due nutrient depletion among other limitations. Nutrient management is therefore an important issue to attain sustainable land-use systems. Improved tree fallow systems are an option. Trees may reduce leaching losses and improve organic nutrient dynamics by recycling nutrients taken up from below the rooting depth of annual crops. A field experiment was conducted on a highly depleted Kandiudalfic Eutrodox in the humid highlands of Western Kenya to obtain information on the dynamics of nitrogen and to determine the comparative effect of an improved tree fallow of *Sesbania sesban*, a weed fallow and a crop on nutrient losses and capture. Hereto soil moisture, phosphorus and nitrogen were monitored during three seasons in four land-use systems: The three above mentioned systems and bare fallow.

Major moisture losses were runoff and evapotranspiration. Runoff caused extreme treatment differences and ranged from 7.5% in the weed fallow to 80% in the bare fallow. Evapatranspiration was also highly variable and ranged from 5 to 350 mm/season in the bare fallow and weed fallow, respectively. In spite of the different distribution of water, soil moisture contents was similar in all treatments. Leaching losses were therefore also similar.

Erosion losses, caused by the high runoff, were the most important losses of nutrients. The combined nutrient losses of leaching, denitrification and erosion were larger than the inputs of nutrients, independent of treatment. The average net balance for nitrogen ranged from -40 to -196 kg Nha^{-1}season^{-1} in the weed and bare fallow, respectively. The excessive losses in the bare fallow was the combined effect of erosion and high leaching and denitrification losses due to high soil nitrate levels. Soil erosion was also the main cause of the negative phosphorus balance in all treatments which ranged from -0.6 to -17.9 kg Pha^{-1}season^{-1} in the weed and bare fallow respectively.

Organic nitrogen dynamics was another point of difference between the treatments. Sesbania stored much nitrogen in its wood, while the weed fallow had a high mortality of above-ground material. Litter conversion in the sesbania fallow was retarded, while termites promoted litter conversion in the weed fallow, resulting in some litter mineralisation. Less new soil organic nitrogen was formed and hence - as only new organic nitrogen was mineralised - a lower soil mineralisation rate was obtained in the weed fallow than in the sesbania fallow. The organic nitrogen dynamics of maize fulfilled an intermediate position.

From this experiment it was concluded that none of the fallow systems is suitable to maintain soil fertility in continuous maize. The weed fallow had the least negative nutrient balance, but had only short residual effects as it recycled its own nutrients. The sesbania fallow released enough nitrogen for long term residual effects, but the soil is depleted in the long term due to removal of wood and a decrease in soil organic matter. Sesbania can be useful in a crop rotation if wood is considered to be a useful product.

ACKNOWLEDGEMENTS

This report is the result of a 6 and a half months' research period at the International Centre for Research in Agroforestry (ICRAF). During that period I was based at Maseno Agroforestry Station and conducted soil fertility research at Ochinga farm, an experiment managed by researchers. The collected data were analysed and written as a thesis 'Soil Fertility and Plant Nutrition' (Bodemvruchtbaarheid en Plantevoeding) at Wageningen Agricultural University in the Netherlands. I would not have been able to carry out this study without the help of a large number of persons. I would like to thank some of them personally:

Great appreciation goes to Roland Buresh, senior soil scientist and lead scientis in the Nutrient Management Programme at ICRAF. Out of his devotion to the work originates a tremendous support and enthousiasm for the research work, including its conditions. Without his efforts I would not have been able to avoid a lot of pits within the field of conducting research. I would also like to thank him (and his family) for all the hospitality I received during my stay in Nairobi and the all the discussions we had.

Many thanks go to Dr. Janssen, senior lecturer in soil science and plant nutrition at WAU. Thanks to his contacts with ICRAF, I could be based there.

I further would like to thank Bashir Jama, postdoctoral research fellow of the nutrient management programme in Maseno. He helped to streamline the daily execution at Maseno. I appreciate his enormous cooperation in organisation of the field- and laboratory work and the daily discussions. Justus Juma, the driver of the nutrient management programme at Maseno, was extremely helpful in the actual execution of the field work. Without his diligence and patience with me, running around to get everything done, time would have been much harder. God bless you, Justus.

Justus Muli, the manager of the laboratory, and the team (John, Nancy, Opondo, Paul, Evans) is thanked for all the work at the station. Extractions, filtrations, grinding and sorting sometimes had to be carried out under stress and at ackward times. Justus, I also want to thank you for the pleasant weekends and our plays of table tennis.

Tom Ochinga, foreman at the experiment of his father's farm, James Kinyangi, field technician of the Nutrient Management Programme in Maseno, and all fieldworkers at Ochinga farm are largely thanked for their efforts and their abilities to work and analyse situations independently and to undertake action if necessary. Tom and Jozef Ochinga are thanked for their hospitality and humour during the fieldwork.

Director and staff of Maseno Agroforestry Research Station are kindly acknowledged for their hospitality at the station. The staff of the ICRAF laboratory at Machakos are thanked for all analyses carried out on all samples. Paul Smithson is thanked for the special attention he gave checking the process and the data.

Arnoud Braun is thanked for all fruitful discussions we had and the very pleasant cooperation in Kenya and in Wagenin-

gen. He, and Alfred Hartemink, developed the experiment at Ochinga farm and smoothened the path for me.

Mirjam Njoroge, associate soil scientist at ICRAF headquarters, was helpful in the discussions on runoff and infiltration measurement. Prof. Goudriaan, professor at the department of Theoretical Production Ecology (WAU), is thanked for his discussion on plant development and evapotranspiration. Dr. Driessen of the department of Soil Science and Geology (WAU) and Drs. de Ridder of the department of Agronomy (WAU) are thanked for their check on the results of the evapotranspiration calculations.

Last, but certainly not least, I would like to thank Ida who read some of the work and made some of drawings. Above all, however, I want to thank her for finding the patience to live together with me during this period.

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PART I: GENERAL INTRODUCTION

Chapter 1. Introduction

1.1 Background and objectives of this study

background

Soil fertility depletion (indicated by a negative nutrient balance) occurs in large parts of Sub-Saharan Africa (Stoorvogel and Smaling, 1990). Rates of nutrient depletion are highest in areas with a favourable climate for crop production and high population density (Stoorvogel et al., 1993). Yields are decreasing and fallowing is usually not an option due to the high population pressure. Low nutrient reserves, low nutrient and water holding capacity, the lack of easily weatherable minerals and rapid turnover of organic matter are primarily responsible for the rapid decline of these soils with cropping (Grimme and Juo, 1985). Firewood is usually hard to find in the highly populated areas with the result of deforestation.

For this reason, nutrient management research to attain sustainable land-use systems with the conservation of natural sources becomes an important issue (van Reuler and Prins, 1993). Agroforestry, the integration of trees in land-use systems (Young and Muraya, 1990), is one of the options to overcome the soil depletion. The potential of trees includes pumping of nutrients from deeper layers, reduction of leaching losses, maintainance of soil organic matter and physical properties, protection against soil erosion and runoff and the addition of nitrogen through biological nitrogen fixation by perennials (Szott et al. 1991; Buresh, 1993; Young, 1989). *Sesbania sesban* was one promising tree species.

The International Centre for Research in Agroforestry (ICRAF) based in Nairobi (Kenya) has the mandate for process-oriented agroforestry research to test hypotheses and to obtain scientific data on nutrient cycling and on how trees and crops compete for water and nutrients (ICRAF, 1993). The Nutrient Management Project was set up to quantify the various processes by which trees improve the cycling of nutrients, maintain soil organic matter, ameliorate problem soils and contribute to efficient nutrient management. In Western Kenya the focus is on mitigation of land depletion caused largely by cultivation with little or no inputs (ICRAF, 1993). Shepherd et al. (1993) calculated nutrient balances for an existing mixed farm system and an improved agroforestry system. They suggested that denitrification and leaching were the major N losses. Direct quantification of leaching and denitrification under field conditions is however difficult (See e.g. leaching studies of Arora and Juo, 1982; Grimme and Juo, 1985; Seyfried and Rao 1991).

An experiment was set up to obtain indirect information on these losses. The objectives of this experiment (started in March 1993) were to (i) compare the effects of maize, weeds and *Sesbania sesban* on mineral N-dynamics, movement and spatial distribution and (ii) determine the comparative effect of a crop, tree and weeds on nitrogen loss and capture (ICRAF, 1994a). A bare fallow was introduced as a control. A similar experiment in four agro-ecosystems with a similar experimental set-up is described in Paustian et al. (1990). *Sesbania sesban* was used because of its potential to maintain soil fertility and increase crop yields (ICRAF, 1991) and because it is an indigenous species that is left in cropping fields at a wide spacing by farmers (Swinkels et al., 1994). This farmers technique was used. Between March 1993 and August 1993 maize was intercropped with the sesbania trees. After harvest in August 1993 the fallow period started for the *Sesbania sesban* treatment and for the weed fallow treatment.

Measurements started in September 1993 and were continued until January 1995 (in total 3 seasons). Some evidence was raised that nitrogen losses are indeed mainly due to leaching (Hartemink, 1994; Braun, 1995). In February 1995, the fallow systems were terminated and the plots were planted with maize to measure residual effects during two seasons. Conversion and mineralisation of the organic inputs from the fallow vegetation and improved root distribution via old root channels are thought to positively affect the growth of the following crops.

Objectives of the study

The present study forms a part of this experiment. Its objectives were to (i) synthesize and complete the nitrogen and water (seasonal) dynamics in the different land use systems and (ii) develop a preliminary (seasonal) description of the dynamics for phosphorus. In order to quantify the dynamics it was necessary to estimate and measure different water, nitrogen and phosphorus (organic and inorganic) flows. The study was focused on organic material flows (mortality, conversion and mineralisation processes), denitrification, evapotranspiration and leaching. The quantification of these processes was wrapped in the largest uncertainties.

The phosphorus study was started because phosphorus depletion (in addition to leaching) turned out to be one of the largest problems encountered in the region (Braun, 1995).

To achieve the objectives mentioned a new system approach, consisting of the interpretation of experimental data on processes within an analysis of the complete system, was followed. Such approach is important to take care of the holistic view, necessary in any agroforestry research, to my opinion. The same approach is also advised by Rabbinge (1994). Existing computer models on processes assist this description. A review of potential useful models is given by Shepherd (1993).

In former studies it was already indicated that *Sesbania sesban* fallows and weed fallows have an effect on the inorganic nitrogen balance. Comparison between the improved fallow and the natural fallow is emphasised in this study, because these two systems have the largest potential to be applied by farmers. The comparison was however limited to an approach of natural sciences and did not take into account economical or sociological aspects. An analysis of residual effects could not be taken into account either.

A major challenge in this study was to deal with the variability of the data collected and with the heterogeneity caused by effects of termites, striga and rhizosphere. This variability and heterogeneity are probably interrelated.

Objectives of the report

The purpose of this report is twofold, (i) to be a thesis report for Wageningen Agricultural University (WAU), and (ii) to be a research report for the Nutrient Management Programme (NMP) of ICRAF. Thanks to the fortunate circumstances for students to conduct research at NMP at ICRAF a large amount of data has been collected. All data of the short rain season 1994 and some draft reports for further thinking are presented in the appendices. Data collected by Hartemink (1994) and Braun (1995) are not given in the appendices, but these data are used in the calculations presented in this thesis whenever necessary. The dynamics described, therefore, represent all three seasons investigated in this experiment.

As Hartemink (1994) and Braun (1995) already emphasized inorganic nitrogen dynamics in improved fallows, less attention will be paid to it in this report. Inorganic nitrogen dynamics are used only to explain their share in the total nitrogen dynamics. Most emphasis will be on the organic nitrogen dynamics and to the calculations of evapotranspiration, as these processes needed most attention after the studies of Braun (1995) and Hartemink (1994). All processes and calculations are presented within the framework of a system approach.

With the use of a new system approach, dynamics are described for water, N and P in natural and improved fallow systems and maize. With the use of these balancesit is possible to compare the usefulness of each system.

Results of this study were presented on seminars held on the 21st of February 1994 in Maseno for the staff and students of the station and was presented for staff and students of the department of Soil Science and Plant Nutrition of WAU on the 4th of October 1995.

1.2 Research location

The research was carried out at the Maseno Agroforestry Station at Maseno in Western Kenya (See Figure 1.1). This is a collaborative project of the Kenya Forestry Research Institute (KEFRI), the Kenya Agricultural Institute (KARI) and the International Centre for Research in AgroForestry (ICRAF). A number of research projects are based at the Maseno Agroforestry Station. This study for carried out for NMP. The project activities of NMP at Maseno are coordinated by Dr. Bashir Jama, while the NMP is headed by Dr. R.J. Buresh (ICRAF, HQ Nairobi).

The research activities of the projects are partly at the station itself and partly at farmer's fields, so-called 'on farm research'. On farm research can again be subdivided in farmer's managed experiments and scientist's managed research. The soil fertility experiments of NMP belong to the latter category. The farmers have (verbal) agreements with NMP: The farmer receives the yield of the experiment al field and is compensated for losses resulting from research activities, while all activities at the site are induced and supervised by the scientists of NMP.

The site of this study is Ochinga farm, located 11 km North west of the Maseno Agroforestry Station, in Luanda Division, Vihiga District, Western Province.

1.3 The system approach

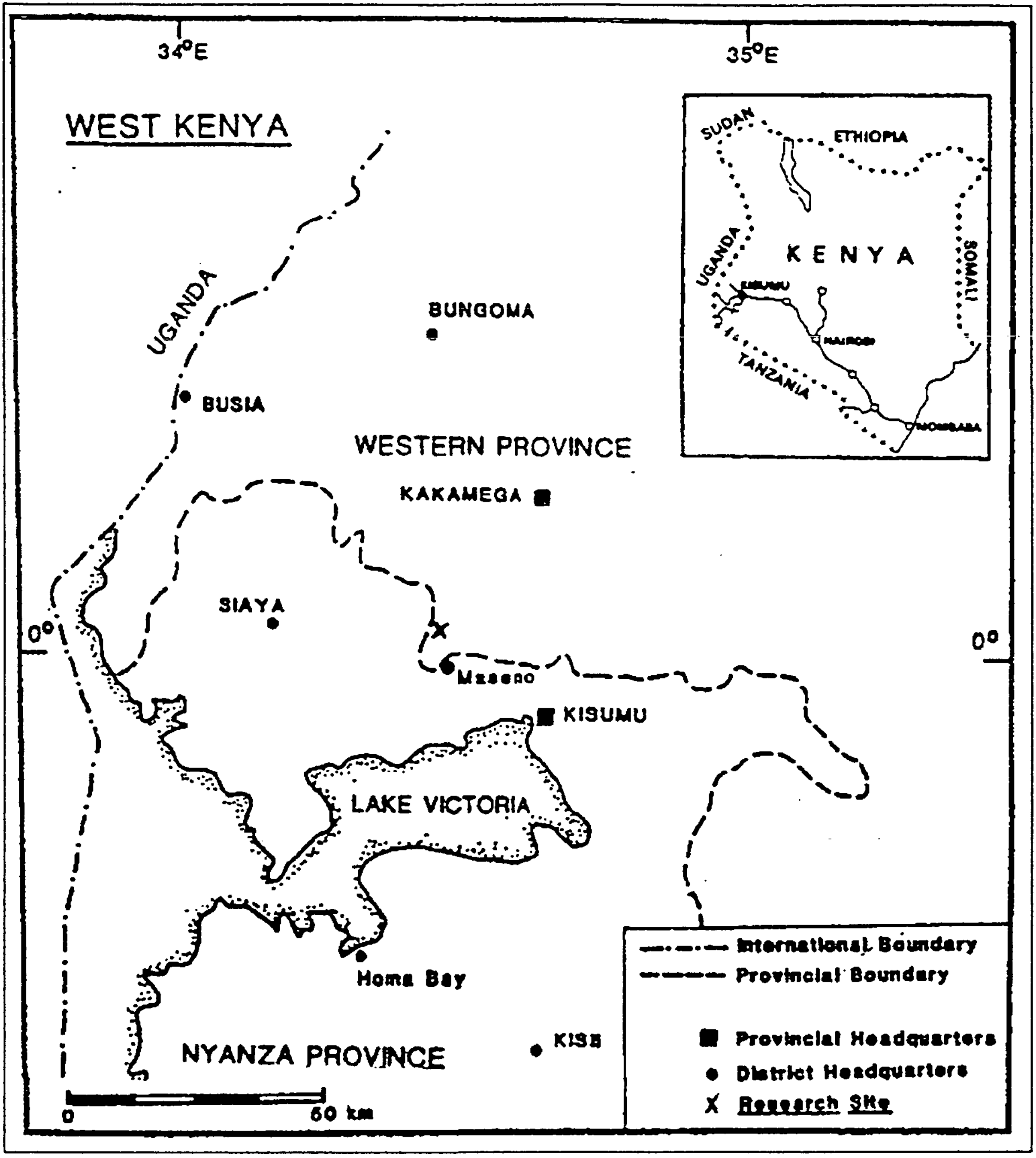

Figure 1.1: Map of Western Kenya including the research site (Hartemink, 1994)

A system

The most simplified definition of a system is 'an organised whole'. This leaves a lot of questions. More information gives the definition 'collection of elements having a specific, not-randomly pattern of interactions and relationships'. This shows that a system is something of a higher order. A system is more than the sum of the elements alone. This is the holistic view. The assessment of the border between system and the environment has always some arbitrariness. The researcher will always have to define the borders and the conditions along the borders. Systems can be defined at all scales and each system can be divided in sub-systems on the condition that the sub-systems again have more cohesion than randomly selected elements.

Two types of systems can be distinguished: open and closed systems. Open systems have always some interaction with their environment, contrary to closed systems. The number of relationships between system and environment must be limited to allow the system to function and maintain itself within the environment. However the relations must be strong enough to develop strategies and alternatives in the ever changing conditions in the environment. This already shows that a closed system can never exist (except for the whole universe as one system) or can only exist artificially. From the old Greek on, scientists try to describe the universe as a system and try to catch this system in a few equations (see e.g. Barrow (1991) and Hawking (1988)).

Also the earth itself is sometimes considered as one system. J.E. Lovelock (1979, 1988) even views the earth as one coherent system of life, self-regulating, self-changing, a sort of immense organism. This is the famous Gaia-hypothesis, called after the Greek goddess Gaia; Mother Earth. The human culture has a limited role in this system.

Other researchers, like Capra and Prigogine, try to combine culture and science of nature in one system. I don't want to go that far, but see a separate role for culture, hopefully in peaceful coexistence with science and technology in the tradition of Habermas (1989).

For simplification, I confined the system in this study to a small entity, horizontally restricted to the plot size. This is the entity in which interactions between plants and soil take place. The feedback of interactions of this entity with the environment are not abundant within the period of the experiment. Inputs and outputs could therefore be described with the environment as a blackbox. The way to deal with systems in general is described in the next section. All subsystems, pools and conditions belonging to the system distinguished in this study are described in Chapter 2.

Dealing with a system: a historical review

Soil fertility as a science began to develop in the 19th century. After Von Liebig had found that a relationship existed between the yield of a crop and the amount of nutrients in the soil a lot of field experiments started. All those experiments were block-designed tests in which various levels of fertilizer were tested. This resulted in an enormous amount of experiments investigating the correlation between inputs and outputs. The internal flows were treated as a black box (see Figure 1.2). Nowadays this kind of system studies still take place, but less frequently.

Attempts to quantify the internal flows and the processes that take place in the plant and in the soil and their interactions only started in the 50's of this century. Knowledge of the processes could reduce the number of field experiments enormously. Correlations were converted into relations. The complexity and heterogeneity forced scientists to simplify their

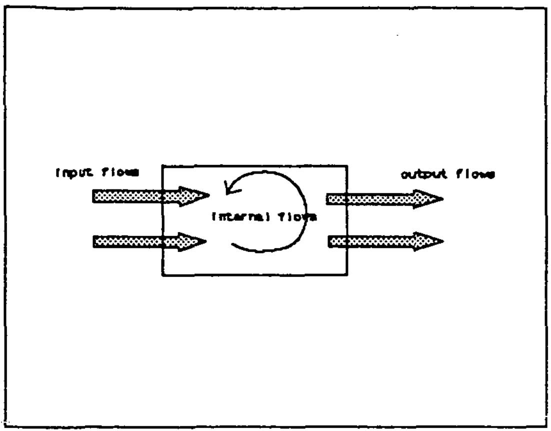

Figure 1.2: General nutrient flows

systems a great deal. For this reason laboratory experiments keeping variables under control, artificial systems and very controlled field experiments were developed. In the 80's scientists started to develop simulation models to deal with the complexity.

Both approaches of course have their disadvantages. The main question is whether results from simplified systems and computer systems can be extrapolated to the real situation. This question is answered negatively by many scientists.

By studying the processes new questions were encountered and the studies became more and more complicated and specialised. Scientists explored sub-systems and were able to describe some processes in the finest details under laboratory conditions. Contact with the field situation was lost.

Soon a reaction developed against the specialists: the holists. Ecological sciences and Lovelock's theory (1979,1988) are characteristic examples of the holistic view.

As usual in science (Kuhn, 1972), slowly after the revolutionary paradigma had been developed, the contradictory views started to draw nearer each other.

The new system approach can be described as a holistic-specialistic-holistic cycle. First the total system is defined; the boundaries, conditions, major processes (their fluxes ,their pools), missing information are distinguished. For the missing data, experiments on the encountered processes are designed and carried out, either under field conditions or under artificial conditions. The final step consists of returning to the system, taking care of interactions between processes. The total system (the field situation) is constructed out of the processes. This becomes relatively easy because the system was already defined, the interactions were already distinguished and the measurements were taken subordinate to the system. This new system approach is not only useful in natural sciences, but is also used in social sciences (Vayda, 1983; de Groot, 1989) and philosophy (Habermas, 1989).

The construction of this report is different from usual reports to allow usage of the new system approach. Results on the measured processes are not the main goal of the report, but only facilitate a system analysis. In Chapter 2 the investigated system is described for each of component (water, nitrogen and phosporus). Boundaries, conditions, major processes and assumptions necessary to describe the total system are included in this chapter. In part II, Chapter 3 and 4, the measured processes are treated. Chapter 3 contains the materials and methods used to measure the processes. Chapter 4 deals with the results of the measurements per process. A literature review for each process is included in Chapter 4, before the data are presented. This literature review is not included in a separate chapter, because the literature only facilitates explanation of the measured data on the processes and the literature does not include an analysis of the complete system. A return to the system is carried out in part III. The synthesis of the dynamics takes place in Chapter 5, followed by discussion and conclusions in Chapter 6 and 7 respectively. Recommendations for further research as given in Chapter 8.

Appendix I contains a lay-out of the field experiment, while Appendices II and III contain papers for additional thinking. Appendix II treats the determination of bulk density and Appendix III deals with the calculation of evapotranspiration. Appendix IV contains a list of symbols and abbreviations used in the thesis.

The other appendices contain all field data obtained from September 1994 to January 1995 (the end of this part of the experiment). Data from other seasons were presented by Hartemink (1994) for the 2nd season and by Braun (1995) for the 3rd season. Data of those seasons are only presented, if not presented yet in this extensive form. The field data are arranged in the same order as the descriptions in Chapter 3 and 4. Appendix V contains all data used in the description of water dynamics being rainfall (Appendix V.1), soil moisture changes (Appendix (V.2), throughfall and interception (Appendix V.3), infiltration (Appendix V.4), runoff (Appendix (V.5), plant growth (Appendix V.6) and the meteorological data from the automatic meteorological station (Appendix V.7). Appendix VI contains all data used in the description of nitrogen and phosphorus dynamics being wet deposition and nutrients in throughfall (Appendix VI.1), dry deposition (Appendix VI.2), biomass assessment data (Appendix VI.3), root production (Appendix VI.4), litter and weed mortality (Appendix VI.5), root conversion (Appendix VI.6), litter conversion (Appendix VI.7), soil organic matter mineralisation (Appendix VI.8), soil inorganic nitrogen (Appendix VI.9), nutrients in runoff (Appendix VI.10), sediment (Appendix VI.11) and denitrification (Appendix VI.12). Appendix VII contains the field data of total carbon, total nitrogen and soil phosphorus used for the seasonal balances (Chapter 5).

Chapter 2: Conceptual models in this study

2.1 General model

An agroforestry system

Soil fertility depletion occurs in areas with a favourable climate for crop production and high population densities in Sub-Saharan Africa, as described in chapter 1. Agroforestry systems have the potential to increase the supply and availability of nutrients in the crop rooting zone through the presence of perennials. Nutrient supply can be increased through reduction of leaching losses and pumping of nutrients from below the rooting zone. Nutrient availability for crops can be increased by recycling nutrients through tree litter and pruning. Other benificial effects of agroforestry systems are protection against soil erosion and maintenance or improvement of soil physical properties (Young, 1989). Agroforestry can be applied in a temporal rotation (as in improved fallows) and can in a spatial rotation (intercropping). Both have their own advantages and disadvantages. In this thesis only agroforestry as applied in improved fallows will be treated.

The list of benificial effects already indicates that an agroforestry system can never be an independent unit in a small-holders farm system as many interacting processes are influenced. In Western Kenya farm sizes are small (with a median of 1.2 ha (Ohlsson et al., in prep.)) and agroforestry fallowing has to be incorporated in the total farm system.

Recently, in a study for UN Food and Agriculture Organization, Smaling et al. (1993) quantified nitrogen, phosphorus and potassium balances in the root zone in Sub-Saharan Africa. To monitor the effects of changing land use and suggested interventions a decision-support model (NUTMON) was developed (Smaling and Fresco, 1993). In order to describe nutrient inputs and outputs in the system at farm level a subdivision into different subsystems had to be made (Van den Bosch, 1994). Shepherd et al. (1993) also describes a static model at farm level in which the following subsystems were distinguished: Field/hedgerow (1), Livestock(2), Boma (3), Compost (4) and Homestead (5). In the present study only the subsystem 'Field/hedgerow' is described. Only in this subsystem agroforestry practices are applied, but this will of course influence the other subsystems of the farm. These influences will not be described directly, but should be taken into account when final recommendations are made on the most benificial fallow system. In later chapters I'll return to this issue.

System characteristics

The system of this thesis is the 'Field/hedgerow' system. Horizontally the system is therefore confined to the borders of the plot, being 10x10m^2. Vertically the system is restricted to air up to 10 m high. This is the height of the planatary boundary layer in sesbania under the prevailing wind conditions at Ochinga farm. Soil depth is taken up to 2 m deep. In this soil layer most interactions between plant and soil take place. Ideally soil depth should be taken up to rooting depth, but this was not obtainable due to the deep rooting pattern of sesbania. Sesbania roots were found even at a depth of 4 m deep. One soil sampling took place up to 4 m deep to determine nitrogen levels in the deeper layers. It will be assumed that no activity influencing the agroforestry system occurs outside the boundaries described except for the described inflows and outflows.

Processes are described per period, because they differ depending on the season. In this way the description can become more accurate. Five periods were distinguished. In the study two short rainy seasons (the 2nd and the 4th season) and one long rainy season (the 3rd season) were involved. The short rainy seasons lasted from September to January and the long rainy season lasted from March to August. The exact times differ from season to season and start at the day of planting of maize and finish at the harvest of maize (or of sesbania as in the 4th season). The dry period between the seasons, 'between seasons', start the day after harvest of maize and finishes the day before the planting of the new maize plants. The periods are presented in Table 2.1.

Table 2.1: Seasonal boundaries for each of the periods and the length of each period (in days)

	date	length	soil sampling period
2nd season	01/09/93-17/01/94	139	16/09/93-10/01/95
between seasons	18/01/94-13/03/94	54	04/01/94-07/03/94
3rd season	14/03/94-04/08/94	134	08/03/94-12/08/94
between seasons	05/08/94-24/08/94	19	13/08/94-07/09/94
4th season	25/08/94-16/01/95	144	08/09/94-13/01/95

2.2 Water model

2.2.1 General description of the water dynamics

The only water pool distinguished in this study is soil moisture (in chapter 5 indicated by moisture storage). Water enters the system by rainfall and leaves the system by leaching, runoff, interception and evapotranspiration. Evapotranspiration is the major outflow process. Water is transported by several processes inside the system. A spatial flow diagram of the water model is presented in Figure 2.1.

Leaching and evapotranspiration could not be measured and had to be estimated. This gave some problems, particularly for the calculation of evapotranspiration. Variability as a result of this calculation and as a result of runoff calculations in maize and bare fallow will contribute to a large extent to the variability of the total system.

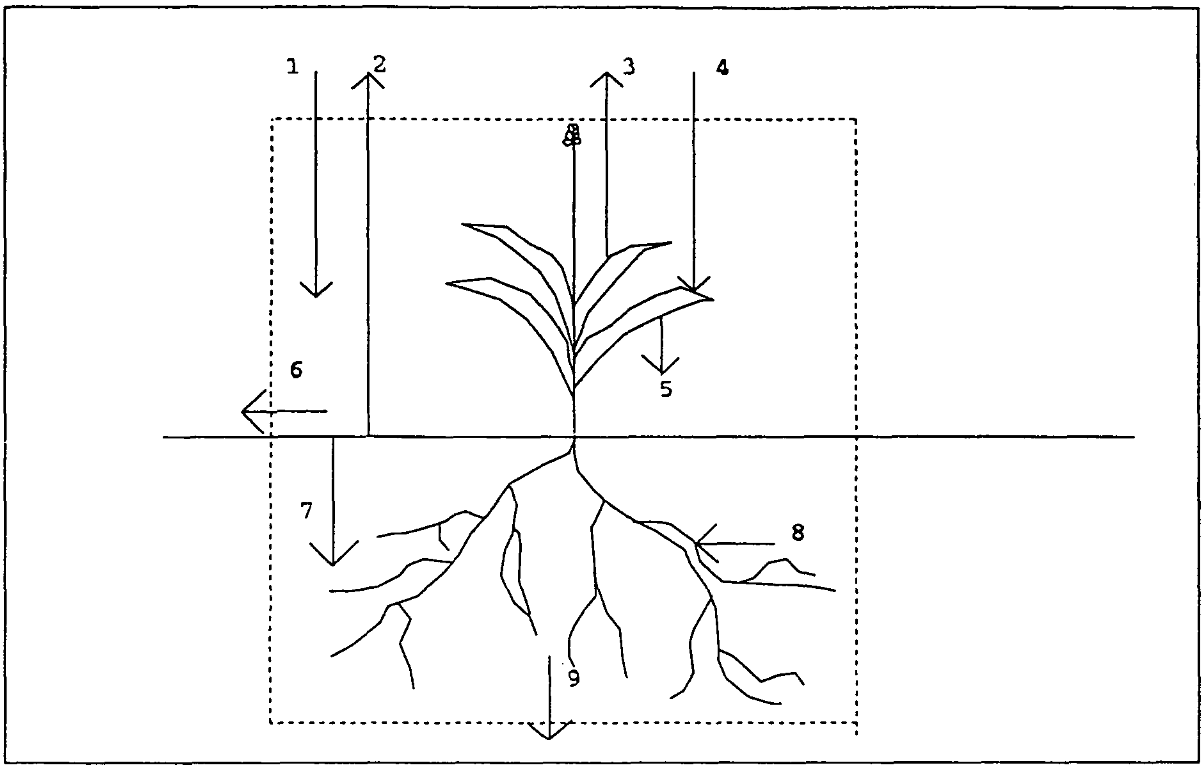

Figure 2.1: Spatial diagram of water flows into, inside the system and from the system. Processes are indicated by numbers: 1. Precipitation, 2. Evaporation, 3. Transpiration, 4. Interception, 5. Throughfall, 6. Runoff, 7. Infiltration, 8. Water uptake by plants, 9. Leaching

2.2.2 Neglected flows

Some assumptions on the boundary conditions and the processes inside the system underlie the model presented above. Each assumption will be treated separately.

Lateral flow

Lateral flow is the horizontal inflow of water from outside the system through the soil due to sloping land. Lateral flow is dependent on the pore distribution, rainfall (and rainfall intensity), clay content and slope. For a accurate estimation of the lateral flow a two-dimensional hydrological model and a extensive measurement network are needed. The slope at Maseno was on average 4.1% (see section 4.1.1.5). Lateral flow will have been small, because of the slight slope and supply will have been similar to discharge. Qualitative influences of lateral flows were also small: Lateral interconnections do not change either the diffusion coefficient nor the permeability (Ball, 1985) and do not influence other fluxes in the system. Lateral interconnections could therefore be ignored.

Capillary rise

Capillary rise is the vertical inflow of water through the soil from the soil layer below the system. Capillary rise is caused by the adhesive and cohesive forces which bind water in capillary pores. The water-solid potential, γ, for soil particles is negative, which means that soil particles will spontaneously attract water. The water is then transported upwards in the profile (Koorevaar et al., 1983). In Maseno the drainage was rather good, a net downward flow occurred during major parts of the year and the groundwater table was deeper than at least 4 m, so capillary rise could not reach the system. Capillary rise was therefore assumed to be zero.

Stem flow

Stem flow is the fraction of rain water that not evaporates, but reaches the soil surface after interception by the canopy. Stem flow is highly dependent on the plant dimensions and rainfall distribution. According to literature the stem flow is reasonably small. Stem flow was 1.8% in an amazonian rainforest (Lloyd and Marques, 1988), within the error of throughfall measurements. Overall contribution of stem flow was very small (Lloyd and Marques, 1988). The amount of stem flow in foliated canopies can be neglected according to Dolman (1987). Because the small contribution of stem flow and because stemflow has no conceptual difference with throughfall for the water balance it was neglected in this study.

Runon

Runon is the horizontal inflow of water from outside the system over the soil surface. Runon is absent in this study, because rain from the upper plots of a terrace was drained off by channels. At the upper part of the terraces the plots were also bordered with a drainage channel. Runon could therefore not occur.

Deep uptake by plants

As described in section 2.1, the soil layer description was restricted to 2m deep. This implicitly means that it was assumed that no plant uptake occurs below 2 m deep. This is not completely true; some deep uptake could have occurred in the weed fallow having roots up to 2.45 m and in the sesbania fallow, where roots went up to at least 4 m deep at the end of the 4th season (Mekonnen, in prep.). Maize roots did not extend further than 1.45 m at maximum. In the weed fallow 99.6% of the root biomass was within 2 m. In the sesbania fallow 93.4% of the root biomass was found within 2 m at the end of the 4th season. Earlier in the experiment this percentage will have been even higher. It was therefore assumed that deep uptake was small. Interactions with the soil system in questions will have been small. Errors occuring in the calculation of evapotranspiration due to deep uptake were probably within the variability due to other errors in the calculation of evapotranspiration and was assumed to be absent.

Foregoing shows that it was reasonable to limit the interaction between the system and its environment to the inflow of rain water and the outflow by evaporation of intercepted water, evapotranspiration, runoff and leaching. All other possible interactions with the environment could assumed to be absent.

2.3 Nitrogen model

2.3.1 General description of the nitrogen dynamics

Nitrogen can occur in different forms. It can be present in the inorganic forms of ammonia (NH_4^+) or nitrate (NO_3^-) in water or soil moisture. Both inorganic forms can be adsorbed to the surface of soil particles, be it under different conditions (see below). It can also be present in an organic form in plant tissue or within the soil organic matter. Within the model three pools are distinguished: Plant nitrogen, organic soil nitrogen and inorganic soil nitrogen. Nitrogen enters the system by dry deposition, wet deposition, non-symbiotic fixation, symbiotic fixation and by seed input. Inorganic nitrogen leaves the system by leaching, runoff and denitrification and organic nitrogen leaves the system by erosion and in harvested products. Generally the sum of output flows is larger in quantity than the sum of input flows, leading to a negative balance (see also Chapter 5). The only major internal flow of inorganic nitrogen is by plant uptake. Most nitrogen is transported in organic form inside the system. A spatial flow diagram of the nitrogen model is presented in Figure 2.2.

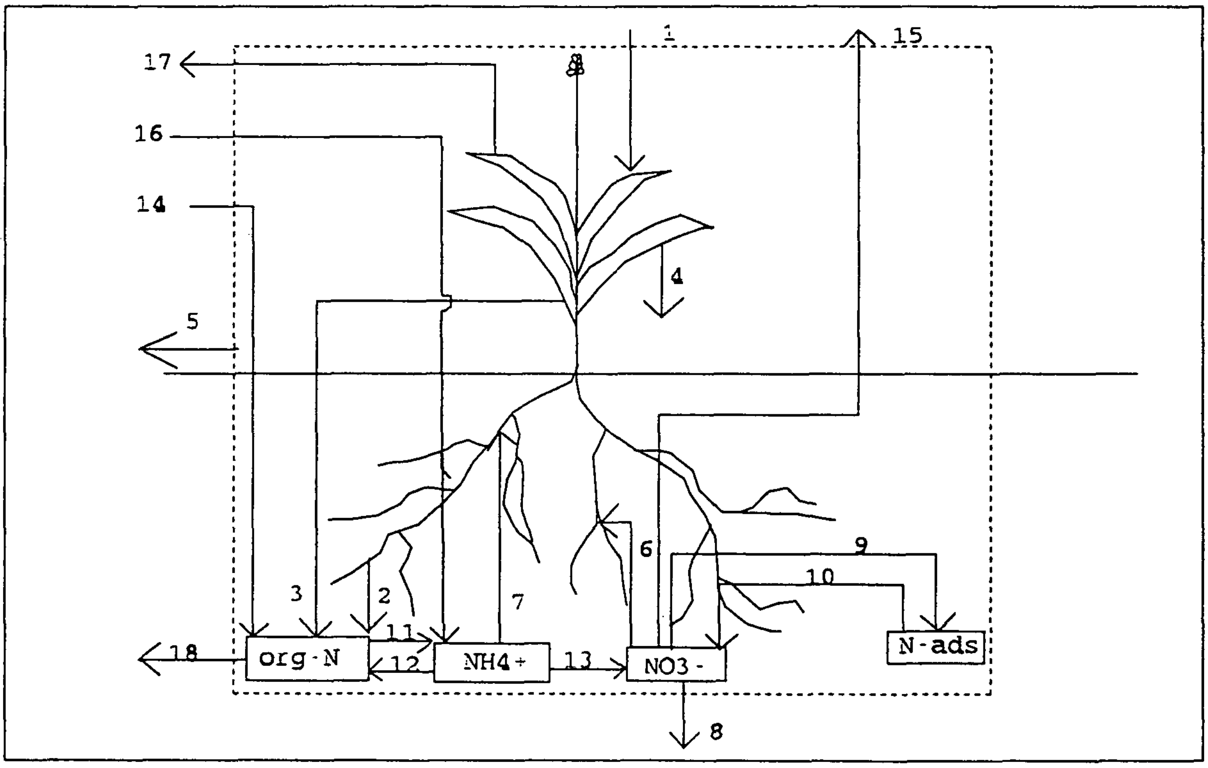

Figure 2.2: Spatial diagram of nitrogen flows to, inside and from the system. Processes are indicated by numbers: 1. Symbiotic fixation, 2. Root mortality and root decomposition, 3. Litterfall and litter decomposition, 4. Nutrient enrichment of wet deposition by plants, 5. Runoff of water soluble nitrogen, 6. Nitrate uptake by plants, 7. Ammonia uptake by plants, 8. Leaching, 9. Adsorption of nitrate, 10. Desorption of nitrate, 11. Ammonification, 12. Immobilisation, 13. Nitrification, 14. Non-symbiotic fixation, 15. Denitrification, 16. Dry deposition and wet deposition, 17. Harvest output, 18. Erosion of (mainly) organic nitrogen

Leaching, non-symbiotic fixation and symbiotic fixation could not be measured and had to be estimated. This gave some problems, particularly for the calculation of symbiotic fixation. A sensitivity analysis for symbiotic fixation was included in the calculations (see Chapter 5). Variability in the calculations on mineralisation, denitrification and harvest will contribute most to the variability of the total system.

2.3.2 Neglected flows

Some assumptions on the border conditions and the processes inside the system underlie the model presented above. Each assumption will be treated separately.

Soil deposition due to runon

Due to the absence of runon, no deposition of soil due to erosion at upper terraces occurred. Neither was runon be able to enrich the inorganic nitrogen pool.

Volatization of NH_3

In alkaline soils at pH > 9.0 (Brady, 1985) and in sandy soils ammonia can be lost in significant quantities due to volatization. This will not be the case in the clayey, acid soils of Ochinga farm. For this reason volatization was set at zero.

Other gaseous losses of nitrogen

Other gaseous losses can be caused by Nitrosomonas producing also small amounts of N_2O during ammonia oxidation but that is not of practical importance. Neither is the chemical denitrification (via urea) (Brady, 1985). Nitrate respiring bacteria can reduce nitrite to ammonia, which must not be confused with denitrification. But this process is not of practical importance either (Anderson and Ingram, 1993). All those gaseous losses were assumed to be absent.

Adsorption and desorption of NO_3^-

The adsorption of nitrate is determined by the AEC (anion exchange capacity). High organic matter contents can decrease the AEC (Cameron & Haynes, 1986). Nitrate is attracted by coulombic attraction of kaolinitic and allophanic materials and protonated hydroxyl groups of Fe- and Al-oxides, which are common at Ochinga farm. Nitrate sorption increases with electrolyte concentration and decreases with increasing pH. Cahn et al. (1992) mention that the sorption increases with depth, as was also found by Hartemink (1994) at Ochinga farm. Nitrate adsorption can be described with a Freundlich-isotherm (Cahn et al.,1992). Not much is known about the dynamics of the process. For simplicity I assume that adsorption is in equilibrium with desorption, implying that the net adsorption rate is zero.

Leaching of nitrate is influenced by the adsorption of nitrate. When nitrate leaches from the topsoil, it can accumulate in the subsoil by adsorption. Leaching is retarded by this process. A retardation factor of 2.4 was calculated for Ochinga farm using nitrate adsorption data presented by Hartemink (1994), meaning that leaching occurred 2.4 times as slow as without nitrate adsorption. The dynamics of leaching were influenced, but potential leaching remained equal. So, adsorption influenced the leaching process, although net adsorption was zero. More on leaching of nitrogen can be found in section 4.2.2.3.

Fixation, adsorption and desorption of NH_4^+

Fixation of ammonia can occur in the hexagonal holes in interlayers of some clay minerals. This especially occurs in clays of the mica type (illites and vermiculites) (Bolt and Bruggenwert, 1978). As these clay minerals only occur in hardly weathered material, it will not occur in the very old soils of Ochinga farm (see also Chapter 3) and fixation was therefore assumed to be zero.

The amount of exchangeable ammonium is a function of the CEC (Cation Exchange Capacity), which is again a function of the pH. The problems with measuring the CEC have been discussed by Landon (1991). At the rather low pH of Ochinga farm, the effective CEC was rather low. Analogous to nitrate adsorption, net exchange rate was assumed to be zero. Besides, exchangeable NH_4^+ can't be distinguished from ammonium in the soil solution, when extracting the soil with 2 M KCl (Buresh, pers. comm.). It was assumed that these processes don't play a significant role in the nitrogen dynamics.

Deep uptake by plants

As described in section 2.2 little deep uptake below 2 m can have occurred during the 4th season in the sesbania fallow. Earlier in the experiment this is even less likely. Potentially it can have occured in the weed fallow, but these changes are very small, as can be concluded from root biomass data. In the maize fallow, deep uptake below 2 m deep can't have occurred. It was assumed that deep uptake was small. Errors due to ignoring of this deep uptake may have had some influence on the calculation of inorganic nitrogen storage. In the calculations it is assumed that all nitrogen comes out of the inorganic nitrogen pool, underestimating its pool size. The errors occurring due to this assumption are probably within the variability due to other errors in the calculation of inorganic nitrogen, like soil mineralisation, and will assumed to be absent.

The foregoing shows that it was reasonable to limit the interaction between the system and its environment to the inflows and outflows described in section 2.3.1. All other possible interactions with the environment could be assumed to be absent.

2.4 Phosphorus model

2.4.1 General description of the phosphorus dynamics

Phosphorus can also occur in different forms. It can be present in the inorganic form in rain water or soil moisture as phosphate (PO_4^{3-}). The inorganic form can be adsorbed to the surface of soil particles. It can also be present in an organic form in plant tissue or within the soil organic matter. Within the model four pools are distinguished: Plant phosphorus, organic soil phosphorus, adsorbed soil phosphorus and inorganic soil phosphate. Phosphorus enters the system by dry deposition and wet deposition in inorganic form and by seed input in an organic form. Inorganic phosphorus leaves the system by runoff and erosion (by phosphorus in minerals) and organic phosphorus leaves the system by erosion and in harvested products. Generally the output flows are larger in quantity than the input flows, leading to a negative balance (see also Chapter 5). The major internal flow of inorganic phosphorus is by plant uptake. Most phosphorus is transported in organic form inside the system. A spatial flow diagram of the phosphorus model is presented in Figure 2.3.

Rock weathering, mineralisation, adsorption and desorption kinetics could not be measured and had to be estimated. This will give only minor problems, because these processes have only a small contribution in the total system, only mineralisation has a large influence and will be treated to a larger extent. Variability in the calculations on mineralisation and harvest will contribute most to the variability of the total system.

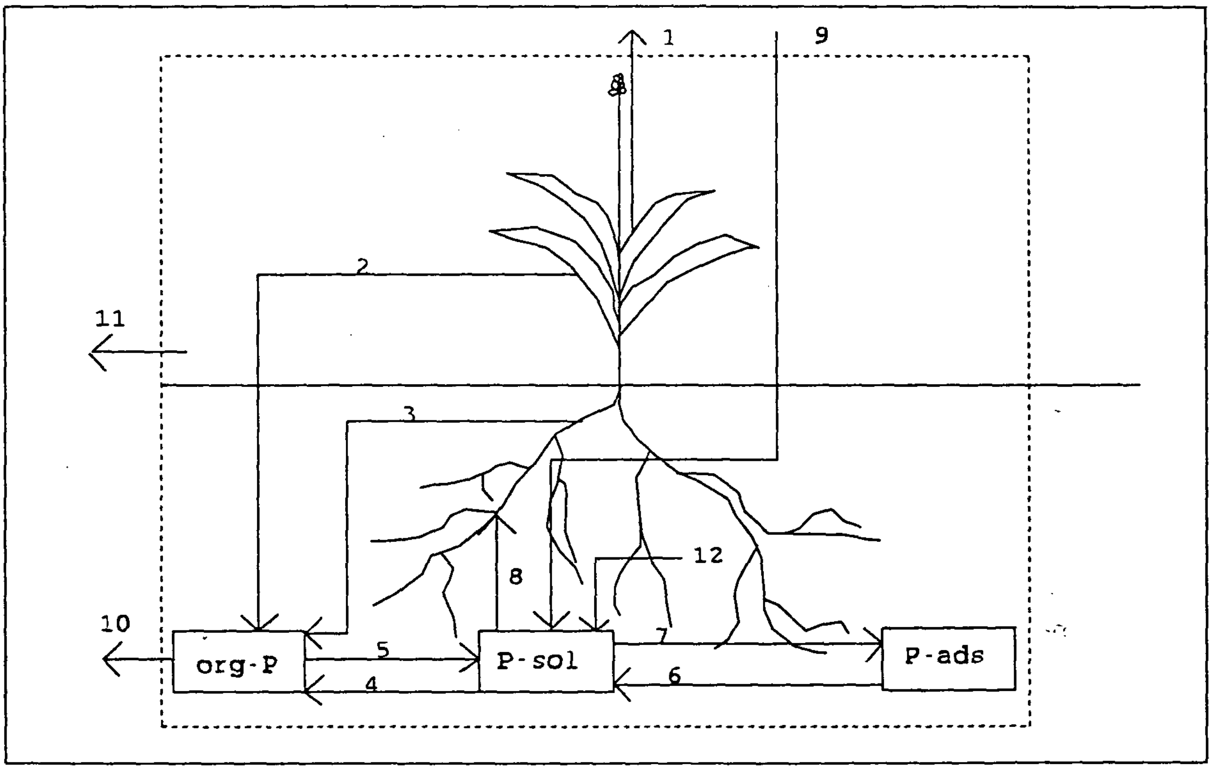

Figure 2.3: Spatial flow diagram of phosphorus to, inside and from the system. Processes are indicated by numbers: 1. Harvest output, 2. Litterfall and litter decomposition, 3. Root mortality and root decomposition, 4. Immobilisation, 5. Mineralisation, 6. Desorption of phosphate, 7. Adsorption of phosphate, 8. Plant uptake of phosphorus, 9. Dry deposition and wet deposition, 10. Erosion of (mainly) organic phosphorus, 11. Runoff, 12. Rock weathering

2.4.2 Neglected flows

Some assumptions on the border conditions and the processes inside the system underlie the model presented above. Each assumption will be treated separately.

Leaching of phosphorus

It is assumed that no leaching of phosphorus occurred, a reasonable assumption according to Stoorvogel and Smaling (1990). Leaching of phosphorus is absent, because the very low phosphorus concentrations in the soil solution. This is caused by the high adsorption, indicated by its high adsoprtion coefficient, K_a (Noordwijk, 1989). Phosphorus is very fixed and that no leaching could occur.

Adsorption and desorption of phosphorus

Similar to the adsorption of nitrate, adsorption of phosphorus is also determined by the AEC (anion exchange capacity). Phosphorus is attracted by coulombic attraction of kaolinitic and allophanic materials and protonated hydroxyl groups of Fe- and Al-oxides to a much higher extent than nitrate and is fixed strongly.

Phosphorus sorption increased with depth at Ochinga farm (see also Chapter 5). Not much is known about the dynamics of the process. Phosphorus adsorption at Ochinga farm had been determined, but the value of those data is questionable. To measure phosphorus adsorption soil aggregate structure was destructed, while soil aggregate structure and aggregate stability influence phosphorus adsorption. Due to the destruction, phosphorus adsorption is probably overestimated as surface area of the soil and hence sorption sites for phosphorus increase by crushing (Linquist et al., 1994). These determination problems are of minor importance for nitrate sorption, because nitrate sorption is of greatest importance in the subsoil while aggregation is not so important in the subsoil (Buresh, pers. comm.). Phosphorus availability, phosphorus sorption and aggregation are all of greatest importance to crop growth in the top soil layer. Aggregation problems are therefore much larger for phosphorus.

Besides, measurement of phosphorus adsorption will probably not be sufficient as a site characteristic, because different treatments will have a different aggregate stability and therefore different amounts of phosphorus will become available.

It was also tried to measure phosphorus desorption as a site characteristic to get more insight in soil phosphorus dynamics. It was tried to use an (unrevised) methodology for the measurement of phosphorus desorption described by van der Zee et al. (1987) and Raven and Hossner (1993) to allow comparison with literature. The methods did not give satisfactory results so far, so no data are available yet.

For simplicity, net adsorption rate was assumed to be zero until the methodology problems are solved, similar to nitrate adsorption. It has to be kept in mind however, that the adsorbed phosphorus is an enormous stock of inorganic phosphorus, but that this stock can hardly be used by the plants as long as the inorganic phosphorus in the soil solution remains similar. Verification of this assumption takes place in Chapter 5 when treating measured changes in inorganic soil phosphorus.

Deep uptake by plants

Similar to the nitrogen plant uptake and with the same arguments, described in section 2.3.2, it was assumed that phosphorus uptake form soil layers below 2 m did not occur.

Errors due to ignoring of this deep uptake may have had some influence on the calculation of inorganic phosphorus storage. In the calculations it was assumed that all phosphorus comes out of the inorganic phosphorus pool, underestimating its pool size. The errors occuring due to this assumption are probably within the variability due to other errors in the calculation of inorganic nitrogen, like mineralisation and adsorption/desorption of phosphorus, and was assumed to be absent.

The foregoing shows that it was reasonable to limit the interaction between the system and its environment to the inflows and outflows described in section 2.4.1. The assumptions related to adsorption and desorption processes of phosphorus are most weak of the assumptions related to processes inside the system. All other possible interactions with the environment could assumed to be absent.

Part II: Data collection and assessment on the processes

Chapter 3: Materials and methods

3.1 Environment

3.1.1 Climate

The experiment took place at Ochinga farm, Vihiga district, which is situated in the highland of Western Kenya at an altitude of 1420 m. The Agro-Ecological Zone to which Ochinga farm belongs is the Tea-Coffee Zone with permanent cropping posibilities (UM1), dividable in two cropping seasons (Jaetzold and Schmidt, 1982). Rainfall is bimodal with for 1994 an total of 1930 mm (The Tea-Coffee Zone has an annual rainfall ranging from 1600 to 2000 mmyr^{-1}). The long rains start in March and end in May, followed by a dry spell till about August. The short rainy season starts in September and lasts till the beginning of December. January and February are usually dry months.

The location of the farm near the equator leads to high radiation levels at a low zenith angle. Wind direction is variable and wind speed is low due to the absence of strong monsoon winds.

3.1.2 Land use systems

The area in which this study was conducted, the highlands of Western Kenya, has a high agricultural potential due to climatic cicumstances, but soil depletion is quite severe. Especially phosphorus and nitrogen are strongly limiting. The area has a subsistence-level mixed crop/livestock farming system. The major crops are maize (mostly unimproved varieties), millet, beans, cassava, bananas, sweet potatoes, groundnuts and sorghum (Shepherd et al., 1993). The land use system was coded P.R.L. 1 with no manure and low fertilizer input (Stoorvogel and Smaling, 1990). Cattle (mostly unimproved breeds of zebu) are kept mainly as a source of liquid capital, though there is increasing interest in small-scale dairying. Land tenure is mostly secure as most land has been purchased (Sands, 1983).

Western Kenya is a densely populated area with permanent small holdings. The original vegetation has practically disappeared (Wielemaker and Boxem, 1982). Average farm size ranges from 0.5-2.0 ha (with a median of 1.2 ha) (Ohlsson et al., in prep.) and the population density varies from 300 to over 1000 persons km^{-2} in some areas (KEFINCO, 1990). In spite of this, half of the farmers do allow their land to lie fallow. Households engaged in agroforestry testing trials in the area fallow 10-20% of their main farm every year. Farmers who allow land to lie fallow have a significantly larger farm size, have significantly higher sources of off-farm income and have a lower labour/land ratio than those who do not (Ohlsson et al., in prep.). The most common reasons to fallow is to allow soil fertility to restore and lack of labour. The length of the fallow varies from one season (13%), one year (18%) or two or more years (21 %). The remaining 58% of the land is not fallowed. Again farm size plays a role in deciding the length of the fallow.

Three quarters of the farmers reported that they have some *Sesbania Sesban* in the cropland where it often grows naturally and is left at a wide spacing by farmers when weeding the crops.

These farmers have a higher labour/land ratio. A fifth of the farmers scatter sesbania seeds in the cropland, in addition to the windsown sesbania seeds. The main purpose of this practice is firewood production, but farmers are also aware of the benificial effects of this tree on soil fertility (Ohlsson et al., in prep). No farmer reported sowing sesbania at high densities at the start of a fallow (ICRAF, 1993). To see any effect of weed decline farmers claim to need at least five year to fallow.

3.1.3 Soils

The landscape is gently undulating, dominated by Acrisols, Nitisols and Ferralsols (FAO/UNESCO) (Andriesse and van der Pouw, 1985). The hills are mostly remnants of older erosion surfaces (Wielemaker and Boxem, 1982). The soils are very deep (> 4 m), well drained and have clayey textures throughout the profile.

For Ochinga farm, Hartemink (1994) used Landon (1991) to describe the soil fertility status: Topsoils (0-16 cm) have a rather low pH and extermely low levels of available phosphorus. Organic carbon contents are moderate according to Janssen (WAU, pers. comm.). Levels of exchangeable bases are high for magnesium, medium for calcium and low for potassium. The cation exchange capacity (CEC) of the topsoil is low to moderate. Subsoils have a medium soil reaction and medium levels of exchangeable calcium and magnesium, while the levels of exchangeable potassium are very low. The levels of exchangeable phosphorus are extremely low in the subsoils. More information about total nitrogen and phosphorus levels in the soil and the dynamics of soil organic nitrogen can be found in Chapter 5. More specific information about soil inorganic nitrogen can be found in section 4.2.1.10.

The soils were classified as very fine, kaolinitic, isohyperthermic Kandiudalfic Eutrodox (USDA-Soil Taxonomy).

Table 3.1: Physical properties of the soils at Ochinga farm

depth (cm)	bulk density (g/cm^3)	moisture volume fraction at pF			Soil porosity	Available moisture (mm)
		0.0	2.0	4.2	(-)	
0-15	1.10	0.561	0.301	0.181	0.585	18.0
15-30	1.22	0.569	0.367	0.229	0.54	20.7
30-50	1.25	0.516	0.383	0.24	0.528	28.6
50-100	1.32	0.601	0.376	0.258	0.502	59
100-150	1.28	0.492	0.383	0.254	0.517	64.5
150-200	1.29	0.523	0.383	0.254	0.513	64.5

A number of basic soil physical properties are presented in Table 3.1 (modified after Hartemink (1994)). Values presented in this table will be used in this study for several calculations. Field capacity is assumed at pF=2, a good estimate for oxisols according to Sanchez (1976) and Harry Booltink (WAU, pers. comm.). The topsoils are moderately to weakly structured and vulnerable to splash erosion (Hartemink, 1994). Bulk density was determined several times during the 2nd, 3rd and 4th season. Note that soil porosity, based on bulk density measurements, is lower than the moisture content at pF=0.0 in some layers. This is an indication of overestimation of the bulk density. A more extensive discussion about these bulk density determinations can be found in Appendix II. Unsaturated hydraulic conductivity varies between 0.5 and 0.8 md^{-1} for the profile (Hartemink, 1994). Saturated hydraulic conductivity was determined using the constant head method. Braun (1995) presents 1.8 md^{-1} (0-15 cm), 3.0 md^{-1} (15-30 cm), 1.3 md^{-1} (150-150 cm) and 1.2 md^{-1} (150-200 cm). The conductivities presented for the first layer seem to be low, compared to qualitative visual observations (not presented). Infiltration rates were also measured, results will be presented in section 4.1.1.4.

3.2 Experimental design

The NM1 experiment consists of a randomized complete block design with 4 treatments (land-use systems) and 4 blocks. The blocks are laid perpendicular to the slope, along which most differences in soil characteristics are to be expected. Each block contains 4 plots of 10*10 m^2 located on two approximately 20 m wide terraces. A lay-out of the experimental field of NM1 is presented in Appendix I.

A land-use system is defined as a combination of land utilization type and land unit. The land utilization types investigated in this experiment are: sesbania fallow, maize (*Zea Mays*), weed fallow and bare fallow. The bare fallow treatment serves as a control to assess the potential magnitude of inorganic nitrogen formation and loss. Differences in nutrient dynamics between the bare fallow and other treatments can be caused by the absence of vegetation and differences in water dynamics. Maize serves as a control of a continuous cropping system. The land unit was equal to the plot size mentioned.

The experimental area was uniformly cropped with maize (Hybrid 512) for one short rainy season (September 1992 to February 1993). Before the experiment started in March 1993 the area was uniformly ploughed, after which plant residues and weeds were removed. During the first season a uniform maize crop (Hybrid 512) was planted and thinned to a density of 53,330 plants ha^{-1} (0.75*0.25 m^2) The plots were regularly weeded. On 29th April 1993 *Sesbania Sesban* (Provenance K7) was directly seeded at treatment 1 and had a density of 11,000 plants ha^{-1} (0.4*2.25 m^2) after thinning. At the end of the first season, after maize harvest, all plots were uniformly tilled by hand (stover was removed). During the 1993 short rains the sesbania fallow was weeded, but this was stopped during the 1994 long rains to create a system a farmer would realise (Ohlsson et al., in prep.). The borders of the sesbania plots were regularly trenched to avoid root interference in neighbouring plots.

Treatment 2 continued with the same maize cropping system during the 2nd, 3rd and 4th season. From 1 september 1993 the weeds were left to grow in treatment 3. In the bare fallow (treatment 4) weeds were frequently removed by hand pulling.

After maize harvest of 9 January 1995 and biomass assessment of the weed fallows and sesbania fallows of 16 January 1995, all fallows were cut down. Sesbania stems were removed, while all litter was left to fall in the plots. At the end of February all dead plant material was incorporated in the soil (a common practice along farmers (Ohlsson et al., in prep.)) and the bare fallows and maize plots were tilled to achieve a uniform tillage among treatments. During the 1995 long rains (see Table 3.2) the residual effects of the removed fallow on maize growth will be assessed. An additional root study will be carried out to obtain more information about root mortality, root conversion and root channeling.

Table 3.2: Treatments of 5 growing seasons of experiment NM1 at Ochinga farm

	1993 long rains	1993 short rains	1994 long rains	1994 short rains	1995 long rains
treatment	1st season	2nd season	3rd season	4th season	5th season
1	maize/ sesbania	sesbania fallow	sesbania fallow	sesbania fallow	maize
2	maize	maize	maize	maize	maize
3	maize	weed fallow	weed fallow	weed fallow	maize
4	maize	bare fallow	bare fallow	bare fallow	maize

3.3 Materials and Methods

All methods described in this chapter are described more extensively by Jama et al. (in prep.).

3.3.1 Water dynamics

Inputs:

3.3.1.1 Rainfall

Several manual raingauges have been installed at the Ochinga farm spread over all experimental areas. Their positions are indicated in Appendix I. Every morning at 9.00 am the collected rainfall was measured manually with a calibrated measuring cylinder (in mm). Besides, a automatic weather station (from Delta-T Devices Ltd, Burnwell, Cambridge, UK) has been installed at the lowest terrace of the Ochinga farm. Part of this station is a rain gauge connected to the logger registering data at half hour intervals. Other parameters measured at the station are: global radiation, relative humidity, air temperature, soil temperature (at 5, 20 and 50 cm deep), wind speed and wind direction. To be able to compare the met data with the manual data, a day is defined starting at 9.00 am and ending 9.00 am the next day. Every 10 days the logger was downloaded with the aid of LOGGER, a computer program from the same company.

Internal:

3.3.1.2 Soil moisture storage

Measurements of gravimetric moisture contents and inorganic nitrogen up to two meter deep (taking composite samples from six depths:0-15, 15-30, 30-50, 50-100, 100-150 and 150-200 cm) were carried out at all four treatments in six sampling rounds during the short rains season of 1994 (at 8-9-1994, 11-10-94, 3-11-1994, 22/23-11-1994, 13-12-1994 and 13-1-1994). The fourth sampling round went up to four meters deep (with additional composite samples from 200-250, 250-300, 300-350 and 350-400 cm). Only data up to 2 m deep are presented in this report. The period between two sampling rounds is between three and four weeks, depending on the amount of rain (The period between two sampling rounds was about 150 mm of rain.).

In the sesbania fallow soil samples were taken at three equivalent sampling locations perpendicular to the sesbania rows (meaning three transects per plot). Each sample consisted of six sub-samples. The distance between two locations was 37.5 cm (See Figure 3.1).

	sesb							sesb
	#	1	2	3	3	2	1	#
distance(in cm):	0	19	46	84	121	159	196	225

Figure 3.1: Sampling locations for the sesbania plots

In maize, weed fallow and bare fallow, 16 sampling locations perpendicular to the maize rows were distinguished with a distance of 37.5 cm between the locations. At each sampling round, eight locations were sampled (in pairs) (See Figure 3.2). After having sampled all locations the sampling line was moved 40 cm. Details of the sampling method are described by Braun (1995).

Maize rows	X	X		X		X		X		X		X		X		X		X		X		X		X
Sampling loc.		*	*	*	*			*	*	*	*			*	*	*	*			*	*	*	*	
Sampling time		A	A	B	B			A	A	B	B			A	A	B	B			A	A	B	B	

Figure 3.2: Sampling locations for maize, weed fallow and bare fallow plots

The method underwent some minor changes in sampling locations at the plots 23 (bare fallow), 44 (bare fallow) and 11 (maize). In these plots the eight locations of the lower slope have been removed and every sampling round all remaining eight locations were sampled. After each sampling round the locations were moved 20 cm. This has been done because of interference of sesbania roots (in the maize plot) and because of deposition of eroded material downslope (at the bare fallows).

The samples were analysed for moisture and extractable ammonia and nitrate.

3.3.1.3 Throughfall and Interception

Throughfall was measured in the sesbania plots only. In each plot five labeled jerrycans with funnels of a diameter of 30 cm (with a mesh sieve inside to avoid contamination of plant material) were installed between two rows of trees. The jerrycans were placed in such a way that all of them covered a same area in a representative way (See figure 3.3). Each two weeks the jerrycans were relocated between two other pairs of sesbania trees to reduce the total sampling error (Lloyd and Marques, 1988).

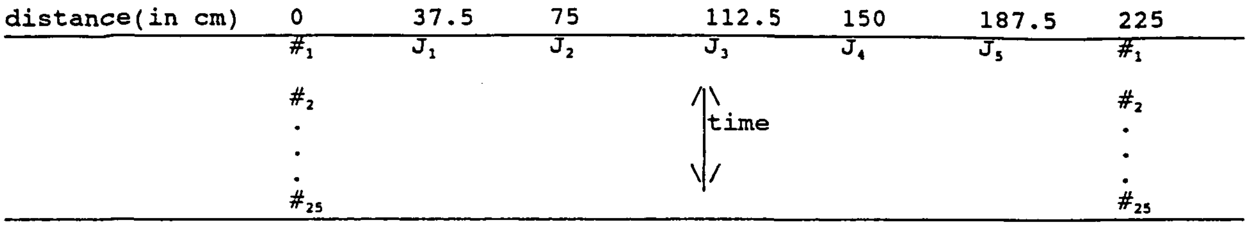

Figure 3.3: Field situation for the throughfall experiment. $\#_i$ is the i^{th} sesbania tree in the row and J_i is the i^{th} jerrycan.

Every morning at the same time the jerrycans were collected and their contents were measured using a measuring cylinder. The throughfall is expressed in mm:

$$Throughfall_{mm}=Throughfall_{ml}*\frac{10}{\pi(0.5*Diameter)^{2}} \qquad (1)$$

In which *Diameter* Diameter of the funnel in cm (= 30 cm)

The throughfall per sesbania plot has been calculated as the average of the five funnels (because they all represent the same area between the sesbania rows). The throughfall was also investigated as a function of the distance from the tree.

Part of the rainfall that is intercepted by the canopy leaves evaporates directly from the leaves (Noij et al., 1993 and Lloyd and Marques, 1987 among others) and is not available for the soil. The interception is dependent on, among others, rainfall, rainfall intensity and LAI. The interception of rainfall is, assuming that stemflow is absent, equal to:

$$Interception_{mm}=Rainfall_{mm}-Throughfall_{mm} \qquad (2)$$

The throughfall and interception have been expressed as a percentage of the rainfall to apply multiple regression.

3.3.1.4 Infiltration

The infiltration rate can be calculated in the sesbania and weed plots with the use of runoff and throughfall data. To try to extrapolate these data to the other treatments, the infiltratrion rates were also measured directly. A method modified from Landon (1991) was used. The infiltration rates were determined in a pre-wetted soil by measuring the flux of water from a calibrated jerrycan. On the outside of the jerrycan marks were made indicating units of 100 ml of water.

The soil at the site (with a surface area of 1*1 m2) was completely soaked to a depth of about 80 cm for 3 hours (consuming on average 200 l.) After wetting two sets of double rings were installed (for a duplicate measurement) by hammering down to 20 cm deep uniformly and exactly vertically avoiding cracking. Soil on the inside and outside of both rings was firmed and leveled to the ring. Any space between the ring and the soil level was filled with cement to avoid outflow and leaching of applied water. Numbered, water filled, calibrated jerrycans were connected to the inner ring.

The outer rings and inner rings were filled with water by throwing water on a sponse (in the innerring) to avoid splash erosion. After reaching a water level of 5 cm in the inner ring the sponse was removed and a water filled tube connected with the jerrycan was inserted in the water of the inner ring. The height of the jerrycan was adjusted to support a constant water level. The actual measurement was started at exactly this moment (t=0).

During the measurement, water from the jerrycan infiltrated in the soil of the inner ring. The water level in the jerrycan was read and recorded at the following moments (time in minutes): t=0, t=2, t=5, t=10, t=15, t=20, t=30, t=45, t=60, t=90, t=120, t=150 and t=180. The water level in the inner ring was kept constant by adjusting the height of the jerrycan. During the measurement the water in the outer ring was also kept at a constant level (the same level as in the inner ring, being 5 cm) by pouring water from buckets in this ring. This water was not taken into account for the calculations.

In the period from 1-2-1995 to 10-2-1995 the infiltration rates were measured in maize (in plots 31 and 42), in the bare fallow (in plots 14,23 and 33) and in weed plots 32 and 43.

The infiltration rate was calculated in ml/interval during the measurement. The infiltration rate in $cmhr^{-1}$ was calculated by:

$$Infiltrationrate = \frac{Infiltrated*60/Interval}{\pi*0.5*Diameter^2} \qquad (3)$$

In which		
	Diameter	Diameter of the inner ring of measurement
	Interval	Interval in minutes between two measurements
	Infiltrated	The infiltrated amount of water (in ml) between two moments of measurement

The cumulative infiltration F was calculated by:

$$F = \frac{\Sigma(Infiltrated_{0..end})}{\pi*0.5*Diameter^2} \qquad (4)$$

The maximum rate of infiltration and the basic rate of infiltration were read from the graph relating infiltration rate to time. The maximum rate rate of infiltration takes place at the beginning of the measurement. The basic rate of infiltration is the constant infiltration achieved after a considerable infiltration period. The relation was described in two ways by plotting the relations $F=a*time^n$ and by using the Philip equation $F= a*\sqrt{time} + b*time$.

Outputs:

3.3.1.5 Runoff

slope determination

Runoff is a function of the slope. The slopes of each plot seperately were measured with a land survey instrument (from GKO Kern aarau). With this instrument the height differences at two locations on the slope (in the direction of the gradient) is taken very accurately. The slope can be calculated easily by combining this with the distance between the two locations.

The slope in percentage gradient is (through the low gradients; $\sin\alpha = \alpha$):

$$Slope=\frac{(Backside-Foreside)}{Distance}*100 \qquad (5)$$

In which:		
	Backside	The height reading (in m) at the backside location
	Foreside	The height reading (in m) at the foreside location
	Distance	The distance (in m) between the backside and the foreside location measured along the soil surface

Collection of runoff water

Runoff plots were installed in the sesbania plots and the weed plots during the long rains season of 1994 by A. Braun, using the method described by Njoroge (1994) based on the principle presented in Edwards et al. (1974). This was done to determine the amounts of runoff water, sediments and nutrients in the runoff water. Runoff water was collected in a so-called tipping bucket. Once filled it tipped over the contents of the bucket and this amount was recorded with magnetic counters, recording the amount of tips. When tipping a small amount of the runoff water was collected by a sampling pipe for sediment collection (see 3.3.2.10).

Every morning at 9.00 am the amount of runoff was determined by recording number of tips and by collecting the amount of runoff water remaining in the tipping buckets. After collection the amount of runoff water was determined with the aid of a measuring cylinder of 1 l..

The amount of runoff in liters ($Runoff_l$) is equal to:

$$Runoff_l=(Tips*Bucket)+water_{remaining} \qquad (6)$$

In which		
	Tips	The amount of tips recorded.
	Bucket	The amount of water (in liters) the tipping bucket can contain before tipping.
	$Water_{remaining}$	The amount of water remaining in the tipping bucket after a runoff event in liters.

The amount of runoff in mm ($Runoff_{mm}$) is equal to:

$$Runoff_{mm}=\frac{Runoff_l}{Area} \qquad (7)$$

In which *Area* The size of the runoff plot in m2 (is 9*3 = 27 m^2).

The tipping bucket tips when its contents exceeds about 3 l of water. The buckets have not necessarily the same size and were therefore calibrated seperately plot by plot. The intensity of the rain did not have a direct influence on the amount of water the tipping bucket can contain before tipping (No significant difference on a 95%-confidence interval was found). A dynamic calibration as described by Calder and Kidd (1978) was therefore not necessary, probably because the number of tips per minute was always much lower than 1 and hence the error induced by the flow rate was smaller than 2% (Edwards et al., 1979). The calibration was repeated three times to determine an average value and statistical deviation. Results are shown in Table 3.3.

Table 3.3: Calibration results of the runoff tipping buckets. All amounts are in milliliters. Data were collected by A. Braun and P. van Bodegom.

plot	left bucket	right bucket	sampling pipe
12	2960	2950	29
13	3360	2980	49
21	3315	3325	35
22	3525	3280	50
32	3285	3230	49
34	2970	3185	25
41	3210	3165	26
43	3285	3330	33

3.3.1.6 Plant growth

LAI measurement

The LAI (Leaf Area Index) is the area of leaves per area of soil cover (both in m^2), and it is used as an indirect measure of the aboveground biomass. LAI can be determined non-destructively with the ceptometer. Principally the method consists of measuring the ratio of the Photosynthetic Active Radiation (PAR) above the canopy and the PAR below the canopy. This ratio is directly related to the LAI. The PAR is measured and averaged over a length of 80 cm. The ratio of light penetrating the canopy (τ) is:

$$\tau=\frac{PAR_{below}}{PAR_{above}} \tag{8}$$

To be able to measure at any time during the day, it is necessary to make some corrections for diffuse light and zenith angle (as can be seen in eq. 11). The fraction of diffuse light is the ratio of the PAR in the shade and the PAR in full light. Both are measured with the ceptometer (Under an overcast sky the fraction of diffuse light is one.). The fraction of light coming from the direct beams is:

$$F_{direct}=1-F_{diffuse} \tag{9}$$

Including the measurement of the zenith angle (by measuring shade lengths of a perfectly vertically placed stick) facilitates measurements throughout the whole day. The zenith angle can be calculated as follows:

$$Zenith=atan(\frac{Shade_{length}}{Stick_{length}}) \tag{10}$$

If there is no direct sunlight the zenith angle has to be calculated with the use of meteorological formulas (see annex 1).

From these parameters the LAI can be calculated by the extensive formula:

$$LAI=\frac{(1-0.122*\sqrt{1+\tan(Zenith^2)})*F_{direct}*\ln(\tau)}{(0.861)*(1-0.47*F_{direct})} \qquad \textbf{(11)}$$

The sampled areas have to be representative for the total area. This makes the procedure dependent on the type of plant sampled. Under maize the measurements were taken diagonally, sawtooth like, between the maize rows to eliminate the influence of shade patterns (see Figure 3.4).

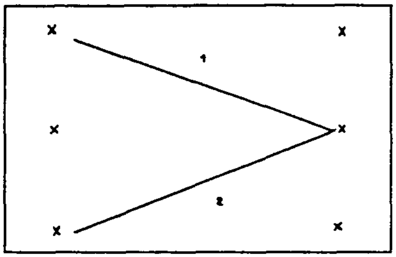

Figure 3.4: Measurement of LAI in maize (maize plants indicated by 'x'). A line represents the light cells of in total 80 cm of the ceptometer.

In the sesbania plots the measurements were taken diagonally, sawtooth like (analogous to maize) at five equal distances from the hedgerow. In the randomly distributed weeds the measurements were taken randomly. The measurements were repeated 5 times per plot for a statistical relevant measurement.

The LAI was measured at 17-9-1994, 5-10-1994, 19-10-1994, 2-11-1994, 16-11-1994, 7-12-1994, 15-12-1994, 20-12-1994 (only maize) and 9-1-1995 (at the harvest of the maize).

Calibration of the LAI-ceptometer

The relationship between LAI and input parameters given in the section above was checked. An experiment was carried out to determine the relationship between leaf area index (LAI) obtained with the ceptometer readings and actual (destructive) measurements of the LAI.

Two similar methods were used to determine this relationship.

Method 1 (carried out at 11-11-1994):

The LAI of the maize crop was determined with the Ceptometer at four seperate locations of different densities. These densities were created manually by selective thinning. The measurements themselves were taken in an area of uniform maize growth of $3.75*3.75\ m^2$.

After measurements all maize plants were harvested and total fresh weight of the leaves per selected location was determined. After weighing five leaves from each harvest were selected randomly. From each of the selected leaves 10 cores of 1.95 cm diameter were punched. This gave a total of 50 punches per replicate. The punches were collected in a polythene bag with a moist paper and transproted to the station. At the station fresh weight of the 50 punches was taken with a balance (sensitively: to 1 mg accurately).

The area of the punches was calculated and related to the total leaf area (in m^2) with:

$$LeafArea=\frac{FreshWeight_{total}}{FreshWeight_{punch}}*50*10^{-4}*\pi*(1.95/2)^{2} \qquad (12)$$

LAI is easily calculated as:

$$LAI=\frac{LeafArea}{3.75^{2}} \qquad (13)$$

Method 2 (carried out at 9-1-1995):

Four different plant densities at one location (of initially 15*5 plants making 3.75*3.75 m^2: The distance between plants was 0.25 m and the distance between the rows was 0.75 m.) instead of four separate locations were used. A special scheme of subsequent thinning was used for this purpose, see Table 3.4.

Table 3.4: The method of thinning for the LAI calibration (2nd method). The numbers indicate the positions of the maize plants and the moment of thinning (number 1 was thinned first).

2	1	3	2	1	4	2	1	3	2	1	4	2	1	3
2	1	4	2	1	3	2	1	4	2	1	3	2	1	4
2	1	3	2	1	4	2	1	3	2	1	4	2	1	3
2	1	4	2	1	3	2	1	4	2	1	3	2	1	4
2	1	3	2	1	4	2	1	3	2	1	4	2	1	3

Before each thinning was carried out, the LAI was measured with the ceptometer. At the end also the LAI of the bare soil was measured. The total fresh weight (of the leaves) of each thinning was determined and punches of each thinning were taken in the same way as described above. The advantages of this method are that less crop is used and that the variability in the measurements is less. The disadvantages, however, are the more complicated administration and calculations.

For this method, the total leaf area is the sum of the total fresh weights belonging to a certain original density. The fresh weights of the punches are also summed. Of course an correction for the amount of punches has to be taken into account too.

$$LeafArea_{i}=\frac{\sum FreshWeight_{total_{(1..i)}}}{\sum FreshWeight_{punch_{(1..i)}}}*50*i*10^{-4}*(1.95/2)^{2} \qquad (14)$$

The LAI is calculated in the same way as in method 1.

Linear regression analysis was applied to the measurements obtained with the ceptometer and those from the punches. The regression equation obtained would be used to correct for any over- or under-estimations in LAI measurements by the ceptometer, but that turned out not to be necessary, see Figure 3.5, and the measured data of the ceptometer have been used in all calculations without correction.

Determination of plant dimensions

Throughout the season some plant dimensions were measured to have some other non-destructive measurements of the standing biomass. The heights of the highest weeds in the weed plots and the height and crown diameter of the canopy of the sesbania trees in the sesbania plots were measured at 15-9-1994, 2-11-1994 and 5-12-1994. The height was determined by measuring shade length of the tree against the shade length of a stick:

$$Height_{tree} = Shade_{tree} * \frac{Height_{stick}}{Shade_{stick}} \quad (15)$$

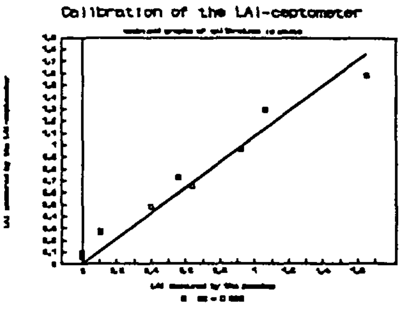

Figure 3.5: Calibration of the ceptometer measuring the LAI in maize

The stem diameter of sesbania trees was measured at 20-12-1994 and 12-1-1995. The stem diameters were determined with a vernier calliper at 30 cm (base diameter) and at breast height (because of the multiple stems). All plants were randomly selected each time. The results have been compared to former seasons to determine the growth and development.

Height, width and number of leaves of maize plants were determined at 15-9-1994, 5-10-1994, 19-10-1994, 2-11-1994, 18-11-1994, 15-12-1994 and 9-1-1995. These data were used for the evapotranspiration calculations.

3.3.2 Nitrogen and phosphorus dynamics

Inputs:

3.3.2.1 Seeds

In maize plots and sesbania fallow, seeds containing some nutrients were added to the soil. This nutrient input was determined by taking a representative sample of 200 seeds of sesbania and 40 seeds of maize. The seeds were dried in two batches and analysed for nitrogen and phosphorus.

3.3.2.2 Throughfall and rainfall

When there was enough rainfall, throughfall was also sampled for nitrogen and phosphorus assessments. A composite sample, of in total 100 ml, was made by sampling the same amount from each jerrycan (because they cover the same area).

To be able to calculate the leaf leaching of nitrogen an independent measurement of nitrogen in rainwater is necessary: the wet deposition of nitrogen. Rain water was collected in a small tube with a funnel on top at bare places in four replicates. The tubes were installed only when a heavy rain was coming, otherwise contamination by faeces of birds or plant materials would have occured. Wet deposition was sampled simultaneously with the throughfall samples.

In the laboratory the samples were filtered and analysed for ammonia, nitrate and water soluble N and P after correction for a blank.

The amount of nitrogen (in g N/ha) per event is:

$$N_{Throughfall}=N_{conc}*Throughfall_{ml}*\frac{10,000}{Area} \tag{16}$$

In which	N_{conc}	The concentration of nitrogen (g/ml).
	$Throughfall_{ml}$	The amount of throughfall in ml in the jerrycan.
	$Area$	The surface area of the funnel (= $\pi*15^2$ m^2).

The amount of nitrogen lost due to leaching from leaves (in g/ha) per event is:

$$N_{Leach}=(N_{conc}-N_{WetDepo})*Throughfall_{ml}*\frac{10,000}{Area} \tag{17}$$

In Which $N_{WetDepo}$ The concentration of nitrogen in g/ml in the rain water

3.3.2.3 Dry deposition

Dry deposition was measured during the dry season. Four tins (with a diameter of 9.9 cm) were installed at 2 m height at bare spots (out of the direct influence of trees) at 2-12-1994. Every night and every rainfall event the tins were closed to avoid the incoming of rain water. At 11-1-1995 the tins were retrieved and dried. After cleaning and drying the tins were weighed again. For the calculation of the dry deposition of N and P (kg/ha) it has been assumed that the nutrient concentration in the dust is equal to total N and P (in mg/kg) measured in the top soil, because the amounts of dust were too small to be analysed for nutrients.

$$DryDeposition=\frac{Dust_{kg}*TotalNutrients_{dust}*10^{-2}}{\pi*(9.9*10^{-2}/2)^{2}} \tag{18}$$

Internal:

3.3.2.4 Plant uptake

Data of the standing biomass and yields (described below) give a first indication of total plant uptake and plant production. The estimation must be corrected however for plant mortality during the season (being litter fall and weed mortality, the maize mortality until the biomass assessment of maize is assumed to be zero) to avoid large underestimations. The total plant balance between two sampling moments is equal to (all in kg nutrients/ha):

$$PlantProduction=\Delta Plant+PlantMortality \tag{19}$$

In which $\Delta Plant$ Differences in plant nutrients between two sampling moments

Assessment of maize biomass at maximum LAI and at harvest

In earlier seasons it turned out that in the ripening phase of maize a lot of biomass was lost through termites. Therefore a biomass assessment was carried out at the moment of maximum LAI and maximum nutrient uptake before reallocation of the nutrients. This moment was at 16-12-1994. This moment was determined by visual observations and with the use of plant growth models (like

SUCROS, Simple and Universal CROp growth Simulation (van Laar et al., 1992)). The method used however is the same as the method for harvesting (which has been carried out at 9-1-1995) and the methods will be described simultaneously.

Harvest areas in all maize plots were marked with strings ($8.25*0.75$ m^2 and $3.25*8.25$ m^2 for assessment of biomass at maximum LAI and at final harvest, respectively). The cobs were separated from the standing maize stalks in the field, counted and total fresh weight was recorded. A representative subsample for moisture and nutrient contents was taken. The stalks were cut to the ground level and total fresh weight was recorded. After chopping a subsample was taken for assessment of moisture and nutrient contents. All weeds in the harvest area were harvested, weighed and subsampled. At the station samples were dried, ground and analysed for nutrients. For analysis of the cobs, grains and rachis were separated.

The total yield, at a dry weight basis, attained is:

$$Biomass_{kg/ha}=\frac{(100-\frac{Moisture_{(\%)}}{100+Moisture(\%)})*FreshWeight_{total(kg)}*10^{-4}}{Area_{(m^2)}} \quad (20)$$

In which *Area* Harvest area in m^2

Assessment of weed biomass

The method for biomass assessment of the weeds is similar to the one described for maize. Assessment was carried out at 16-1-1995. The harvest area was 10 m^2. Besides this area also the area (of 7 m^2) used to measure new growth of the weeds (installed by A. Braun) was cleared this day. Total fresh weight was recorded and a subsample was taken for moisture and nutrient analysis.

Assessment of tree biomass

Biomass was measured directly by harvesting on a number of selected trees at 16-1-1995. To select trees to be sampled all diameters of the trees were measured using the method described above (see 3.3.1.6.). Eight trees of average diameter were selected in each sesbania plot. The selected trees were cut down and laid on a polythene sheet spread on the field. The tree were cut into pieces and partitioned into four parts: wood > 2 cm diameter, wood < 2 cm diameter, leaves and pods (Flowers were absent.). Total fresh weight of each part was taken. After chopping and mixing each part a subsample of 200 - 300 g was taken. At the station the samples were dried, ground and analysed for nutrients.

The biomass yield of a tree (kg d.w./ha) is:

$$Yield_{kg/ha}=\frac{(100-\frac{Moisture_{(\%)}}{100+Moisture(\%)})*FreshWeight_{total(kg)}*10^{-4}}{Area_{(m^2)}} \quad (21)$$

In which *Area* The area occupied by the tree (= 0.9 m^2)

Yields of various trees were averaged to estimate for the whole population. The next step was to determine the allometric relationship between biomass and more easily measured variables, principally height, stem and crown diameter using regression analysis. These non-destructive estimations of yield facilitate future research.

3.3.2.5 Root production

In many root studies soil cores are taken at fixed times and the roots in the cores are analysed. The root production is then calculated as the difference in root biomass between two moments. This gives a large underestimation of the root production due to simultaneous root decomposition and root production (Publicover & Vogt, 1993; Santantonio and Grace, 1987; Vogt et al., 1986; Steen, 1989 a.o.). Independent measurements of root decomposition and root production are therefore necessary.

An independent measurement of root production can be achieved by means of root ingrowth cores. This method was used in this study, although the method also has disadvantages like soil compaction and other production rates than under undisturbed circumstances (Caldwell and Viriginia, 1991). Mesh bags of known volume (having a diameter of 5 cm and a length of 35 cm) were made of metallic mesh (to avoid eating by termites) with a mesh size of 5 mm. This mesh size was chosen to allow free root ingrowth while keeping the soil as much as possible inside. With an auger having the same diameter as the mesh bags, holes were made up to a depth of 30 cm. All the roots were removed from this soil. While this can be done by drying and sieving in the case of a sandy soil (Steen, 1989), it had to be done by manually picking in this case.

The ingrowth cores were installed in the holes at 27-10-1994. The ingrowth cores were refilled and compacted with a dowel after each few centimeters. This process was repeated until all the soil had been put back and the surface of the soil was flat to get the same bulk density as before. Similar root ingrowth techniques are decribed in Schrötz and Kolbe (1994) and Steen (1989).

At the end of the growth season (at 6-1-1995) the cores were removed very carefully (to avoid losses of roots): Around the core and a few centimeters away from the core the roots were cut with a sharp knife up to 30 cm deep. Thereafter the total core with the soil around the core was dug out of the soil and the core was cleaned from soil material. The roots in the core were seperated from the soil manually and dried.

The holes were chosen in a representative way: In the case of the randomly distributed weeds eight cores were distributed randomly in one of the weed plots (A number of eight should be enough for a statistical relevant measurement according to a preliminary t-test.). For the row crops (maize and sesbania) the situation was different. The holes were distributed at equal distances perpendicular to rows (at 12.5, 25 and 37.5 cm from the row in the case of maize and at 25, 50, 75 and 100 cm from the row in the case of sesbania) and representative positions parallell to the rows (at 0, 6.25 and 12,5 cm from a plant of maize and at 0, 10 and 20 cm from a sesbania tree respectively). One plot of maize and one plot of sesbania was selected randomly for this experiment.

The root biomass (in kg d.w./ha) produced during the season is:

$$DryWeight=DryWeight_{core}*\frac{10}{Area}*\frac{1}{Fraction_{roots}} \qquad (22)$$

In which

$DryWeight_{core}$	Average dry weight of roots in the cores after retrieval.
$Area$	Surface area of the ingrowth core in m^2.
$Fraction_{roots}$	Average fraction of the total root biomass in the 0-30 cm layer compared to the total root biomass through the whole profile. This fraction was determined using available root distribution data (K. Mekonnen, unpublished data).

Root mortality can now be eliminated out of the equations of the basic root balance equations (Publicover and Vogt, 1993; Santantonio and Grace, 1987):

$$\Delta LR=RootProduction-RootMortality \qquad (23)$$

$$\Delta DR=RootMortality-RootConversion \qquad (24)$$

In which

ΔLR	Differences in living roots between two sampling moments
ΔDR	Differences in dead roots between two sampling moments

Rearranging of the two equations gives:

$$\Delta Roots(=\Delta LR+\Delta DR)=RootProduction-RootConversion \qquad (25)$$

The conversion rates and the production rates were measured in independent studies (see this section and section 3.3.2.7). It was possible to calculate the amount of roots at any moment from the calculated changes in root biomass, because the root distribution at one moment is known (K. Mekonnen, unpublished data). The root balance is complete.

3.3.2.6 Leaf mortality

Sesbania leaf mortality

Proctor (1983) mentions that for litter fall data to be comparable across sites, litter traps must be appropriately sited and replicated and sampling must be for a period not less than one year. Littertraps of polythene mesh (with a mesh size of 1 mm) on a wooden carcass with a surface area of 0.8*2.1 (= 1.68) m^2 have been installed by A.Braun in the sesbania plots during the long rain season of 1994. The three traps (placed between the sesbania rows, see Braun (1995)) in the plots were moved regularly after sampling to reduce the sampling error. Litter was collected every three weeks (at 19-8-1994, 7-9-1994, 19-10-1994, 9-11-1994, 7-12-1994, 21-12-1994 and 11-1-1995). The length of the period was a compromise between the weighing error and the losses through decomposition of litter. Anderson and Ingram (1993) recommend collection after every two weeks for litter which decompose rapidly, e.g., of some tree legumes, while less frequent collection may be made under dry conditions.

Total fresh weight for each replicate was recorded. Moisture and nutrient contents were determined at the station.

The litter fall (kg/ha) equals:

$$LitterFall_{(kg/ha)}=\frac{FreshWeight_{total(kg)}*(100-\frac{Moisture_{(\%)}}{100+Moisture_{(\%)}})*10^{-4}}{Area_{(m^2)}} \qquad (26)$$

In which	*Area*	The surface area of the litter trap (1.68 m^2)

Weed mortality

Weed litter mortality (i.e. the production of dead material by weeds) can't easily be measured. In the case of trees it is possible to use littertraps, but that is not possible with weeds because of their spatial distribution. Instead of littertraps microsites were used. In all weed plots microsites of 0.5 x 0.5 m were marked in four replicates. Directly after marking all dead material including the standing dead biomass was removed from these sites. After weighing, the material was dried and weighed again. The dry material was analysed for total nitrogen. This is moment t=0. Every three weeks (at the same dates as litter collection of the sesbania) this procedure was repeated.

By following the production of dead material over a longer period a better understanding of the dynamics and equilibrium of the system became available. Production of dead material (in kg/ha/day) was used as an input value in the litter decomposition study:

$$LitterMortality_i=\frac{DryDead_i*10}{0.25*time} \qquad (27)$$

In which	*Dry_Dead$_i$*	Dry weight of the dead material sample at time i in g.
	Time	Period between two sampling moments in days

The calculated litter mortality were averaged per plot and checked for time (rainfall) interactions to calculate the seasonal mortality.

3.3.2.7 Root conversion

The rate of conversion of dead root material was determined using mesh bags. For this purpose 25 meshbags of 10x10 cm were made out of 2 mm metallic mesh (because of the high termite activity). This size is chosen as a compromise between the error introduced by subtracting the weight of the meshbag (compared to the weight of the plant material inside the bag) and the microclimatic changes introduced by the meshbags (especially higher moisture content under meshbags has to be mentioned). The mesh size of 2 mm is large enough to allow most of the macrofauna to enter the meshbags, which is necessary for fragmentation of the plant material.

Dead root material, collected along a freshly dug trench, was used. Unnaturally died roots have different nutrient concentrations affecting root conversion rates (Steen, 1989) and could not be used. The collected material was mixed thoroughly to get an uniform sample (after removal of soil) and a subsample was taken for moisture, N and P analysis for t=0 characterisation.

Each meshbag was labeled (with a metal label) and filled with the material, fresh weight was recorded and the meshbags were incorporated in the soil. Slides were dug in the soils with a spade. Disturbance of the soil was avoided as much as possible during installation, because disturbance can enhance biological activity. The bags were put in the slides at a depth between 10-20 cm. This was chosen because roots are usually most abundant at this depth (K. Mekonnen, unpublished data)) Aboveground the place of burial was indicated by a coloured string.

The meshbags were distributed at 1 m^2 in 5x5 latin squares (see Table 3.5) in one plot per treatment for a statistical sound and a random retrieval of 5 replicates at 5 time events (Cochran and Cox, 1957). The first retrieval took place about one week after installing the bags. The other retrievals were determined after the first retrieval time to be able to cover a range in fractions of dry matter remaining as large as possible.

This experiment was carried out in two partly overlapping runs. The first run started at 16-10-1994 and had retrieval times at 26-10-1994, 2-11-1994, 24-11-1994, 27-12-1994 and 5-1-1995. The second run started at 15-11-1994 and had retrieval times at 24-11-1994, 21-12-1994, 5-1-1995, 11-1-1995 and 16-1-1995. Both runs were conducted with roots of sesbania, weeds and maize separately (having 25 meshbags of each treatment per run).

Table 3.5: Randomized retrieval times using a 5x5 latin square.

1	4	2	5	3
3	1	4	2	5
5	3	1	4	2
2	5	3	1	4
4	2	5	3	1

After retrieval the material was weighed and dried. The material was sorted out manually and meshbag and plant sample were weighed separately. Plant material was analysed for N and P. Ash content was determined too to control whether there was any soil contamination in the plant samples. Grinding of the material was done with a coffee-mill to avoid losses of material.

Moisture content of the litter on time 0 is:

$$Moisture_0 = \frac{(FreshWeight_0 - DryWeight_0)}{DryWeight_0} \qquad (28)$$

The average moisture content of t=0 was used for the calculation of the initial dry weights of all the samples, see eq. 28 (The deriviation of this formula is given in annex 2).

$$DryWeight_{0,j}=\frac{FreshWeight_{0,j}}{1+Moisture_0} \qquad (29)$$

In which		
	$FreshWeight_{0,j}$	The fresh weight of sample j excluding the weight of the meshbag on time t=0 in grammes.
	$Moisture_0$	The average moisture content of the subsample of time t=0 in g/g d.w..

All dry weights were corrected for their ash contents by:

$$DryWeight_{corr,i,j}=(1-Ash)*DryWeight_{i,j} \qquad (30)$$

All corrected dry weights of the roots were expressed as fractions of the initial dry weights. This fraction was plotted against time to calculate the conversion constant k_c (in days^{-1}). This can be done by fitting an exponential curve through the data with a statistical program.

$$\frac{DryWeight_{corr,i,j}}{DryWeight_{corr,0,j}}=Fraction_j=\exp(-k_c*time) \qquad (31)$$

Another fit can be achieved by plotting ln($Fraction_j$) against time. The slope is then equal to $-k_c$. One has however to assume in this case that the distribution of errors ln(error) has the same properties as the errors (+error) of the first equation.

3.3.2.8 Litter conversion

The rate of conversion of dead aboveground plant material (of leaves and twigs) was determined with litterbags of 10x10 cm laid on the soil surface, made of 2 mm metallic mesh (using the same considerations as in 3.3.2.7). Dead plant material was collected in order to make a representative sample. The material was mixed to get an uniform sample and a subsample was taken for moisture, N and P analysis.

For each treatment 48 litterbags were filled with the material, fresh weight was recorded and the litterbags were distributed randomly in the experimental plots. At each retrieval time eight litterbags were collected to get a statistical relevant sample (because the variability is very high). The first time was one week after installing the bags. The other times depended on the rate of conversion, as explained in 3.3.2.7.

Two partly overlapping runs were carried out with weed litter (each run having 24 bags without termite activity and 24 bags with termite activity (This is coincidence.)). Visual observations showed that termites had a very large influence on conversion rates. This influence was investigated separately. The first run started at 16-10-1994 with retrieval times at 25-10-1994, 28-10-1994, 2-11-1994, 8-11-1994, 19-11-1994 and 29-11-1994. The second run (to quantify the influence of the termites more quantitatively) started at 21-11-1994 with retrieval times at 24-11-1994, 29-11-1994, 2-12-1994, 8-12-1994, 16-12-1994, 5-1-1995 and 16-1-1995. The experiment with sesbania litter started at 16-10-1994 and its retrieval times were 25-10-1994, 2-11-1994, 18-11-1994, 29-11-1994, 16-12-1994 and 16-1-1995.

After collection the bags were weighed, dried and sorted. After removal of the soil material the bags and the litter were weighed separately. The litter was analysed for N, P and ash content (to check for contamination with soil remained in the sample) after manual grinding.

The same calculations apply as in 3.3.2.7.

3.3.2.9 Soil organic matter mineralisation

In this report soil mineralisation is considered as the net mineralisation eliminating estimations for immobilisation. Four methods were used to determine the soil mineralisation. All methods have a specific purpose and a specific performance. The field methods (field core mineralisation and tent mineralisation treated in section 3 and 4) give soil mineralisation estimates under field conditions. These estimates were corrected for characteristic depth and moisture interactions with the laboratory soil mineralisation methods (aerobic and anaerobic incubation, treated in section 1 and 2). The methods combined give a seasonal average based on the relationships found (treated in section 5).

1) aerobic incubation

With this experiment soil mineralisation and denitrification rates could be determined as a function of the moisture content and limiting nutrient factors of the site.

The complete ammonia and the nitrate balances are as follows:

$$\Delta NH_4^+ = NetAmmonification - NH_4^+ uptake - Nitrification + NH_4^+ Deposition \tag{32}$$

$$\Delta NO_3^- = nitrification - NO_3^- uptake - leaching - denitrification \tag{33}$$

In the laboratory there was no uptake and leaching allowing quantification of the other processes involved. Deposition was measured independently (see section 4.2.1.2) and turned out to be negligible if wet deposition was avoided. Nitrification is inhibited under circumstances of high moisture levels and no conversion from ammonia to nitrate will take place. Soil mineralisation and denitrification rates were measured at different moisture levels i. This leaves the following simplified equations, for each moisture level i, using an incubation time of ten days:

$$\Delta NH_{4\,(i)}^+ = NH_{4\,(t=10,i)}^+ - NH_{4\,(t=0,i)}^+ = NetMineralisation \tag{34}$$

$$\Delta NO_3^- = NO_{3\,(t=10,i)}^- - NO_{3\,(t=0,i)}^- = -denitrification \tag{35}$$

Two experiments were run at different moisture levels on tension plates starting 9-12-1994 and 8-1-1995 respectively. Different water potentials were applied at the tension plates. The water potential, determining the moisture content of the soil, is linearly related to the height difference between the tension plate and its water reservoir. Seven tension plates were installed at different levels of WFPS, ranging from approximately 0.6 to 0.9 (WFPS = water filled pore space). The relationship between water potential and WFPS was determined by test runs.

The tension plates with dimensions of 40* 60 cm and 10 cm high were made out of ordinary welded (to avoid water leakage) plain aluminium sheets trays. In the middle of the bottom a hole with a welded fitting (of 1.5 cm long) was manifactured. Each plate was connected with a water reservoir with a water filled plastic tube (using a vacuum pump) through this fitting. The water reservoirs (covered with parafilm to avoid incoming insects and other contaminations) were positioned at heights relative to the plate varying from +10 cm to -50 cm. On the inside of each plate a sieve with a mesh size of 0.5 mm was placed and glued to the fitting. Sieved, water saturated river sand was uniformly distributed in the plate up to 1 cm thick. The tension plates were covered with a plastic cover to avoid evaporation as much as possible while allowing aeration.

In the field undisturbed soil samples were taken with soil cores. A core sampler (with the soil core fixed inside) is necessary to avoid compaction. The high variability in soil structure and consequently in bulk density also gives problems. Representative sampling and a number of replicates were necessary. To take the cores, a pit of two meters deep was dug next to a bare fallow plot. The cores were taken vertically for each of the six layers (The same subdivision between the layers as with the sampling rounds for moisture and inorganic nitrogen has been applied, as indicated in 3.3.1.2). For each incubation 14 cores were taken per layer.

The cores were saturated overnight. The cores became saturated and only drained afterwards because of a lower hydraulic potential applied after the night. This avoided hysteresis effects. Thereafter the cores were equilibrated on the plates for three days. One randomly selected core of each pair of cores was used for a t=0 determination. The total fresh weights of the cores, including the moist soil, were determined. Subsamples were taken for moisture, nitrate and ammonia determination. Extraction was done in duplicate to accomodate for the high spatial variability in mineral-N. The cores were weighed after cleaning. Their volume was obtained as accurately as possible by measuring diameter and height with a vernier calliper.

The remaining cores were incubated for 10 days, while recording minimum and maximum temperature every morning. During the incubation the plates were controled on air bubbles, emerging weeds and water levels. After 10 days the remaining cores were removed from the tension plates, the total fresh weight was recorded and extraction for inorganic nitrogen (in duplicate) and moisture content determination was started. The weight and volume of the cores were determined after cleaning. The measured soil mineralisation rates were correlated to available stocks of organic carbon and total nitrogen.

The bulk density in g/cm3 is equal to:

$$BulkDensity=\frac{(FreshWeight_{total(g)}-CoreWeight_{(g)})*\frac{DryWeight_{sample(g)}}{FreshWeight_{sample(g)}}}{Volume_{(cm^3)}} \qquad (36)$$

With the use of this bulk density it is possible to calculate the water filled pore space:

$$WFPS=\frac{BulkDensity*Moisture*100}{1-\frac{BulkDensity}{2.65}} \qquad (37)$$

In which *Moisture* moisture content of the sample in grams water per gram dry weight.

2) anaerobic incubation

This analysis is a so-called specialty analysis described in the laboratory manual of ICRAF (ICRAF, 1994b). The anaerobic incubation uses the fact that nitrification is insignificant under anaerobic conditions, so that net soil mineralisation can be determined from the changes in ammonia only. During the fourth sampling round of the short rains of 1994 field moist subsamples were taken for this analysis. A selection of 90 samples was made for a statistical analysis. The samples contained per layer four replicates per treatment from the first three layers and six samples, randomly chosen, from the lower 7 layers.

Immediately after removal from the fridge subsamples were taken for gravimetric soil water determination and for a pre-incubation extraction T(0). The extraction and the following determination of nitrate and ammonia were carried out in the usual way (see section 3.4).

After the extraction had started, subsamples of 10-11 g were collected for the anaerobic incubation. The soil was added to a tared 30-ml labelled glass bottle. The bottles were closed tightly with rubber stops after adding 25 ml of deionized water. The bottles were shaken for 30 seconds to remove any air bubbles and were placed in an incubator at 40°C. After seven days the samples were extracted and nitrate and ammonia were determined.

The soil mineralisation rate (in mg N/kg/day) is equal to:

$$Mineralisation=\frac{NH_{4(t=7)}^{+}-NH_{4(t=0)}^{+}}{Time} \qquad (38)$$

In which NH^{+4} Ammonia concentration in soil moisture
Time Incubation time in days (=7)

3) field core mineralisation

The field core mineralisation has been carried out to measure net mineralisation rates in the field at constant water content to allow comparison between plots and/or treatments within a site. The method is less accurate than the tent mineralisation.

Raison et al. (1987) described a method to estimate mineralisation, immobilisation, leaching and plant uptake by means of field incubations. Because of practical and theoretical problems it is recommended to use this method only to estimate N-mineralisation as stated by Anderson & Ingram (1993). The cores have been installed in pairs to accomodate the high spatial variability in N-mineralisation.

At 27-10-1994 six plastic cores with an 100 mm internal diameter (to avoid compaction) and a length of approximately 25 cm were inserted in pairs in each plot up to exactly 15 cm deep, cutting the roots, leaving the rest of the core above the soil surface.

Three of the cores were sampled immediately, while the other three were covered with polyethylene (and a rubber band) to protect the cores against incoming rain water and leaching achieving constant moisture contents. Subsamples were taken and analysed for moisture, ammonium and nitrate. The subsamples were extracted in duplicate to accomodate the high spatial variability.

After 21 days (at 17-11-1994) the remaining cores were removed and moisture, ammonium and nitrate were determined.

The net soil mineralisation rate in 10^{-6} g N/g d.w./day is:

$$Mineralisation = 1000 * \frac{(NH_4^+{}_{(t=1)} - NH_4^+{}_{(t=0)}) + (NO_3^-{}_{(t=1)} - NO_3^-{}_{(t=0)})}{Time} \qquad (39)$$

In which	NH4+,i	Ammonium concentration at time i in mg/kg d.w.
	NO3-,i	Nitrate concentration at time i in mg/kg d.w.
	TIME	Incubation period in days, which is 21 days.

This calculation is only valid if the water content is not too high (WFPS < 0.7) to avoid denitrification. This assumption was indeed valid.

4) tent mineralisation

The tent mineralisation method had been developed to get an accurate measurement of net soil mineralisation at constant moisture levels under field conditions as an absolute measure of the soil mineralisation rates.

In total two tents were built. A soil surface area of 6x9 m2 per tent was cleared from all plant materials (including roots to avoid root conversion), tillage, homogenization and equilibration of a site to obtain a bare soil (to avoid plant uptake). Along the borders of this area the plots were trenched to avoid root interference and for drainage of excess water. Wooden frames with a maximum height of 60 cm (See Figure 3.6) treated with wood preservative were built to hold canvass tents to avoid evaporation from the site. With these measures it was tried to obtain constant moisture contents during the experimental period and to avoid leaching. The tent canvass were tightened to pegs (treated with wood preservative) with sisal twine. The tightening was done in such a way that no rain water on top of canvas would accumulate. Any rain water was removed. Every three weeks during the experiments the area was weeded to keep the soil completely bare.

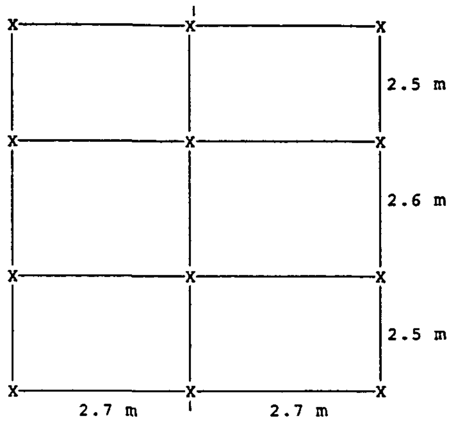

Figure 3.6: Schematic representation of the mineralisation tents. X indicates the position of poles.

There were three sampling moments, t=0 at 27-10-1994, t=1 (after 6 weeks at 8-12-1994) and t=2 (after 12 weeks at 19-1-1995). The last has been used as an extra control on the measured mineralization rates. The t=0 sampling took place after a rainfall event to incubate with a field moist soil. After t=0 sampling the canvases were tightened.

Within each tent three replicates were constructed (making in total six replicates). Each replicate was sampled for water, nitrate and ammonium. Per replicate, composite samples from 8 auger holes per layer were made. The same six soil layers as for the sampling of soil moisture (0-15 cm, 15-30 cm, 30-50 cm, 50-100 cm, 100-150 cm and 150-200 cm) were distinguished to get an impression of the soil mineralisation rates with depth.

Along each side of the tent, a boundary area of 1.5 m was taken care of. This left a distance of 45 cm between the holes. The holes for the three sampling moments were selected at random using the randomized aselected alpha design per replicate (as explained by Patterson et al., 1978). The basic alpha design for one replicate is shown in Table 3.6. This was repeated for each replicate within a tent. The result of the exercise is shown for one tent in Table 3.7.

Table 3.6: The alpha scheme used as the basis for the randomizing of the sampling moments of a replicate.

1	7	13	19	block 1
2	8	14	20	block 2
3	9	15	21	block 3
4	10	16	22	block 4
5	11	17	23	block 5
6	12	18	24	block 6

The sampling procedure was conducted as indicated in 3.2.1.2. After sampling the holes were refilled and the canvas was tightened again. The calculations are the same as for the field core soil mineralisation with the difference that the incubation time is 42 days in this case instead of 21 days. The calculations were repeated for the t=1 - t=2 period. The calculated rates were compared with the rates determined for the t=0 - t=1 period.

Table 3.7: Randomized allocation of sampling moments to the auger holes in the three replicates in one tent. The sampling moments are indicated by their numbers.

0	2	2	1		0	0	1	2		2	2	0	1
2	1	1	0		2	1	0	1		0	2	1	0
1	2	1	0		0	2	2	1		0	2	1	1
2	0	1	0		2	0	1	2		0	0	2	2
0	2	1	0		2	0	1	1		2	1	1	0
1	2	2	0		0	1	0	2		2	0	1	1

5) Calculations of mineralisation rates

The four methods decribed above were used to come to an integral estimation of mineralisation rates. The field core mineralisation method was used as the basis per treatment. The tent mineralisation gave the most accurate estimation of mineralisation rates in the bare fallow under constant moisture contents. The relationship between moisture contents and mineralisation rates in the bare fallow were compared (with regression analysis) with data of the laboratory mineralisation experiments, correcting for differences in moisture during the season.

Soil mineralisation characteristics of the site obtained by the laboratory incubations were used to correct the data per treatment. The influence of depth and moisture on mineralisation rates were described with the aerobic and anaerobic incubation. The anaerobic incubation also revealed the influence of organic matter contents on soil mineralisation rates.

All these relations and correlations together lead to an estimation of mineralisation rates per season, per treatment and per depth. The calculated rates could be checked by comparing the results with the inorganic soil nitrogen profile (described in 3.3.2.10) during the season.

3.3.2.10 Inorganic nitrogen storage

This method of sampling has been described in 3.3.1.2. The sampling round up to 4 m deep was used to obtain nitrate concentrations below the distinguished profile.

Outputs:

3.3.2.11 Runoff water

Runoff water was sampled during the peak of the rainy season once a week (at 10-11-1994, 17-11-1994, 24-11-1994 and 1-12-1994). At 9.00 am about 100 ml of runoff water was collected from the troughs before sediment collection took place. This runoff water is the last runoff water of the previous event. Total water soluble N and P, nitrate and ammonia were determined in the laboratory.

To be able to calculate the total runoff of nutrients per runoff event, the results of the analysis (in mg nutrients/l) was plotted against rainfall (in mm). The fitted curve through these data (assuming no memory in the system) was integrated between zero and the amount of rain (x) during the event to result in total runoff of nutrients in the runoff water in mgm^{-2}. This will be shown in section 4.2.1.11.

3.3.2.12 Eroded sediments

Sediment was collected as part of the erosion/runoff experiment. An idea of the quantity of nutrients lost by erosion can be obtained by analysis of N and P in the sediments. The relationship between the amount of water erosion and the amount of runoff water was investigated.

At the runoff plots (installed in the way described by Njoroge (1994)) a jerrycan was installed under the sampling pipe. This sediment collector collects about 0.5 % of the total runoff water, but was calibrated first to know the exact percentage collected. The calibration was done by applying water in the tipping bucket and by measuring the output with a measuring cylinder. The jerrycans were sampled once a week during the rainy seasons (at 10-11-1994, 17-11-1994, 24-11-1994, 1-12-1994 and 8-12-1994). The amount of sediment remaining in the trough of the tipping bucket was also collected. In the laboratory the water was removed. Chemical flocculation turned out to give a large overestimation of the amount of sediments by precipitation of salts. Therefore filtration (with washed, pre-weighed filtering paper, Whatman no. 1) with a vacuum pump was used. The sediment collected was analysed for N and P after drying.

The total amount of sediment collected in grams:

$$Sediment=Sediment_{trough}+\frac{100}{Fraction_{coll.}}*Sediment_{Jerrycan} \qquad (40)$$

In which		
	$Sediment_{trough}$	Amount of sediment in grams collected in the trough.
	$Sediment_{jerrycan}$	Amount of sediment in grams collected in the jerrycan.
	$Fraction_{coll.}$	The fraction of the total runoff collected in the sampling pipe.

The amount of sediment was converted to an erosion rate by dividing the amount of sediment by the timespan between the collections. The erosion rates were related to the total runoff water. The amount of sediment can also be expressed in kg/ha:

$$Sediment_{(kg/ha)}=Sediment_{(g)}*\frac{10,000}{Area}*\frac{1}{1000} \qquad (41)$$

In which $Area$ Surface area of the runoff plot (is $9*3 = 27\ m^2$).

3.3.2.13 Denitrification

1) aerobic incubation

The conditions in the laboratory experiment described in 3.3.2.9 (1) made it possible to use a simplified equation for the calculation of the denitrification rate (in mg N/kg/day) at moisture $content_i$:

$$Denitrification_i = -\frac{(NO^-_{3(t=10)i} - NO^-_{3(t=0)i})}{Time} \qquad (42)$$

in which *Time* Incubation period in days (=10 days)

In this way, a relationship between denitrification rate and moisture content could be established for the different layers with different nitrogen and organic carbon contents.

2) anaerobic incubation

Determination of nitrate in the soil mineralisation experiment described in 3.3.2.9 (2), allowed the calculation of denitrification rates (in mg N/kg/day):

$$Denitrification = -\frac{(NO^-_{3(t=7)} - NO^-_{3(t=0)})}{Time} \qquad (43)$$

In which *Time* Incubation period in days (= 7 days)

3.4 Routine laboratory analyses

Soil moisture determination

Moist soil stored in the refrigerator was spread on a tray. About 30 g of soil was collected randomly and added to a pre-weighed 50-ml beaker. The beaker was immediately weighed. After drying in the oven at 105 °C for 24-48 hours the beaker with soil was weighed again.

Gravimetric soil moisture content *Moisture* (in g/g d.w.) is:

$$Moisture = \frac{(Soil_{moist} - Soil_{dry})}{(Soil_{dry} - Beaker_{empty})} \qquad (44)$$

In which		
	$Soil_{moist}$	Weight of moist soil in grams including beaker weight
	$Soil_{dry}$	Weight of dry soil in grams including beaker weight after retrieval from the oven
	$Beaker_{empty}$	Weight of the empty beaker in grams

Gravimetric moisture contents can be converted to volumetric moisture contents Theta (in cm^3 water/cm^3 soil) by multiplying gravimetric moisture contents with the bulk density (in gcm^{-3}):

$$\Theta = Moisture * \rho^b_d \qquad (45)$$

Extraction of ammonia and nitrate

About 20 g field moist soil was added to a 150-ml tared plastic bottle after spreading and mixing of the soil on a tray. The bottle was shaken for one hour in horizontal position after adding 100 ml of 2 N KCl. After shaking the soil extract was filtered using pre-washed Whatman no. 5 filter paper and collected in clean 50 ml bottles. Initial moisture contents were determined as described above. The extract was stored in the refrigerator.

Using an Eppendorf Varipette, 1.0 ml of the standards of ammonia in 2 N KCl (in the range of 0-2 mg/l) were transfered to thorougly cleaned test tubes. 5.0 ml of reagent 1 (containing 68 g sodium salicyclate, 50 g sodium citrate, 50 g sodium tartrate and 0.24 g nitroprusside in 2 l deionized water) were added to each test tube and mixed. After 15 minutes 5.0 ml of reagent 2 (containing 60 g sodium hydroxide and 20 ml 5% sodium hypoclorite solution in 2 l deionized water) were added and mixed. After one hour the absorbance was measured at 655 nm with the spectrophotometer.

For the nitrate determination a reduction column with copperized cadmium granules was prepared, packed and percolated with diluted NH_4Cl solution. To the column, 1 ml concentrated NH_4Cl solution was added, followed by 3 ml of standard/sample (depending on what was needed) and 45 ml dilute NH_4Cl solution. Each sample was collected in a tube containing 5 ml sulphanilic acid reagent in 30-35 seconds. When all samples and standards (containing nitrate in 2 N KCl in the range of 0-2 mg/l) had passed through the column, 5 ml of 5-2 ANSA solution were added to each tube and mixed. After 30 minutes, absorbance was measured at 525 nm with the spectrophotometer. Recovery of nitrate through the column was tested.

The amount of nitrogen (in the form of ammonia and nitrate respectively) in mg/kg in the soil is:

$$N_{soil}=(N_{sample}-N_{blank})*\frac{(100+(Soil_{moist}-Soil_{dry}))}{Soil_{dry}} \qquad (46)$$

In which		
	N_{sample}	Concentration of NH_4^+ or NO_3^- in mg/l in the sample
	N_{blank}	Concentration of NH_4^+ or NO_3^- resp. in mg/l in the blank
	$Soil_{moist}$	Weight of field moist soil in grams
	$Soil_{dry}$	Weight of dry soil in grams

Determination of water soluble N and P

The samples were filtered with pre-washed Whatman no. 5 filter paper. For the digestion 10 ml of sample or standard (P and NO3 in deionized water) was pipetted in a 30 ml bottle. 5.0 ml of oxidizing solution (being 25 $K_2S_2O_8$, 15 g H_3BO_4 in 50 ml 3.75 M NaOH made up to 500 ml with deionized water) was added. The bottles were sealed and autoclaved at 121 ^0C at 15 psi for 60 minutes.

For the phosphorus analysis 1.0 ml of each standard and sample was transferred to marked test tubes. To this solution 4.0 ml ascorbic acid solution and 3.0 ml molybdate reagent were added. After mixing the solution was left for 1 hour and afterwards the absorbance was read at 880 nm.

For the nitrate analysis 0.5 ml of digested extract or standard was transferred to marked test tubes. To the tube 1.0 ml 5% salicyclic acid was added. After mixing 10 ml 16% NaOH was added. After mixing, cooling and mixing the absorbance was read at 410 nm.

Water soluble N in mg/l ($WaterSol_N$) is:

$$WaterSol_N = N_{sample} - N_{blank} \qquad (47)$$

A similar equation can be obtained for phosphorus.

Determination of total soil N and P

Wet oxidation of about 0.4 g of soil for a complete breakdown of organic matter for total nutrient contents was based on a Kjeldahl digestion with sulfuric acid. Selenium was added as a catalysator, while potassium sulfate was used to raise the boiling point to achieve the needed 360 °C. Salicylic acid was used to recover nitrate-N. After adding the digestion mixture to the soil the sample equilibrated for two hours and was than heated to 100 °C for two hours. After this period hydrogen peroxide was added as an additional oxidising agent and the temperature was raised to 360 °C for four hours more.

The organic N compounds were converted to the ammonium form, which was determined colorimetrically with the spectrophotometer. Phosphorus was also determined colorimetrically using coloured molybdate P complexes.

The concentration in the soil for nitrogen ($Soil_N$) in % was calculated as:

$$Soil_N = (N_{sample} - N_{blank}) * Volume * \frac{0.0001}{SoilWeight} \qquad (48)$$

In which *Volume* Total volume of the digest in ml

A similar equation can be obtained for soil phosphorus.

Total organic carbon

About 1.0 g of dry ground soil sample was weighed into labelled digestion tubes. To the soil samples and blanks 2 ml of deionized water was added. To both standards (of carbon solution) and sample tubes 10 ml of 5% $K_2Cr_2O_7$ and 5 ml concentrated H_2SO_4 was added. All digestion tubes were digested at 150 °C for 30 minutes. After cooling to room temperature, 0.4% $BaCl_2$ solution was added and mixed thoroughly. The next day absorbance was measured at 600 nm on the spectrophotometer.

Total soil organic carbon (SOIL_C) in % is equal to:

$$Soil_C = (C_{sample} - C_{blank}) * \frac{0.1}{SoilWeight} \qquad (49)$$

In Which C_{sample} Carbon content of the sample in mg C.
C_{blank} Carbon content of the blank in mg C.

Resin extractable phosphate

About 4.0 g of soil was shaken for 16 hours in a tightly closed 60-ml bottle containing water and anion exchange resin. The resin was in mesh bag and was washed beforehand with $NaHCO_3$. The bags were removed, washed and shaken with HCl for 30 minutes (after release of CO2 gas). The solution was filtered and the phosphorus in the extract (desorbed from the soil during shaking) was determined colorimetrically using coloured molybdate P complex.

Determination of plant N and P

About 0.2 g of ground plant material was weighed into digestion tubes. To each tube 4.4 ml of digestion mixture (of selenium, lithium sulphate, hydrogen peroxide and H_2SO_4) was added. The tubes were placed into a block digester and heated slowly to 330°C for 3 hours. After cooling 50 ml deionized water was added and mixed. The volume was made up to 75 ml with deionized water and left to settle.

For the nitrogen analysis 0.1 ml of each standard and sample was transferred to marked test tubes. 5.0 ml of reagent 1 was added and after mixing 5.0 ml of reagent 2 was added (see extraction of ammonia and nitrate). After 1 hour the absorbance was read at 655 nm at the spectrophotometer. The P analysis was the same as in 'determination of water soluble N and P'.

The nitrogen concentration in the plant tissue ($Plant_N$) in % is equal to:

$$Plant_N = (N_{sample} - N_{blank}) * \frac{0.0001}{PlantWeight} \qquad (50)$$

In which N_{sample} Concentration of N in the plant digest in mg/l
N_{blank} Concentration of N in the blank in mg/l

A similar equation can be obtained for phosphorus concentration in plant tissues.

3.5 Computer usage

Table 3.8 Computer packages used for this data

task	Package	version
calculations	LOTUS 123	2.2, 3.4
	EXCEL	5.0
	QPRO	5.0
simulations	GAPS	3.0
	RETC	
	SLIM	
	LEACHM	2.3
Figures	QPRO	5.0
Drawings	Draw Perfect	1.1
	Harvard Graphics	3.0
Statistics	SAS	6.0
	LOTUS 123	2.2
	SLIDE WRITE	5.0
Word processing	WORD PERFECT	5.0
	VAX editor	
Downloading met data	LOGGER	

This work needed computer packages allowing easy exchange of data. The software packages selected for this work are indicated in Table 3.8.

LOTUS 123 was used for most of the calculations on the balances. Plant data and meteorology data came in as XLS-files and were edited in EXCEL before importing into LOTUS 123. After the calculations the files were imported into QPRO for the construction of figures. Sometimes additional calculations were needed for the construction of figures.

Lineair regression analysis with only one parameter was carried out in LOTUS 123. Curve fitting was carried out in SLIDE WRITE. All other statistics were carried out in SAS. For this purpose ASCII files were exported to the VAX computer. Programmes for SAS were constructed with the VAX editor.

Figures from QPRO were imported as PIC-files and drawing were imported as WPG-files into WP. The final editing took place in WP.

Annex 1: Zenith angle calculations

For the calculation of the zenit angle with the use of meteorological formulas one needs the time in the year and the day and some site characteristics: longitude and latitude. Four ways of calculating the zenith angle were found in the literature, one being more empirical than the other. All use the declination and hour angle as starting point.

Method 1 (ceptometer manual)

The zenith angle can be calculated from:

$$Zenith=acos(\sin(Lat)*\sin(Decl)+\cos(Lat)*\cos(Decl)*\cos\frac{t-S_{noon}}{3.82}) \tag{51}$$

In which		
	$Decl$	Declination
	Lat	Latitude
	t	time of the day in hours
	S_{noon}	time of solar noon in hours

This means that for the calculation the following parameters are needed: The declination (Decl) is:

$$Decl=asin(0.4*\sin(4.87+0.017*Day))+0.0033*\sin(2\pi+0.017*Day) \tag{52}$$

In which		
	Day	number of the day in the year 1..365

With the use of a auxiliary variable ϕ it is possible to calculate the equation of time (t_0), indicating the difference between the local time (t) and a reference time. This t_0 is used to calculate the time of solar noon (S_{noon})

$$\phi=279.575+0.986*t*\frac{\pi}{180} \tag{53}$$

$$t_0=\frac{-\frac{\sin(\phi)}{0.00955}+\frac{\sin(2\phi)}{0.001677}-\frac{\sin(4\phi)}{0.07874}-\frac{\cos(\phi)}{0.00233}-2\cos(2\phi)+\frac{\cos(3\phi)}{0.0518}}{3600} \tag{54}$$

$$S_{noon}=12-t_0-\frac{(Longitude*\frac{180}{\pi}-30)}{15} \tag{55}$$

Now all parameters to calculate the zenith angle are known.

Method 2 (Paltridge and Platt, 1976):

The declination in this calculation is derived empirically using Day_0, an auxiliary variable.

$$Day_0=2*\pi*\frac{Day}{365} \tag{56}$$

$$Decl=7*10^{-3}-\frac{\cos(Day_0)}{2.5006}+\frac{\sin(Day_0)}{14.233}-\frac{\cos(2*Day_0)}{147.97}+\frac{\sin(2*Day_0)}{1102.5} \tag{57}$$

The hour angle is defined as the angle between the meridian of the observer and the meridian of the body measured from the observer's meridian. The hour angle is calculated using the equation of time (t_0) (see above), the true solar time (SolarTime) and the true solar noon (S_{noon}):

$$t_0=7.5*10^{-5}+\frac{\cos(Day_0)}{535.33}-\frac{\sin(day_0)}{31.175}-\frac{\cos(2*Day_0)}{68.423}-\frac{\sin(2*Day_0)}{24.48} \tag{58}$$

$$SolarTime=t+t_0+\frac{(Longitude-(\frac{30*\pi}{180}))*180}{\pi*15} \tag{59}$$

$$S_{noon}=12-(t_0-3+\frac{Longitude*180}{\pi*15}) \tag{60}$$

$$Hour_L=-2*\pi\frac{(t-S_{noon})}{24} \tag{61}$$

With the use of these variables the zenith angle is easily calculated, similar to method 1:

$$Zenith=acos(\sin(Lat)*\sin(Decl)+\cos(Lat)*\cos(Decl)*\cos(Hour_L)) \tag{62}$$

Method 3 (Liou, 1980; De Bruin, 1993):

These authors use the parameters already mentioned above, declination and hour angle, to calculate the zenit angle:

$$Decl=\frac{-23.4*\pi}{180}*\cos\frac{(2*\pi*(Day+10))}{365} \tag{63}$$

$$Hour_L=-2*\pi*\frac{(t-12)}{24} \tag{64}$$

$$Zenith=acos(\sin(Lat)*\sin(Decl)+\cos(Lat)*\cos(Decl)*\cos(Hour_L)) \tag{65}$$

Method 4 (Goudriaan, 1977):

For the calculation of the hour angle Goudriaan (1977) uses the true solar time. He introduces the parameter SunHour to calculate the zenith angle:

$$Decl=\frac{-23.4*\pi}{180}*\cos\frac{(2*\pi*(Day+10))}{365} \qquad (66)$$

$$Hour_{l}=\left|2*\pi\frac{(SolarTime-12)}{24}\right| \qquad (67)$$

$$SunHour=acos(\sin(Lat)*\sin(Decl)+\cos(Lat)*\cos(Decl)*\cos(Hour_{l}) \qquad (68)$$

$$Zenith=\arcsin(\frac{\sin(Hour_{l})*\cos(Decl)}{\cos(SunHour)}) \qquad (69)$$

The results of the calculations of all methods have been compared with the measured zenith angles using the shade length (see Figure 3.7).

The results of linear regression using the measured values as the independent variable are given in Table 3.9:

Table 3.9: regression analysis on the simulation of the zenit angle

Method	R^2
ceptometer manual	0.278
Paltridge and Platt (1976)	0.992
Liou(1980) and Bruin(1993)	0.601
Goudriaan (1977)	0.338

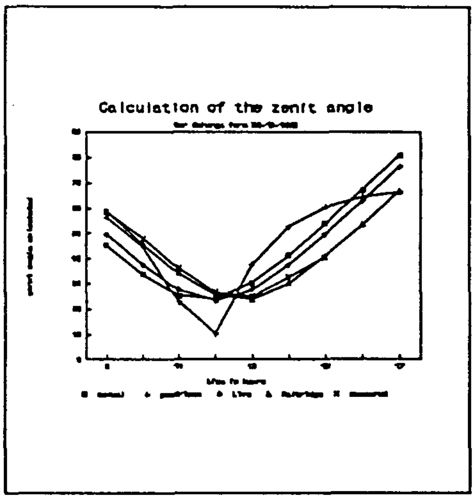

Figure 3.7: Comparison between the zenit angle calculated by different methods and the zenit angle measured in the field.

Obviously the formula given by Paltridge and Platt (1976) is the best and this one is used where necessary.

Annex 2: Deriviation of eq. (28)

The dry weight of plant material can be calculated in two ways from moisture contents of the plant material and fresh weights, depending on the way the moisture content of the plant material is expressed. Both methods will be presented.

Method 1:

$$DryWeight_i = FreshWeight_i - H_2O_i \tag{70}$$

$$DryWeight_i = FreshWeight_i - Water_i * DryWeight_i \tag{71}$$

In which H_2O_i Amount of water in the sample retrieved at time i in grams
$Water_i$ Moisture content of the plant material in g H_2O/g d.w.

Rewriting of eq. (71) gives the following equation:

$$DryWeight_i + Water_i * DryWeight_i = FreshWeight_i \tag{72}$$

$$DryWeight_i * (1 + Water_i) = FreshWeight_i \tag{73}$$

Bringing ($1+Water_i$) to the righthand side of the equation results in eq. (28).

Method 2:

The other way to calculate the initial dry weight is by expressing the water content per gram fresh weight. The calculated dry weight is exactly the same, but maybe this equation is easier to understand.

$$WaterF_i = \frac{(FreshWeight_i - DryWeight_i)}{FreshWeight_i} \tag{74}$$

In which $WaterF_i$ Water content in g H_2O/ g f.w.

$$DryWeight_i = FreshWeight_i - H_2O_i \tag{75}$$

$$DryWeight_i = FreshWeight_i - WaterF_i * FreshWeight_i \tag{76}$$

$$DryWeight_i = FreshWeight_i * (1 - WaterF_i) \tag{77}$$

Chapter 4: Assessment of the processes

For most processes, background information based on a literature review will be treated, before data on the processes at Ochinga farm will be presented. Literature is not presented in a separate chapter to avoid a cutting up of process information and because the literature presented does not deal with system dynamics (the objective of this report), but only deals with one process at a time.

Processes can take place at the plot level (per treatment) and at the field/site level. Sometimes a process is reviewed at the site level only. In that case, the process will be assumed to be the same for all treatments. The final result is a period average for each treatment. This period average is based on one to three seasons, depending on the start of the measurements. The boundaries of the periods were treated in Chapter 2. The number of periods is always mentioned at the concerning paragraph.

The processes mentioned in Chapter 3 will be treated separately. Some processes were not measured, but had to be estimated. Those processes are the last processes treated of each component. Within the paragraphs for measured and estimated processes a subdivision is made between inputs, internal and outputs. This subdivision is based on the system boundaries treated in Chapter 2 (see also Figure 1, Chapter 1).

4.1 Water dynamics

4.1.1 Measured processes

Inputs:

4.1.1.1 Rainfall

Background information:

Rainfall (precipitation) is highly site dependent. Precipitation depends on latitude, altitude, relief, vegetation and many other processes. As soon as rain enters the system, it is modified by the system. Therefore rainfall is measured at 2 m height above short grass. Conditions of excess rainfall over evapotranspiration may favour nitrogen losses by leaching and denitrification.

Results:

The yearly rainfall at the Maseno research station is about 1900 mm. The rainfall is fairly well distributed over months with two distinct peaks. One peak falls in April-May (The season in which this peak falls is called the long rains season) and the other falls in November (short rains season). Dry spells of a longer period can be found in January-February and July (See Figure 4.1).

Rainfall data collected with the automated rain gauge for the months September 1994 to January 1995, the 4th season of the experiment, is presented in Appendix V.7. Data on the 2nd season are presented in Hartemink (1994) and data on the 3rd season are presented by Braun (1995). Sometimes the automated rain gauge recorded 0.2 mm of rain during early morning hours, while the manual rain gauge did not record anything. Probably this is caused by dew on the funnel. This dew has not been taken into account in further analysis. Due to problems with the battery of the logger during the months September 1994 and October 1994 and problems with the rain gauge itself in October 1994, these data are probably not accurate. The average value of the data collected from the manual rain gauges (see Appendix V.1) were therefore used in the calculations. A monthly comparison between the manual rain gauge at the met station and the automated rain gauge is presented in Table 4.1. The differences are usually small, but automatic raingauge clearly underestimated rainfall during the months with battery problems (October 1994 and November 1994) and logger problems (April 1994). The coincidence in the other months gives confidence in the reliability of the rainfall data.

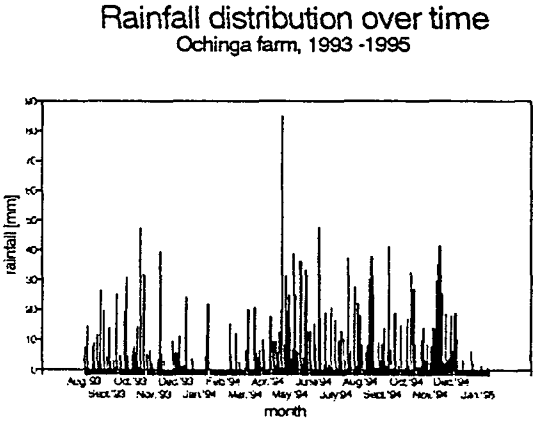

Figure 4.1: Rainfall distribution over time during the 2nd, 3rd and 4th season of the experiment

Table 4.1: Rainfall (in mm) for Ochinga farm determined with manual raingauges and an automatic weather station, respectively for the 2nd, 3rd and 4th season of the experiment

	manual			automatic		
	1993	1994	1995	1993	1994	1995
January		38.4	7.5		44.6	8.3
February		38.9			40.2	
March		126.9			143.4	
April		277.8			131.4	
May		307.7			296.8	
June		137.9			151.4	
July		201.9			203.0	
August	119.7	198.7		133.6	204.4	
September	127.2	114.9		123.2	91.8	
October	163.1	132.8		147.2	101.6	
November	104.1	299.9		108.0	282.4	
December	65.4	56.5		63.6	59.2	

Internal:

4.1.1.2 Soil moisture storage

Background information:

Plant communities are able to modify soil moisture storage patterns. This can have some results or comptetition between different plant species. Kiepe (1995) found a significant higher soil moisture storage under an hedgerow, than under an alley. Soil moisture storage was highest after a rainfall event in the horizon of most root accumulation. This was caused by an increased infiltration under the hedgerow, decreasing runoff. At Ochinga farm soil moisture contents were measured about every month in all treatments.

Results:

Volumetric moisture contents for the 6 sampling rounds of the short rains season of 1994, the 4th season, are presented in Appendix V.2 per plot and per land-use system. The volume fractions of moisture of the 2nd season and the 3rd season are presented by Hartemink (1994) and by Braun (1995), respectively. Bulk densities (in gcm^{-3}) used were retrieved from Table 3.1. A more extensive evalution of bulk densities is presented in Appendix II.

In Figure 4.2$_{a,b,c}$ the changes in moisture contents in time for three seasons per treatment are presented for the layers 0-30 cm, 30-100 cm and 100-200 cm separately.

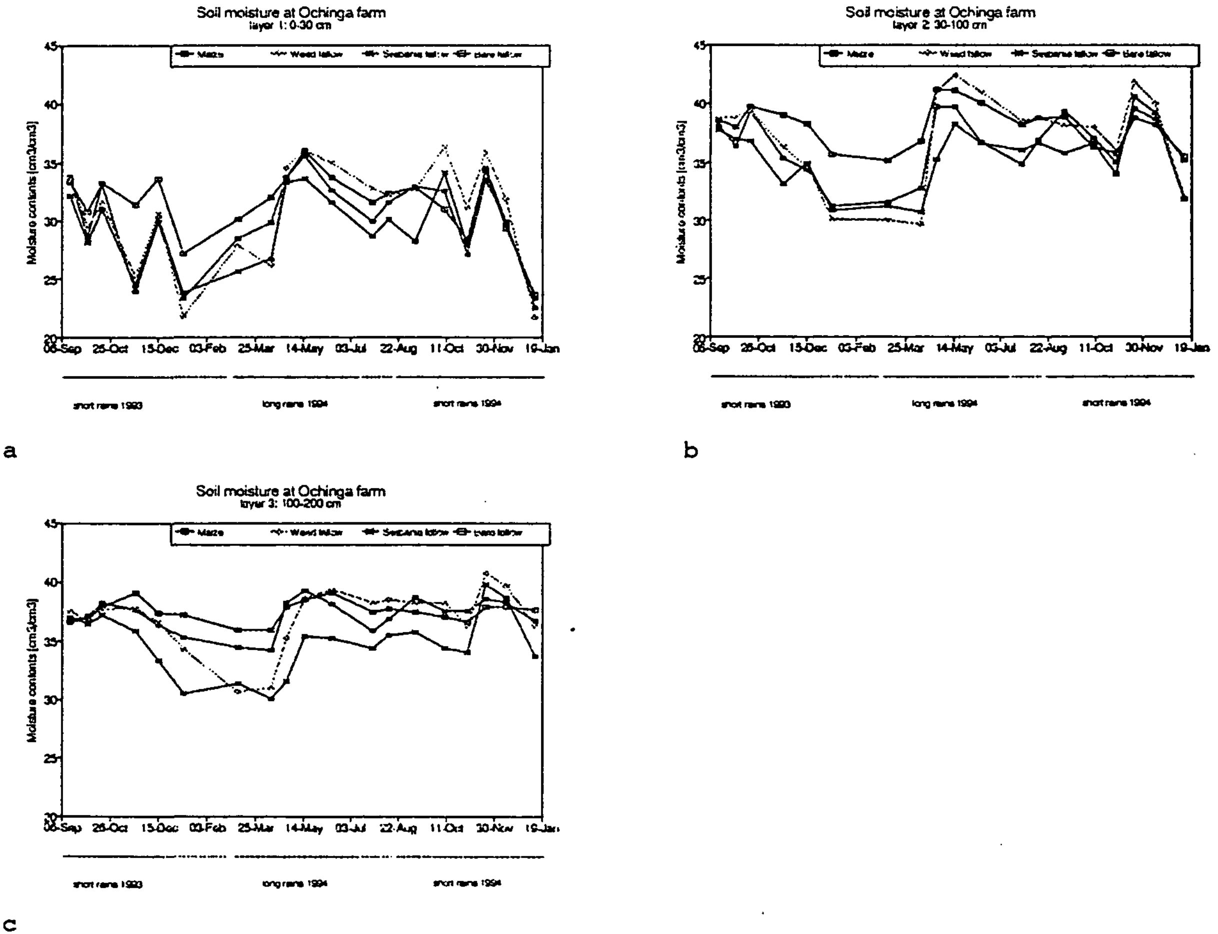

Figure 4.2$_{a,b,c}$: Volume fraction of moisture during the 2nd, 3rd and the 4th season of the experiment for three soil layers
LSD for comparing depths between sampling times in a land-use system: 0.93
LSD for comparing depths within a sampling time in a land-use system: 2.24
LSD for comparing depths between sampling times and land-use systems: 1.15

Overall moisture changes were strongly related to rainfall, leading to the ups and downs which can be observed in the top layer for all treatments. The peaks, caused by high rainfall in a short period, are most pronounced in the weed fallow and the sesbania fallow. In maize and the bare fallow these peaks do not occur, probably because the much higher runoff taking place in these treatments led to much lower infiltration (see 4.1.1.4). These effects can best be seen in the top layer for the April 1994 and September 1994 (see Figure 4.2_a).

Although runoff is very high in the bare fallow (see 4.1.1.5), moisture contents are kept very high due to the low evapotranspiration. The low evapotranspiration is caused by the absence of plants and low infiltration rate caused by crust formation on the top of the soil. This water conservation is the reason that moisture contents in the bare fallow were the highest, near field capacity, during all three seasons. During periods of high rainfall, moisture content at depth also increases remarkably (see Figure 4.2_c), suggesting that some drainage takes place. This drainage (and with the drainage of water also the danger of leaching of nitrogen) will be higher in the bare fallow and maize having highest moisture contents at depth. This combination can lead to extra high nutrient losses, primarily aboveground by runoff and soil erosion and secondly by leaching of nutrients caused by high moisture contents.

At the start of the second season, moisture content was significantly lower (at $P<0.05$) in the sesbania fallow than in the other treatments (Hartemink, 1994). This can be caused by the fact that water uptake in sesbania fallow had continued between the 1st and the 2nd season. Throughout the seasons the sesbania fallow kept its significantly lower moisture content (at $P<0.05$) (Braun, 1995), while infiltration was high. The lower moisture contents were especially noticeable in the deeper layers, suggesting that moisture uptake from depth had taken place.

The weed fallow was also able to keep moisture contents low during the 2nd season, short rains 1993, due to moisture uptake from depth. High rates of moisture uptake actually occuring in the weed fallow (see 4.1.2.1) are masked in the 3rd and the 4th season, because the weed fallow is able to keep moisture contents high due to a high infiltration. High infiltration is possible because runoff is almost absent (see 4.1.1.5), because a complete ground cover was established. That moisture uptake really takes place can be seen from the data collected between the seasons. In maize and bare fallow moisture increases, independent of depth, faster (or decreases slower) during this period than in the weed fallow and sesbania fallow suggesting water uptake in the last two mentioned treatments. The spare rainfall that falls between the seasons is stored in bare fallow plots and in maize plots, while sesbania fallow and weed fallow continue their water uptake decreasing leaching probabilities. This trend is consistent with depth and with time.

4.1.1.3 Throughfall and Interception

Background information:

Intercepted rain water is always lost by evaporation from the canopy. This evaporation is however not included in the evapotranspiration calculations and needs a separate description. The remaining rain water (=throughfall) reaches the soil surface.

Estimates for interception vary between 5 and 40 % depending on method and system (Dolman, 1987). In maize an interception of 34% was measured in one rainfall event (Baldy and Stigter, 1993). On average, however, an interception of 2% was measured (Girardin, 1992). The interception in temperate grasslands is estimated to be 10% and 15.5% of the rainfall (Jackson et al. (1990) and Acevedo and Sarmiento (1993) respectively). Estimates for interception in tropical rainforests are 20% (Ghuman and Lal, 1987) and 21% (Lloyd and Marques, 1988; Calder et al., 1986). In an Eucalyptus canopy an interception of 23% was measured (Sharma, 1984). The examples above already indicate the high variability in interception. The need of large samples is therefore stressed (Lloyd and Marques, 1988).

Results:

At Ochinga farm throughfall was measured in the sesbania plots for two seasons. The data for the short rains season of 1994 (the 4th season) are presented in Appendix V.3. Braun (1995) presented throughfall data for the 3rd season. Interception was calculated based on the throughfall and precipitation. Average throughfall data and average interception data have been plotted against rainfall in Figure 4.3.

Linear regression with rainfall (the best fit using one parameter) for the sesbania trees shows the following empirical relationship (both parameters in mm) indicating an interception of about 12%:

$$Interception = 0.115 * rainfall + 0.583 \qquad (1)$$

Further statistical analysis showed that it was more useful to describe the functional relationships between throughfall on the one side and rainfall, rainfall intensity and plant characteristics (LAI) on the other side. The relationships were investigated with multiple regression (see Table 4.2 and Table 4.3).

Table 4.2: Probabilities (and r^2) of the three, two and one parameter models are given for the best fits of the multiple regression analysis of throughfall. Note: No intercept was taken into account in model 4.

model	r^2	P-model	P-rainfall	P-intensity	P-LAI	P-intercept
1	0.9851	0.0001	0.0001	0.0006	0.0031	0.1694
2	0.9849	0.0001	0.0001	0.0002		0.0001
3	0.9846	0.0001	0.0001			0.0001
4	0.990	0.0001	0.0001	0.0018	0.0001	-

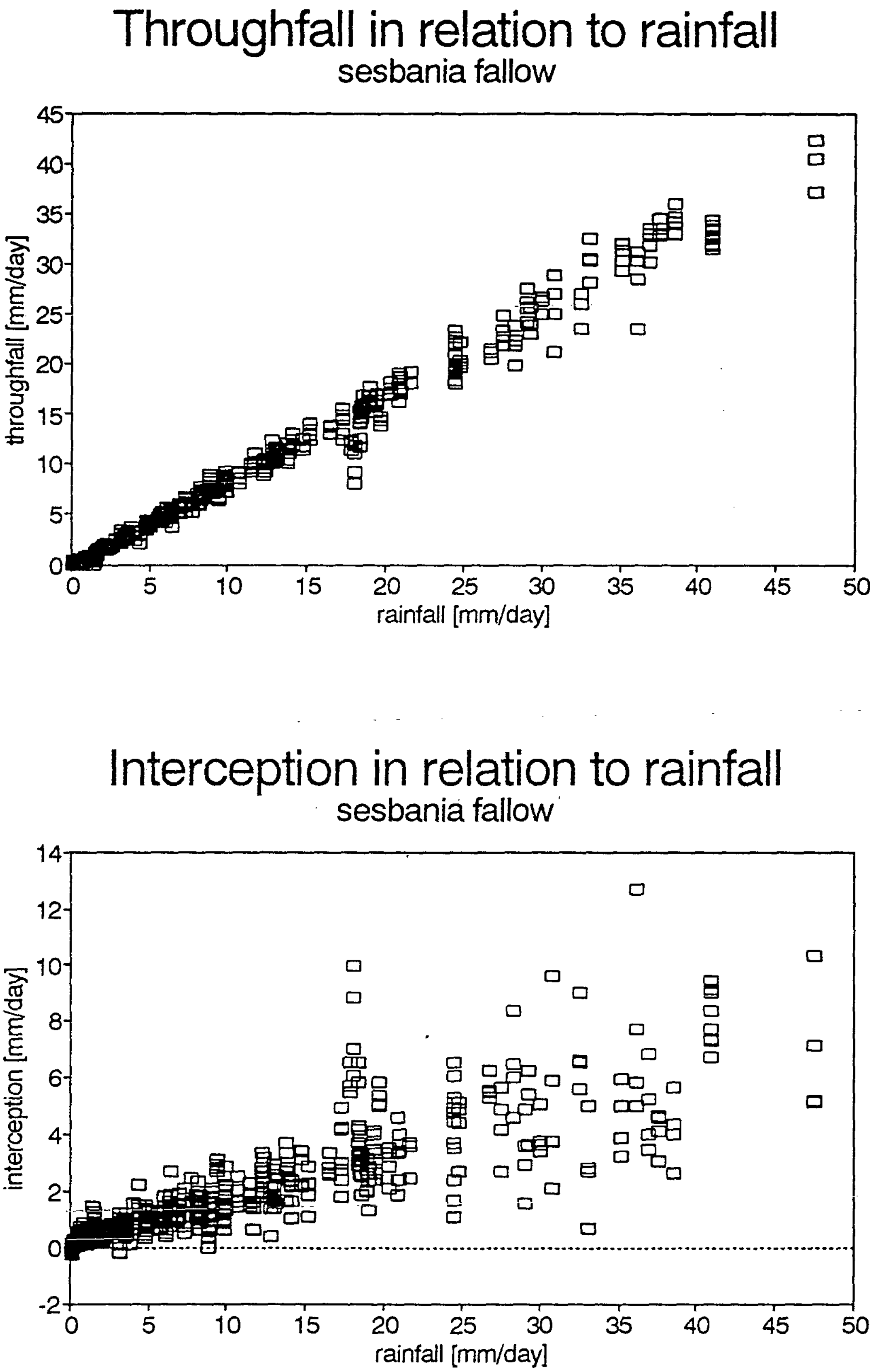

Figure 4.3: Average throughfall and average interception in relation to rainfall

Table 4.3: Probabilities (and r^2) of the three, two and one parameter models given for the best fits of the multiple regression analysis of rainfall interception.
Note: No intercept was taken into account in model 4.

model	r^2	P-model	P-rainfall	P-intensity	P-LAI	P-intercept
1	0.5349	0.0001	0.0001	0.0005	0.0037	0.1809
2	0.5289	0.0001	0.0001	0.0002		0.0001
3	0.519	0.0001	0.0001			0.0001
4	0.7245	0.0001	0.0001	0.0014	0.0001	-

In models 2 and 3, a threshold value had to be included because of the influence of intercept. The intercept was not significant ($P<0.05$) in model 1, because LAI was included. For this reason an additional model without intercept was included. This model gives the best description on a daily basis (with rainfall in mmd^{-1}, intensity in mmd^{-1}, LAI is dimensionless):

$$Throughfall = 0.863 * rain + 0.00109 * intensity - 0.207 * LAI \quad (2)$$

For the weed fallow an interception of 13% and for maize an interception of 2% was assumed based on the literature values mentioned above.

Seasonal throughfall and interception for the sesbania fallow was calculated using measured values for the 3rd and 4th season and using extrapolated values for the 2nd season with the use of eq. 2. The results are shown in Table 4.4.

Table 4.4: Interception and throughfall in the sesbania fallow per period.

	throughfall	interception	
	(mm)	(mm)	(% of rainfall)
2nd season	429.61	59.39	12.10
between seasons	78.35	11.25	12.56
3rd season	885.58	153.22	14.75
between seasons	122.65	24.55	16.68
4th season	494.05	133.75	21.30

The percentage of rainfall intercepted increases during the experiment. This is probably caused by the development of canopy.

4.1.1.4 Infiltration

Background information:

Infiltration is defined as the entrance of water in the soil profile, which changes the water content distribution with depth (Landon, 1991). Driving forces for water entering the soil are the gradient of the pressure heads between the wetting front and the soil surface and gravity (Koorevaar et al., 1983). Hartemink (1994) measured infiltration characteristics at Ochinga farm at the beginning of the experiment and found base infiltration rates ranging from 8 to 18 $cmhr^{-1}$.

Measured cumulative intake (F) can be fitted against two commonly used empirical relationships. Observations can be fitted against

$$F=a*time^{n} \tag{3}$$

and against the Philip equation (Landon, 1991) in which a is equal to the soil sorptivity:

$$F=a*\sqrt{time}+b*time \tag{4}$$

Infiltration can also be estimated indirectly from:

$$Infiltration=precipitation-runoff-interception \tag{5}$$

For the initial infiltration (and runoff) during a rainfall event, the evapotranspiration (ET) was not taken into account because evapotranspiration occurs with a larger timestep.

Results:

For the weed fallow and sesbania fallow, infiltration could be calculated for the 2nd, 3rd and 4th season out of eq 3. using the regression equations mentioned in 4.1.1.3 and 4.1.1.5 for extrapolation where necessary. As a check on this approach and to calculate infiltration rates for the other treatments, direct measurements were carried out in the weed fallow, bare fallow and in maize, see Appendix V.4.

Infiltration rates of maize and bare fallow were not significantly different. Infiltration rates in the weed fallow are higher than the infiltration rates in maize and bare fallow at all sampling times. Known infiltration rates in weed fallow (from the approach mentioned above) and the constant factor between the infiltration rates between weed fallow and the other treatments, 4.02 for bare fallow and 4.17 for maize (see Table 4.5), were used to calculate the infiltration rates for maize and bare fallow. Infiltration rates of maize and bare fallow were again used to calculate runoff in these treatments (see 4.1.1.5).

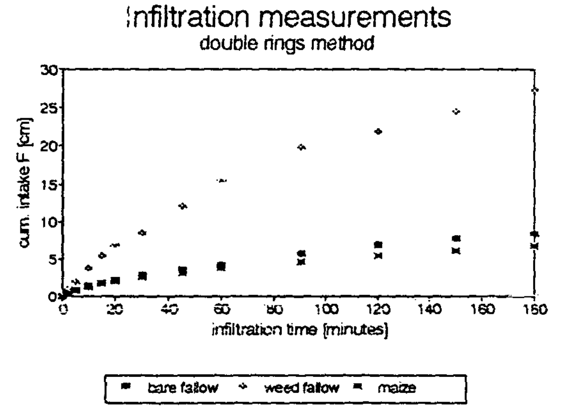

Figure 4.4: Cumulative intake F in relation to time.

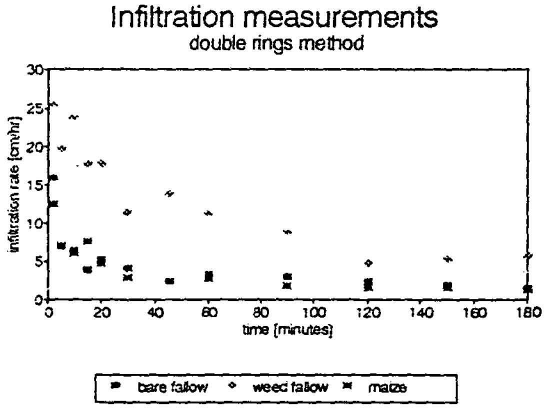

Figure 4.5: Infiltration rates as a function of infiltration time

Average cumulative intake for the three treatments is presented in Figure 4.4, while the relationship between infiltration rates and time is presented in Figure 4.5.

The good fit of measured intake and the empirical formulas mentioned above, gives confidence in the reliability of the measurement (see Table 4.5). The n value was in the range 0.5-1, indicating that soil cracks are absent. This supports the assumption that no bypass flow occurs. The infiltration rates are moderately high (Landon, 1991).

Table 4.5: Simulated and measured characteristics of the infiltration measured with a double rings experiment

parameters		bare fallow	weed fallow	maize
$F=a*t^n$	a	0.301	0.588	0.0921
	n	0.641	0.768	0.675
	r^2	0.896	0.971	0.917
Philip equation	a	0.663	1.266	0.115
$F=a\sqrt{t} + b*t$	b	-0.0203	0.0424	0.0085
	r^2	0.773	0.925	0.918
base infiltration	cm/hr	1.39	6.59	1.34
max. infiltration	cm/hr	15.9	25.5	12.4

The base infiltration rates found by Hartemink (1994) were higher than found in maize and bare fallow, but were still quite similar to the rates measured in the weed fallow. Due to the high runoff in maize and bare fallow some surface sealing due to splash erosion will have occurred. This surface sealing probably reduced the infiltration capacity of the soil. This decreased infiltration rates in these treatments; a result of the soil management. The weed fallow, with a higher ground cover and much less runoff, was able to reduce splash erosion effects and has still high infiltration rates.

Outputs:

4.1.1.5 Runoff

Background information:

Rainfall exceeding the water infiltrating capacity of the soil will flood the surface. Depending on the situation in the field, this will be runoff or runon. In this case only runoff was present (see Chapter 2). The amount of runoff is influenced by rainfall, rainfall intensity, plant canopy, slope and others. Ground cover decreases runoff linearly, while crops not covering the soil surface only have indirect increasing effects by influencing rain drop size and rainfall energy. Slope gradient is linearly related to runoff in the range 3-6% (Wischmeier and Smith, 1978).

Results:

Runoff was measured in the 3rd season, long rains 1994, (Braun, 1995) and during the 4th season, short rains 1994. Data of the 4th season are presented in Appendix V.5. The relationship between rainfall and runoff is presented in Figure 4.6. Slopes at the different plots are indicated in Figure 4.7.

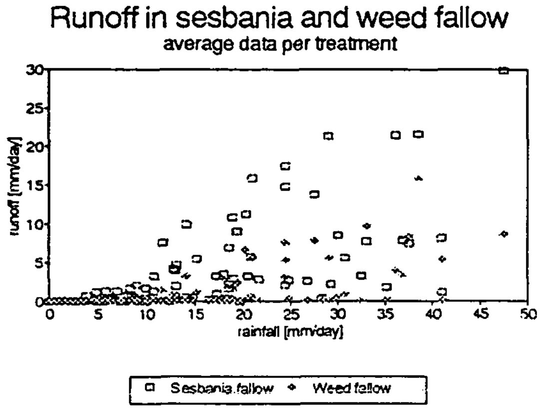

Figure 4.6: Runoff in sesbania fallow and weed fallow in relation to rainfall

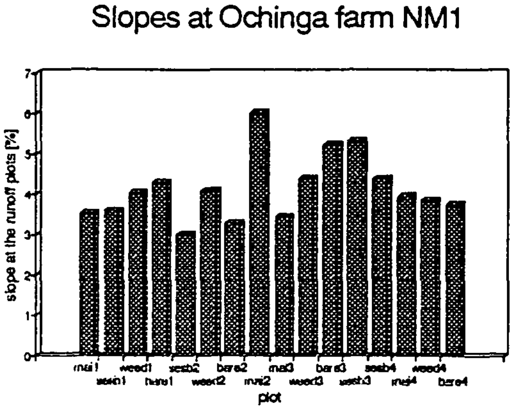

Figure 4.7: Slopes at Ochinga farm. Position and treatment of the plots can be found in Appendix I.

Correlations between runoff and the influencing parameters mentioned above were investigated by multiple regression analysis. Treatment had a significant influence ($P< 0.0001$) on runoff independent of the model used. Total LAI could not overcome this treatment effect.

At first, regression analysis was carried out on average values only to allow a comparison with the regression analysis presented by Braun (1995) (see Table 4.6). The influence of slope could not be taken into account in this analysis. Neither could LAI taken into account in the sesbania plots, because the LAI of sesbania was significantly different per plot ($P<0.05$). Even though average values are used, r^2 values are low indicating a high variability. The variability increased in the 4th season of the experiment (= short rains 1994); r^2-values indicated in Table 4.6 are lower than the values presented by Braun (1995).

Table 4.6: Probabilities (and r^2) of the three, two and one parameter models given for the best fits of the multiple regression analysis of runoff in sesbania and weed fallows, using only average values. The intercept was significant ($P<0.05$) in all models. For sesbania LAI was not taken into account because LAI of sesbania was significantly different per replicate (see 4.1.1.6) and could therefore not be used in an analysis using average values only.

model	r^2	P-model	P-rainfall	P-LAI	P-intensity
$1_{\text{weed fallow}}$	0.6146	0.0001	0.0001	0.0178	0.7616
$2_{\text{weed fallow}}$	0.6143	0.0001	0.0001	0.0172	
$3_{\text{weed fallow}}$	0.5954	0.0001	0.0001		
$4_{\text{sesbania fallow}}$	0.5923	0.0001	0.0001		0.5204
$5_{\text{sesbania fallow}}$	0.5912	0.0001	0.0001		

To be able to investigate the influence of slope and to get a better understanding of the variability, all data were analysed by multiple regression (see Table 4.7 and Table 4.8). A linear relation was used for the slope gradient, because the slopes were all within the range 3-6%. In both treatments only rainfall intensity turned out to be not significant at $P<0.05$. Including slope in the analysis led to a better description for the weed fallows than in the analysis presented in Table 4.6. The relationship in the weed fallows is described by (with runoff in mm, rainfall in mm and slope in %) eq. 6. According to this equation a higher slope would decrease the runoff. This is not in accordance with the observations. The reason for this discrepancy is that slope indirectly influences the growth patterns of plants. The system is not orthogonal. The relationships found are therefore only correlative and do not indicate a causal relationship between the parameters investigated.

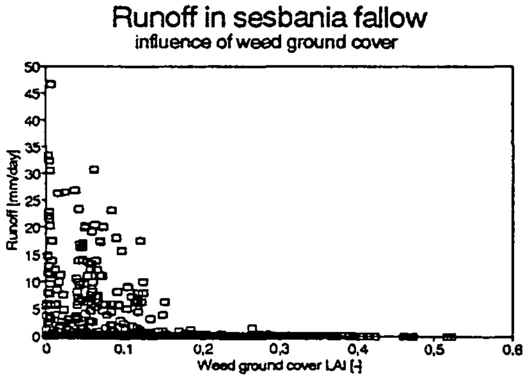

Figure 4.8: Influence of weed ground cover on runoff in sesbania fallows

$$Runoff = 0.0615*Rain + 0.202*LAI - 1.83*Slope + 7.22 \qquad (6)$$

Subdividing the LAI in the sesbania plots in a LAI for the trees and a LAI for the weed ground cover, improved the description considerably (see Table 4.9). This showes the large influence of weed ground cover (see 4.1.1.6) in the sesbania plots on runoff losses. Rainfall intensity and slope are not significant at P<0.05. Runoff in the sesbania plots is best described by:

$$Runoff = 0.242*Rain - 0.176*LAI_{weed\text{-}cover} + 1.18*LAI_{tree} + 0.860 \qquad (7)$$

Table 4.7: Probabilities (and r^2) of the four, three, two and one parameter models given for the best fits of the multiple regression analysis of runoff in the weed fallow. The intercept was significant (P<0.05) in all models.

model	r^2	P-model	P-rainfall	P-slope	P-LAI	P-intensity
1	0.764	0.0001	0.0001	0.0001	0.0001	0.3614
2	0.764	0.0001	0.0001	0.0001	0.0001	
3	0.740	0.0001	0.0001	0.0001		
4	0.149	0.0001	0.0001			

Table 4.8: Probabilities (and r^2) of the three, two and one parameter models given for the best fits of the multiple regression analysis of runoff in the sesbania fallow. The intercept was significant (P<0.05) in all models.

model	r^2	P-model	P-rainfall	P-LAI	P-slope	P-intensity
1	0.461	0.0001	0.0001	0.0001	0.0022	0.1640
2	0.459	0.0001	0.0001	0.0001	0.0019	
3	0.452	0.0001	0.0001	0.0001		
4	0.445	0.0001	0.0001			

Table 4.9: Probabilities (and r^2) of the five, four, three, two and one parameter models given for the best fits of the multiple regression analysis of runoff in the sesbania fallow. LAI values were divided in LAI of trees only (LAI_t) and LAI values of the weed ground cover(LAI_w). The intercept was significant ($P<0.05$) in all models.

model	r^2	P-model	P-rainfall	P-slope	P-LAI_t	P-LAI_w	P-intens.
1	0.630	0.0001	0.0001	0.408	0.0001	0.0001	0.9948
2	0.660	0.0001	0.0001	0.1789	0.0001	0.0001	
3	0.655	0.0001	0.0001		0.0001	0.0001	
4	0.498	0.0001	0.0001	0.0203			
5	0.533	0.0001	0.0001				

In the infiltration experiment (see 4.1.1.4) the ratio between the infiltration rates in weed fallow and bare fallow and maize was determined. With the actual infiltration rates known for the weed fallow, the infiltration rates for maize and the bare fallow could be calculated (using this ratio). With the use of eq. 3 runoff in maize and bare fallow were estimated (which was possible because all other parameters were known). A relationship between runoff and rainfall could therefore be estimated. For the bare fallow this becomes (with all parameters in mm and r^2=0.99):

$$Runoff_{bare}=0.801*rain-0.0322 \qquad (8)$$

For maize (with all parameters in mm and r^2=0.99) this is:

$$Runoff_{maize}=0.790*rain-0.0316 \qquad (9)$$

Runoff in maize is probably overestimated, when this equation is used. Another approach was therefore used. Runoff is linearly related to soil erosion. Soil erosion per treatment only differs in the crop factor of the universal soil loss equation (see 4.2.1.12). Out of the ratio of the crop factors for weed and for maize with a low productivity, the runoff in the maize plots can be calculated with the known runoff in the weed fallow. The relationship then becomes (with r^2 = 0.99):

$$Runoff_{maize}=0.522*Rain-0.0312 \qquad (10)$$

This relationship seems more realistic (based on visual observations and data presented in literature (Wischmeier and Smith, 1978 o.a.)) and was used in further calculations. The discrepancy between the calculated runoff based on infiltration measurements and the calculated runoff based on sediment losses can be caused by the fact that infiltration in maize was underestimated. Surface roughness in the maize plots is higher than in the bare fallow (because of tillage and plant growth) increasing infiltration in normal circumstances. During the infiltration experiment this surface roughness might have been abolished due to splash erosion.

Runoff losses per period were calculated with the regression equations, leading to the results presented in Table 4.10.

Table 4.10: Rainfall and runoff losses per period, both in mm per treatment.

	rainfall	runoff losses			
		bare fallow	maize	weed fallow	sesbania fallow
2^{nd} season	489.0	388.1	255.2	19.7	128.8
between seasons	89.6	71.7	46.7	6.1	12.8
3^{rd} season	1038.8	839.9	542.2	104.3	319.5
between seasons	147.2	118.9	76.8	14.5	22.6
4^{th} season	627.8	494.1	327.7	8.7	28.5

4.1.1.6 Plant growth

LAI

Background information:

The LAI (Leaf Area Index) is a measure of the plant cover per m^2 of soil. Maize can reach a LAI of 5 under non-limiting circumstances (Goudriaan, 1994). Plant growth can be reduced by many circumstances as light, water and nutrient limitation and injury and damage due to biota. Growth reduction due to injuries and damage is described by van der Werf et al. (1990).

LAI changes can be described in different ways. A logistic growth curve (eq. 11, with time in days) describes a system in which no competition occurs in the beginning, while later on competition starts and growth stops at a certain maximum. The asymptotic growth curve (eq 12, with time in days) simulates a competition starting directly at t=0.

$$LAI=\frac{a}{1+b*\exp(-c*time)} \qquad (11)$$

In which
a Maximum possible LAI
c Relative growth rate, while
b Rate of change in LAI

$$LAI=\frac{a_1*time}{1+b_1*time} \qquad (12)$$

The expolinear growth, a simplified growth model, gives the same results as the logistic growth curve. This is however only the case if the improved version (Goudriaan, 1994) is used. In the original article (Goudriaan and Monteith, 1990) it was assumed that the growth rate of a crop is stable for major part of the growing season. This assumption is only valid if light is the dominating limiting factor. If other limitations, like nutrient limitation, are included (f_m in eq. 13) the growth curve becomes similar to the logistic growth curve.

$$GrowthRate=\frac{c_m*f_m}{r_m}*\ln(1+\exp(r_m*(time-time_b))) \qquad (13)$$

In which		
	c_m	Max. absolute growth rate in the linear phase ($gm^{-2}d^{-1}$)
	f_m	Parameter decreasing linearly from 1 to 0 during the season to allow gradual reduction in formation of LAI due to nutrient stress (-)
	r_m	Max. relative growth rate in exponential phase (d^{-1})
	$time_b$	Timing parameter determining the position of the curve on the x-axis

Results:

LAI was measured during the 4th season (see Appendix V.6). The data are much lower than under non-limiting circumstances and indicate a very poor growth rate due to severe nutrient and soil moisture limitation. A trial near Ochinga farm indicated that yields for maize can be increased by a factor 4 if sufficient nitrogen and phosphorus is added. From the LAI data as such it is not possible to determine which factor was most limiting.

Biomass data collected during the 2nd season (Hartemink, 1994) and the biomass data collected during the 3rd season (Braun, 1995) were used to extrapolate the LAI to earlier seasons, with the use of eq. 15. No significant differences (at $P<0.05$) between the replicates of the weed fallows was found. Sesbania plots were significantly different ($P<0.05$) from each other and a separate growth curve had to be developed for each of the sesbania plots. The parameters for each of the fitted curves are indicated in Table 4.11. The asymptotic growth curve gave a somewhat worse simulation than the logistic growth curve (see Table 4.11 and Figure 4.9). Logistic growth curves were used in further analysis, presented for all treatments in Figure 4.10.

Table 4.11: Parameter estimates (and r^2) for a logistic growth curve and an asymptotic growth curve to descibe plant growth. For maize and the weed fallow an average could be used, because LAI differed not significantly between replicates (at $P<0.05$). All sesbania replicates were however significantly different (at $P<0.05$) and separate curves had to be used.

	maize	weeds	sesb.1	sesb.2	sesb.3	sesb.4
a	0.895	1.878	1.661	1.570	1.268	1.599
b	847.7	23.23	41.16	138.6	360.0	145.6
c	0.124	0.0265	0.0179	0.0241	0.0314	0.0241
r^2	0.992	0.968	0.837	0.782	0.847	0.952
a_1	-	0.00754	0.00384	0.00498	0.0102	0.00570
b_1	-	0.00208	0.000477	0.00133	0.00627	0.00173
r^2	-	0.778	0.769	0.660	0.706	0.884

In the sesbania plots the weed ground cover was analysed separately for the runoff calculations. Weed ground cover biomass was measured (see Appendix V.6). LAI could be estimated out of the biomass data with the use of eq. 15. This LAI was fitted against a logistic growth curve (see Figure 4.11) and was used in further calculations.

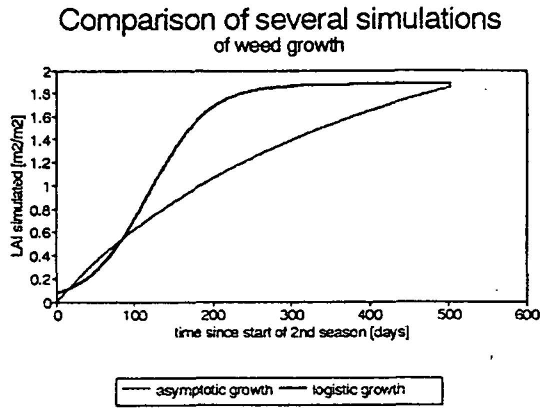

Figure 4.9: Comparison between simulations of growth in the weed fallow by a logistic curve and a asymptotic curve, respectively

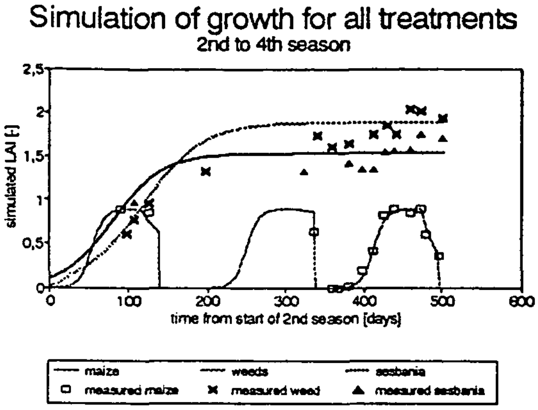

Figure 4.10: Development of LAI during the 2nd, 3rd and 4th season of the experiment. Note: Sesbania was planted before the start of the 2nd season.

In the 4th season total LAI remained constant, while weed ground cover increased. This indicates that the LAI of the sesbania trees decreased during this period. This is consistent with sesbania leaf biomass data (see 4.2.1.4), showing a decrease in the 4th season. This is caused by an increase in litter mortality during this season (see 4.2.1.6).

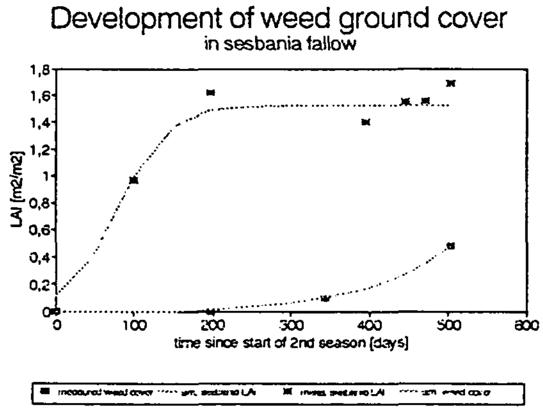

Figure 4.11: Development of weed ground cover compared to total growth development in the sesbania fallow

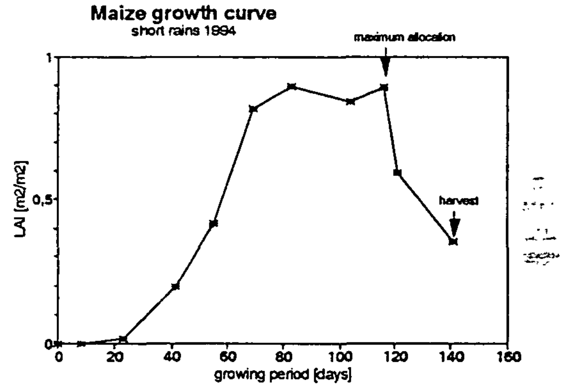

Figure 4.12: Measured growth of maize, indicated by LAI values

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$$LAI_{maize} = 0.90 * e^{-0.015*(time-115)} \quad 2^{nd} \text{ season}$$
$$LAI_{maize} = 0.90 * e^{-0.019*(time-115)} \quad 3^{rd} \text{ season}$$
$$LAI_{maize} = 0.88 * e^{-0.038*(time-115)} \quad 4^{th} \text{ season}$$

Figure 4.13: Exponential decrease of LAI in maize. Note that day 115 is the day of maximum allocation.

Additionally maize had an exponential decrease due to losses of biomass after maximum nutrient uptake was reached. Leaves died during reallocation of nutrients to the grains and by termite activity, similar to the injuries described by van der Werf et al. (1990). The decrease is described by Figure 4.13. Measured data for maize are presented in Figure 4.12.

The plant growth analysis indicates the severe limitations of biota and nutrients at Ochinga farm.

plant dimensions

Plant dimensions (as the height of each plant canopy and the leaf length of maize used in the evapotranspiration calculations, see Appendix III) were as much as possible described with the logistic growth curve (see eq. 11). For maize an exponential decrease was described similar to LAI:

$$Plant_{parameter}=a_2*\exp(-b_2*(time-115)) \tag{14}$$

Additionally a linear relationship between LAI and biomass (in kgha^{-1}) was derived with the use of linear regression:

$$TotalBiomass=a_3*LAI \tag{15}$$

This relationship can be helpful to estimate biomasses non-destructively. In Table 4.12, the empirical parameter estimates for the functions mentioned above are presented.

Table 4.12: Parameter estimates of a, b and c (and r^2) to describe several plant characteristics with eq. 11, parameter estimates a_2 and b_2 to describe maize decrease with eq. 14 and parameter a_3 to describe total biomass with eq. 15. Diameter is given in mm all other plant characteristics are given in m.

	a	b	c	a_2	b_2	a_3	r^2
weed biomass						5.43*10^3	0.66
height	1.45	23.33	0.0265				0.956
sesbania height	5.40	51.43	0.0137				0.913
biomass						1.01*10^3	0.54
width	3.31	175.4	0.0332				0.933
diameter	32.92	205.1	0.0157				0.833
maize height	1.462	17.97	0.0570	1.42	0.0718		0.979
leaf length	0.384	19.18	0.0978	0.38	0.0172		0.917
biomass						3.01*10^3	0.77

It was tried to find an allometric function between some easily measured plant characteristic of sesbania and its biomass. The best fit turned out to be the relation between total sesbania biomass and stem diameter at 30 cm height. The development of the diameter measured at 30 cm height is presented in Figure 4.14. This relation is given by (with diameter in mm and biomass in kgha^{-1}) (r^2=0.365):

$$TotalBiomass=6.276*10^3*Diameter \tag{16}$$

Relationships between biomass on the one side and height, width or height*width of the sesbania tree on the other side were less significant. The relationship is however less accurate than the relationship between biomass and LAI presented above.

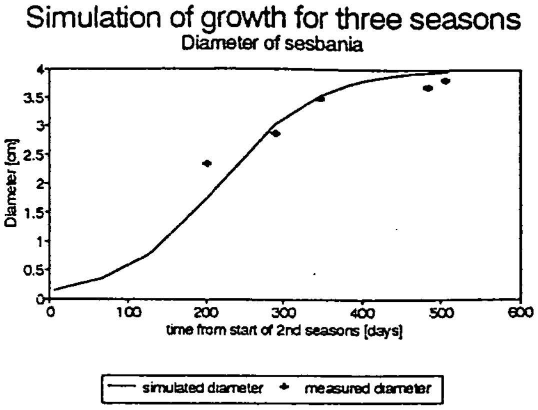


Figure 4.14: Change of the diameter of sesbania (measured at 0.3 m height) over the seasons

4.1.2 Estimated processes

Outputs:

4.1.2.1 Evapotranspiration

Background information:

Evaporation is the loss of soil water to the atmosphere. Transpiration is the loss of water out of the plant to the atmosphere. Evapotranspiration is the sum of evaporation and transpiration. The amount of evapotranspiration (ET) depends on soil cover, radiation, plant physiology and water content of the soil and is complicated to calculate. In the calculations presented below, it was not possible to distinguish directly between transpiration and evaporation. Therefore no subdivision has been made between transpiration and evaporation.

At a nearby experiment it was shown that early growth of sesbania was limited by phosphorus (J.K. Ndufa, unpublished data). Due to the extremely bad performance of the plants, caused by the combined effects of this nutrient stress (see also 4.1.1.6), water stress, striga, streak virus and termites, it was not possible to use normal ET-formulas directly. Commercial computermodels, like GAPS, assume normal performance and could not be used. This made the calculations even more complicated.

Results:

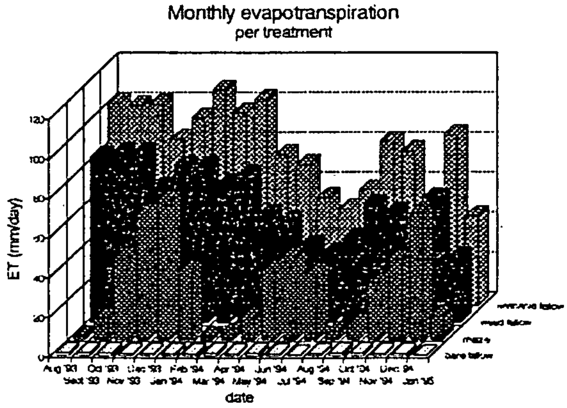


Figure 4.15: Monthly evapotranspiration per treatment

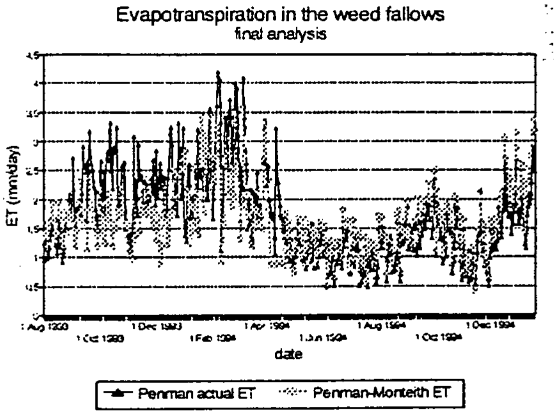


Figure 4.16: Comparison of two methods to calculate actual evapotranspiration in the weed fallow

At this point only the results are presented (see Figure 4.15). Confidence in the reliability of the results was obtained, because of the close similarity between two ways of approaching evapotranspiration (see Figure 4.16). More information about the calculations and the determination of useful approximations for this calculation can be found in Appendix III. Evapotranspiration per period is presented in Table 4.13.

Table 4.13: Calculated evapotranspiration (in mm) per treatment per period

	maize	bare fallow	sesbania fallow	weed fallow
2nd season	215.8	4.9	332.6	355.4
between seasons	1.8	1.8	97.5	89.8
3rd season	128.1	4.1	314.0	347.8
between seasons	0.6	0.6	45.3	55.7
4th season	151.0	5.1	338.9	350.9

4.1.2.2 Leaching

Background information:

For the purpose of soil moisture transport the concept of immobile and mobile water has been developed. Immobile water can't be transported by the force of gravity alone, while mobile water can. Only mobile water is therefore sensitive to leaching. This concept is used in the SLIM-model (Addiscott and Whitmore, 1991).

A more adequate description can be obtained by using soil hydraulic conductivities. Hydraulic conductivities describe the amount of moisture that can be transported through the soil per period of time as a function of soil moisture content. This dependency on soil moisture is extremely large, because of the influence of the pore system on hydraulic conductivity (Ball, 1985). Saturated hydraulic conductivities at Ochinga farm were presented by Hartemink (1994). Unsaturated hydraulic conductivities were measured by Braun (unpublished data) using a simplified version of the method presented in Baker et al. (1974).

Variability in hydraulic conductivity is usually very large. For this reason a thorough analysis of hydraulic conductivities is necessary. Measured hydraulic conductivities were compared with different mathematical approaches. Saturated hydraulic conductivities can be estimated based on the texture of the soil (Fahmy, 1961), see eq. 17.

$$K=\frac{C}{\eta * U^2} * \frac{n^3}{(1-n)^2} \qquad (17)$$

In which
C a constant (=330 kgm^{-2})
η viscosity (=$1.4*10^{-3}$ $kgm^{-1}s^{-1}$)
U specific surface calculated as:

$$U=\frac{1}{\ln(d_2)-\ln(d_1)} * \left(\frac{1}{d_1}-\frac{1}{d_2}\right) \qquad (18)$$

In which $d_{1,2}$ diameter boundaries of texture class

Hydraulic conductivities as a function of soil moisture contents can be estimated by approaches described by Campbell (1974) (eq. 19 and 20) and van Genuchten (1987) (eq 21 and 22). The Campbell model consists of two parts: An exponential part and a quadratic part. In between there is the inflection point, which

is very near saturation in clayey soils. This is the reason why the conductivities go asymptotically to the x-axis leading to too high values in the upper part of the curve.
With the Campbell method it is not possible to estimate saturated hydraulic conductivity independently, while this is possible with the iterative RETC-model van Genuchten (1987).

$$h=a\left(\frac{\theta}{\theta_s}\right)^{-b} \tag{19}$$

$$K(\theta)=K_s*\left(\frac{\theta}{\theta_s}\right)^{2b+3} \tag{20}$$

$$\theta=\theta_r+\frac{(\theta_s-\theta_r)}{[(1+(\alpha h)^n]^m} \tag{21}$$

In which m=1-1/n

$$\frac{K}{K_s}=\sqrt{\theta}*[1-(1-\theta^{1/m})^{m^2}] \tag{22}$$

Wösten et al. (1994) calculated the van Genuchten parameters for Dutch heavy clayey soils and found Θ_s =0.58, Θ_r=0, K_s=5.26, α=0.0243 and n=1.169. The estimated hydraulic conductivities were used to simulate leaching of soil moisture with the LEACHW-model (Wagenet and Hutson, 1989). This computer model calculates soil moisture changes per day using rainfall, soil moisture, plant growth and soil physical data.

Results:

A comparison between measured saturated conductivities and simulated saturated conductivities is given in Table 4.14.

Table 4.14: Comparison of measured saturated hydraulic conductivities (K_{sat}) in mday^{-1} with simulated hydraulic conductivities using approaches desribed by Fahmy (1961) and van Genuchten (1987) for different depths

depth (m)	measured	Fahmy	van Genuchten
0-0.15	1.84	11.3	1.705
0.15-0.30	6.59	10.9	7.068
0.30-0.50	3.92	6.17	4.078
0.50-1.00	0.024	20.3	1.824
1.00-1.50	1.0	12.5	7.797
1.50-2.00	0.30	15.4	7.618

The simplified method of Fahmy seems to overestimate hydraulic conductivities. It is possible that this is due to the fact that this method was originally developed for sandy soils with low clay contents, which is not the case at Ochinga farm. Measured hydraulic conductivity decreases very fast below the 3rd layer. Such a decrease would not be expected as texture and water potentials do not indicate large differences between the moisture regime of the 3rd layer and the moisture regimes of deeper layers. Estimations using Fahmy (1961) and van Genuchten (1987) don't indicate those differences either, nor do visual observations on samples under extraction. Estimations using van Genuchten (1987) were used in further analysis.

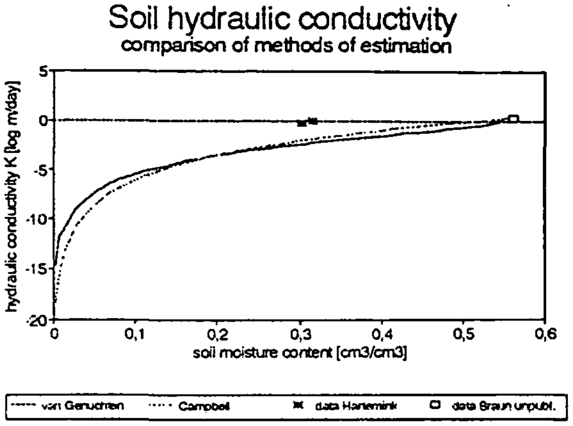


Figure 4.17: The relationship between soil hydraulic conductivity and soil moisture contents for simulated and measured data

The calculations based on van Genuchten (1987) and Campbell (1974) gave similar results on the relationship between soil moisture and hydraulic conductivity (see Figure 4.17), both however deviating considerably from the data collected by Hartemink (1994). The coincidence of both models and the high regression coefficient between calculated soil moisture contents at a certain water potential and observed soil moisture contents however gave some confidence in the estimations. Regression coefficients and parameter estimates for each layer are presented in Table 4.15. The estimated van Genuchten parameters are similar to those estimated by Wösten et al. (1994) for Dutch heavy clayey soils.

Table 4.15: Parameter estimates and regression coefficients for the calculation of hydraulic conductivity as a function of soil moisture content for the Campbell (1974) equations (eq. 19 and 20) and the van Genuchten (1987) parameters (eq. 21 and 22). For van Genuchten α=0.04, l=0.0001 and Θ_r=0.00.

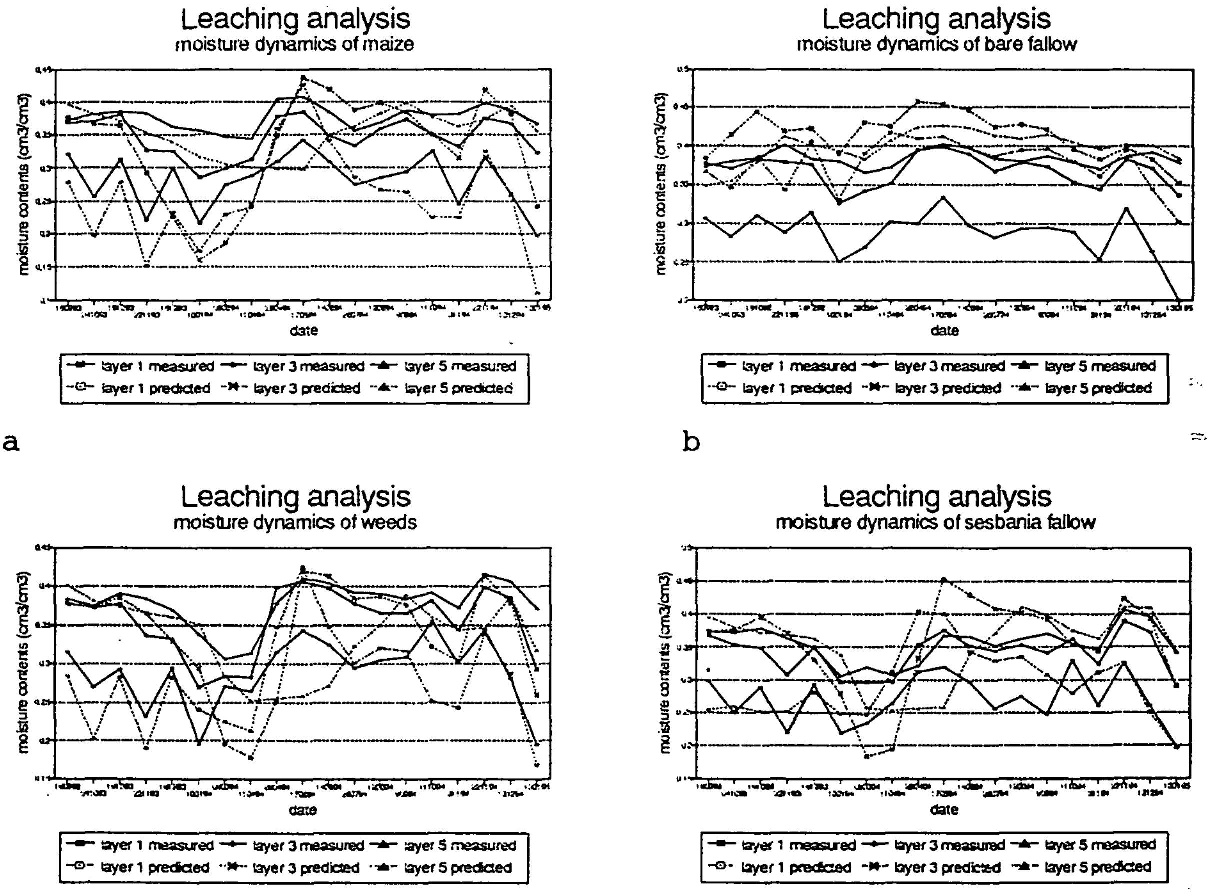
depth	Campbell (1974)			van Genuchten (1987)			
(m)	a	b	r^2	Θ_s	n	K_{sat}	r^2
0-0.15	0.776	8.43	0.993	0.55	1.463	1.71	0.960
0.15-0.30	1.13	10.5	0.997	0.58	1.287	7.07	0.994
0.30-0.50	2.04	12.1	0.976	0.52	1.247	4.08	0.998
0.50-1.00	0.748	11.4	0.992	0.60	1.344	1.82	0.943
1.00-1.50	2.13	14.2	0.974	0.50	1.196	7.80	0.997
1.50-2.00	1.51	13.1	0.990	0.53	1.219	7.62	0.998

Estimates of hydraulic conductivity based on van Genuchten (1987) were chosen for further analysis of leaching, because saturated hydraulic conductivity could be estimated independently with this method. This avoids additional assumptions. This is not possible when applying the Campbell method. Van genuchten parameters were also used in the calculations of evapotranspiration, see Appendix III.

With the confidence gained in the estimates of hydraulic conductivity, it is possible to simulate leaching of soil moisture with the LEACHW-model (Wagenet and Hutson, 1989). This was carried out for all treatments on a slightly revised version of LEACHW using van Genuchten parameters. Results of this simulation are presented in Table 4.16.

Table 4.16: Soil moisture leaching estimates (in mm) for all treatments per period based on simulations with the LEACHW-simulation model.

	maize	bare fallow	weed fallow	sesbania fallow
2nd season	112.1	172.1	160.5	137.0
between seasons	20.2	60.8	21.3	16.0
3rd season	114.2	167.7	139.9	221.0
between seasons	17.3	35.5	15.4	21.4
4th season	198.1	191.7	178.6	188.0



a

b

c

d

Figure 4.18$_{a,b,c,d}$: Comparison of observed soil moisture contents with predicted soil moisture contents using the LEACHW simulation model for the 2nd, 3rd and 4th season of the experiment

Reliability of the results was controlled by comparing observed soil moisture contents during the 2nd, 3rd and 4th season of the experiment with predicted soil moisture contents as simulated by the model (see Figure $4.18_{a,b,c,d}$).

Differences in soil moisture storage between two sampling times is an indirect measure of leaching. Large changes in soil moisture storage can indicate the probability of leaching. Changes in soil moisture storage especially occurred at the end of each rainy season and during those periods. Leaching losses were also highest during those periods.

4.1.2.3 Plant water uptake

Plant uptake of water is per definition equal to tranpiration losses. Transpiration could be calculated out of evapotranspiration with the use of the equation given by Ritchie and Burnett (1971) (= eq. 55 in Appendix III). Transpiration values per season are presented in Table 4.17.

Table 4.17: Transpiration (in mm) per period per treatment. For the seasons two moments where used. Subscript a indicates the season until biomass assessment at maximum LAI (December and June), while subscript b indicates the rest of the season until harvest (January and August). The period of each season is indicated in Chapter 2.

	2nd season$_a$	2nd season$_b$	between seasons	3rd season$_a$	3rd season$_b$	between seasons	4th season$_a$	4th season$_b$
maize	115.4	3.5	0	57.5	22.6	0	62.0	28.3
sesbania	99.3	92.7	87.2	238.9	44.6	37.3	232.8	74.9
weed	110.0	102.1	79.2	350.0	63.8	57.8	352.9	124.0

With the use of the plant uptake per season and biomass assessments (presented in 4.2.1.4) (corrected for biomass losses by termites, weed turnover, litterfall, thinning and weeding) it is possible to calculate the transpiration coefficient. The transpiration coefficient indicates the production of biomass (based on a dry weight basis) per amount of water transpired, in kgm^{-3} see Table 4.18.

The transpiration coefficient increases when a crop is exposed to drought, according to Haverkort and Goudriaan (1994). This trend was however not found in this experiment. Maybe this is caused, because for LAI<2 the transpiration coefficient is fairly constant (Ritchie, 1983). Hanks (1983) also mentions a constant transpiration coefficient under different circumstances. Nutrient stress on the other hand, as in this case, can have an effect on transpiration coefficient due to its large impact on yield. Also losses of biomass in the weed fallow and sesbania fallow contribute to the decrease in transpiration coefficient in the course of the experiment.

Table 4.18: Transpiration coefficients in kgm^{-3} per season per treatment based on biomass data and transpiration estimates

	2nd season$_a$	2nd season$_b$	between seasons	3rd season$_a$	3rd season$_b$	between seasons	4th season$_a$	4th season$_b$
maize	3.55	3.44	0	5.01	5.28	0	5.54	3.82
sesbania	4.37		4.58		3.51			2.59
weed	3.35		1.54		2.69	2.31		2.01

4.2 Nitrogen and phosphorus dynamics

4.2.1 Measured processes

The nitrogen and phosphorus dynamics will be presented together, because the methodology of measurement was similar for both components.

Inputs:

4.2.1.1 Seeds

Background information:

Seed input and tree nursery input are hardly measured. Paustian et al. (1990) mention an input of 5 kg Nha^{-1}. For phosphorus inputs no data could be found at all.

Results:

Input of nitrogen and phosphorus with seeds at Ochinga farm was measured by drying a selected amount of seeds for nutrient analysis. For maize the nutrients contents were 0.005 g N/seed and 0.001 g P/seed respectively. This led to an input of 0.550 kgNha^{-1} and 0.108 kgPha^{-1}, respectively, due to double sowing for even rise.

For sesbania the nuntrient contents were $4.1*10^{-4}$ g N/seed and $4.4*10^{-5}$ g P/seed, leading to an input of 0.0045 kg Nha^{-1} and 0.0005 kg Pha^{-1} in April 1993. Most of the measurements however started in August 1993. By then the sesbania had grown and this biomass of sesbania is treated as the initial plant input. The biomass of sesbania was however not measured directly. Out of the logistic growth curve for LAI, which is linearly correlated to biomass (see 4.1.1.6) it was possible to calculate the initial biomass of sesbania at the 1st of September 1993. The initial biomass was 11.4% of the biomass measured at 8 December 1993. This means a tree nursery input of 6.65 kg Nha^{-1} and 0.330 kg Pha-^{1} respectively. These values were used in further calculations.

4.2.1.2 Throughfall and rainfall

Wet deposition

Background information:

Young and Muraya (1990) assume a constant wet deposition of 6.0 kg N/ha/yr in the humid tropics. Wolf et al. (1989) estimate wet deposition to be 15 kg Nha^{-1}yr^{-1} in Western Europe and Paustian et al. (1990) estimate wet deposition to be 5 kg Nha^{-1}yr^{-1}. For wet deposition of phosphorus, no data based on measurements were found in literature.

Two empirical formulas were given: Parton et al. (1987) estimate the wet deposition (in kg Nha^{-1}yr^{-1}) (with rain in mmyr^{-1}) by:

$$Wetdeposition = 2.1 + 0.0028 * rain \qquad (23)$$

This would become 7.5 kg Nha^{-1}yr^{-1} under the conditions of Ochinga farm. Stoorvogel and Smaling (1990) used the following equation (yielding 6.15 kg Nha^{-1}yr^{-1} for Ochinga farm) with the same units as above:

$$Wetdeposition = 0.14 * \sqrt{rain} \qquad (24)$$

The authors used a similar transfer equation for wet deposition of phosphorus with wet deposition in kg $Pha^{-1}yr^{-1}$ and rainfall in $mmyr^{-1}$ (yielding 2.31 kg $Pha^{-1}yr^{-1}$ for Ochinga farm):

$$P_2O_5 = 0.053 * \sqrt{rain} \qquad (25)$$

Results:

Wet deposition was measured at Ochinga farm during several rainfall events in the 4th season. The data of these measurements can be found in Appendix VI.1 and Figure 4.19. Total nitrogen gave the best correlation with rainfall (better than nitrate, ammonia or total inorganic nitrogen) and was used in further analysis. Total phosphorus in water was used in the phosphorus analysis. Multiple regression on nitrogen data (see Table 4.19) showed that rainfall intensity had no significant influence (at $P<0.05$) on wet deposition.

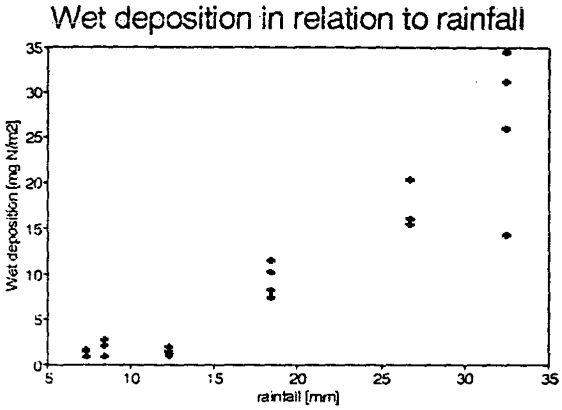


Figure 4.19: Relationship between the measured wet deposition and rainfall.

Table 4.19: Probabilities (and r^2) of the two and one parameter models given for the best fits of the multiple regression analysis of wet deposition of nitrogen. Note: No intercept was taken into account in model 3.

model	r^2	P-model	P-rainfall	P-intensity	P-intercept
1	0.924	0.0097	0.1418	0.555	0.1959
2	0.948	0.001	0.001		0.0326
3	0.909	0.0009	0.0009		-

Forcing the function through the square root of rainfall also gave worse results ($r^2=0.495$ for nitrogen). The best fit without intercept, with wet deposition in kg Nha^{-1} and rainfall in $mmyr^{-1}$, is given by ($r^2=0.909$):

$$WetDeposition_N = 6.64 * 10^{-3} * rain \qquad (26)$$

The best fit for phosphorus, with wet deposition in kg $Pha^{-1}yr^{-1}$ and rainfall in $mmyr^{-1}$, is given by ($r^2=0.401$):

$$WetDeposition_P = 7.19 * 10^{-4} * rain \qquad (27)$$

Seasonal wet deposition of nitrogen and phosphorus are presented in Table 4.20. The seasonal wet deposition for nitrogen is lower than would be expected on the transfer functions given above, while the wet deposition for phosphorus is lower than would be expected from the transfer function of Stoorvogel and Smaling (1990).

Table 4.20: Wet deposition of nitrogen and phosphorus (in kgha^{-1}) per period

	nitrogen wet deposition	phosphorus wet deposition
2nd season	3.25	0.352
between seasons	0.59	0.064
3rd season	6.90	0.747
between seasonS	0.95	0.106
4th season	4.17	0.451

Throughfall

Background information:

In a forest a throughfall of 3 kg Nha^{-1}yr^{-1} (Hart et al., 1991) and 5 kg Nha^{-1}yr^{-1} (Young and Muraya, 1990) respectively was measured. No phosphorus data were found in literature.

Results:

Throughfall was also measured at Ochinga farm. Data are presented in Appendix VI.1. Throughfall was significantly influenced by rainfall only at P<0.05. This yields for nitrogen, with throughfall in kg ha^{-1} and rain in mmyr^{-1} (r^2=0.708):

$$Throughfall_N = 9.19*10^{-3}*rain - 2.32 \qquad (28)$$

Phosphorus in throughfall could also best be described with a linear relationship (with the same units as above) (r^2=0.826):

$$Throughfall_P = 1.11*10^{-4}*rain \qquad (29)$$

The difference between the amount of nutrients in throughfall and rainfall is taken up by plants or leached from leaves. The amount of nitrogen leached from the leaves was not significantly different from zero (at P<0.05). Sesbania had some significant uptake of phosphorus (at P<0.05) from rain water, howver. This uptake of phosphorus is another indication of the phosphorus deficiency of the site (Data presented in Appendix VI.1).

4.2.1.3 Dry deposition

Background information:

According to Stoorvogel (1993) dry deposition is only significant if rainfall is low. This is the reason why dry deposition was only measured in the drier periods. In the rainy seasons dry deposition was assumed to be absent.

Results:

Dry deposition collectors were installed at Ochinga farm directly after the long rains of 1994 (in the 4th season) ended. Data are presented in Appendix VI.2. Dry deposition was equal to 0.713 kg d.w.ha^{-1}day^{-1}. With the use of the measured nitrogen and phosphorus in the topsoil it was possible to calculate the dry deposition of nutrients. This was calculated to be 1.076 g $Nha^{-1}day^{-1}$ and 0.460 g $Pha^{-1}day^{-1}$. Dry deposition was only significant between two rainy seasons.

Dry deposition for the period between the short rains of 1993 and the long rains of 1994 was estimated at 0.0581 kg Nha^{-1} and 0.0165 kg Pha^{-1}. Dry deposition between the long rains of 1994 and the short rains of 1994 was estimated to be 0.0204 kg Nha^{-1} and 0.00592 kg Pha^{-1}. These were very small amounts as expected.

Internal:

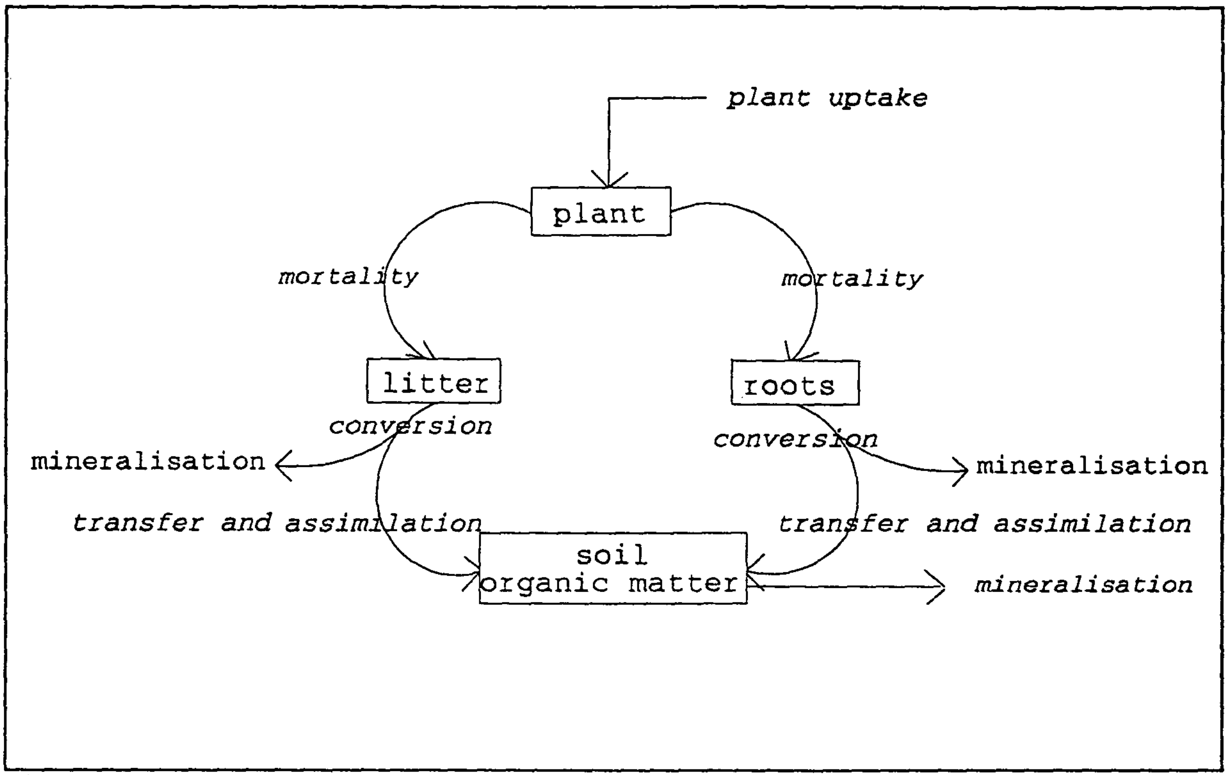


Figure 4.20: Schematic repressentation of organic nitrogen dynamics

Most of the transformations of nitrogen and phoshorus are organic matter transformations. Transformations of organic matter are shown schematically in Figure 4.20. Inorganic soil nitrogen is taken up by plants. This plant uptake is divided in uptake for aboveground biomass (section 4.2.1.4) and root production (section 4.2.1.5). After uptake it flows back into the soil through different paths. After mortality, for aboveground biomass presented in section 4.2.1.6, the dead material will be conversed. This conversion is described separately for litter (section 4.2.1.8) and for roots (section 4.2.1.7). Under certain conditions nutrients can mineralise directly from this dead material. The remaining material will be immobilised and flows into the soil organic matter pool. From the soil organic matter pool nutrients will be transformed into inorganic nutrients, soil mineralisation (section 4.2.1.9). An integrated model of soil organic matter dynamics is presented by Parton et al. (1987). After mineralisation nutrients are back in the soil solution. Changes in inorganic nitrogen in the soil solution are described in section 4.2.1.10.

4.2.1.4 Plant uptake

Background information:

Some yield data on fallow systems were found in literature. Paustian et al. (1990) present a production of $8.4*10^3$ $kgha^{-1}yr^{-1}$ for a weed fallow and $9.0*10^3$ $kgha^{-1}yr^{-1}$ for a nitrogen fixing fallow. Leguminous species contain more nitrogen than non-leguminous species (Oglesby and Fownes, 1992). Wielemaker and Boxem (1982) mention a nitrogen uptake of 56 kg Nha^{-1} for the first season of a fallow. Phosphorus content data were less available than nitrate and total biomass data. Shepherd et al. (1993) mention a content of 10.5 kg $Pha^{-1}yr^{-1}$ for an improved fallow. Wielemaker and Boxem (1982) mention an average phosphorus content of 8.7 kg Pha^{-1} in the first fallow season in the Kisii area.

Nitrogen uptake by maize is about 250 kg $Nha^{-1}yr^{-1}$ in temperate regions (Brady, 1985). Osmond et al. (1992) mention an uptake of 120 kg $Nha^{-1}yr^{-1}$ for maize in tropical regions. Plant uptake can however not be taken as a fixed value, because nitrogen uptake is determined by the most deficient nutrient. Under nutrient limiting circumstances plant uptake, and crop yields, are much lower than under fertile conditions. Shepherd et al. (in draft) simulated a nitrogen content of 38 $kgNha^{-1}$ for maize under similar limiting circumstances as at Ochinga farm. Wielemaker and Boxem (1982) mention an average nitrogen content of 25 kg Nha^{-1} for maize in the Kisii area in Western Kenya. Both literature values do not take losses into account. Shepherd et al. (1993) mentions a maize content equal to 3.9 kg $Pha^{-1}yr^{-1}$. Wielemaker and Boxem (1982) present an average maize content equal to 9.6 kg Pha^{-1} per season for the Kisii area.

Plant uptake is not constant during the season, but depends on the age of the plants. When all leaves have uniform nutrient contents, the uptake rate is simply the derivation of the growth curve of LAI (Goudriaan, 1994). This means for the Ochinga situation that during the 4th season the uptake rate for weeds and sesbania was rather constant (see 4.1.1.6). In this study uptake dynamics was not necessary and biomass and nutrient contents were measured at the end of each season.

Results:

Plant biomass was measured at the end of each season, see Tables 4.21, 4.22 and 4.23. Complete data sets for the 2nd and 3rd season were already presented in Hartemink (1994) and by Braun (1995), respectively. Data on the 4th season are presented in Appendix VI.3.

The data presented in the Tables 4.21, 4.22 and 4.23 only contain data of aboveground biomass. Root production and root mortality are treated in separate sections (4.2.1.5 and 4.2.1.7 respectively). Weeds in sesbania had the same nutrient contents as weeds in the weed fallow. The weed species were also comparable (see 4.2.1.8). Plant nutrients presented are not equal to total nutrient uptake, because some of the nutrients taken up were lost before harvesting. Most losses occurred by mortality. Another part of the losses were however caused by weeding and thinning and part of the losses in maize were due to termite consumption. Termite consumption also caused an exponential decrease in maize biomass in the last month before harvest. Between maximum allocation and harvest, nutrients were not only reallocated, but were also lost and incorporated in soil organic matter by the termites. A correction for total nutrient uptake per period was therefore carried out.

Table 4.21: Average plant biomass and plant nitrogen data and standard deviation (S.D.) of the average values (all in $kgha^{-1}$) for the sesbania fallow

	yield		plant N		Plant P	
	mean	S.D.	mean	S.D.	mean	S.D.
Season 2						
weeding 6/10/93	235	102	3.53	1.83	0.226	0.110
weeding 23/11/93	61	8	1.18	0.09	0.069	0.008
biomass leaf 8/12/93	984	599	40.31	25.27	1.787	1.319
biomass wood 8/12/93	2954	2221	17.95	11.24	1.102	0.805
Season 3						
biomass leaf 18/3/94	1648	919	48.5	27.73	1.635	0.953
biomass wood 18/3/94	8123	4389	64.3	37.49	2.047	1.224
biomass weed 10/8/94	522	286	6.5	3.65	0.481	0.264
biomass wood >2 cm 9/8/94	12515	6450	37.0	17.68	2.295	1.489
biomass wood <2 cm 9/8/94	16486	4406	90.1	38.06	4.938	2.733
biomass leaf 9/8/94	7146	2493	256.5	95.87	11.43	5.348
biomass pods 9/8/94	113	116	2.1	2.16	0.142	0.169
Season 4						
biomass weed 16/1/95	2637	332	26.7	2.12	2.23	0.94
biomass wood >2 cm 16/1/95	10257	1451	66.6	27.95	3.06	1.42
biomass wood <2 cm 16/1/95	10337	592	84.3	47.71	4.00	2.20
biomass leaf 16/1/95	1813	398	64.1	41.43	2.41	1.56
biomass pods 16/1/95	76.5	40.6	3.4	3.16	0.25	0.23

Table 4.22:Average plant biomass and plant nitrogen data and the standard deviation (S.D.) of the average values (all in kgha^{-1}) for maize

	yield		plant N		plant P	
	mean	S.D.	mean	S.D.	mean	S.D.
Season 2						
thinning 6/10/93	159	22.1	3.84	0.925	0.220	0.053
weeding 6/10/93	177	68.2	2.77	0.945	0.183	0.067
weeding 23/11/93	127	16.7	2.35	0.432	0.152	0.028
biomass maize 8/12/93	3630	648.3	50.83	10.64	3.817	0.891
harvest stover 17/1/94	1912	160.9	17.75	3.402	1.231	0.133
harvest rachis 17/1/94	138	42.7	1.85	0.721	0.198	0.093
harvest grain 17/1/94	414	160.9	8.16	3.187	1.974	0.830
Season 3						
thinning 19/4/94	164	22.1	4.8	0.60	0.244	0.042
weeding 27/4/94	37	16.1	1.2	0.59	0.060	0.026
biomass maize 13/6/94	2681	346.3	44.6	4.93	2.737	0.385
weeding 4/8/94	726	413.0	12.6	10.49	1.075	0.819
harvest stover 4/8/94	2573	725.2	20.4	5.47	1.366	0.331
harvest rachis 4/8/94	293	106.2	1.5	0.47	0.112	0.043
harvest grain 4/8/94	1654	813.7	24.4	12.46	2.435	1.384
Season 4						
thinning 17/9/94	258.8	129.3	7.50	3.77	0.50	0.25
weeding 17/9/94	42.0	6.97	1.11	0.14	0.074	0.008
weeding 14/12/94	330.7	76.9	5.96	1.21	0.45	0.11
biomass stover 16/12/94	2482	481.0	35.0	6.8	2.56	0.50
biomass cob 16/12/94	325.4	268.3	6.02	5.0	0.93	0.77
weeding 9/1/95	13.6	6.51	0.29	0.14	0.025	0.011
harvest stover 9/1/95	1241	431.1	9.93	3.45	0.683	0.237
harvest rachis 9/1/95	106.0	53.0	0.54	0.27	0.042	0.021
harvest grain 9/1/95	408.3	299.8	5.89	4.41	0.780	0.605

Table 4.23: Average plant biomass and plant nitrogen and phosphorus data and the standard deviation (S.D.) of the average values (all in kgha^{-1}) for the weed fallow

	yield		Plant N		Plant P	
	mean	S.D.	mean	S.D.	mean	S.D.
Season 2						
biomass 8/12/93	3282	1131	63.45	22.87	2.897	0.983
Season 3						
biomass 18/3/94	3876	1070	67.5	15.02	2.795	0.797
biomass 8/8/94	9390	2654	69.9	19.89	7.532	3.335
biomass regrowth 8/8/94	3389	1544	30.5	14.02	3.144	1.537
Season 4						
biomass regrowth 16/1/95	2407	387	21.43	3.12	2.790	0.552
biomass 16/1/95	10561	2858	86.61	39.16	11.002	5.043

For Ochinga a yearly yield of 9.0*10^{3} kgha^{-1}yr^{-1} in the weed fallow and of 10.1*10^{3} kgha^{-1}yr^{-1} in the sesbania fallow can be derived from the measured data. These yields are similar to those mentioned by Paustian et al. (1990). Total nitrogen uptake was much higher in the sesbania fallow than in the weed fallow. This is not necessarily caused by the fact that leguminous species contain more nitrogen than non-leguminous species. It can also have been caused by the fact that sesbania root production was higher (see section 4.2.1.5) and that sesbania roots were deeper, facilitating a better extraction of nutrients. Nutrient uptake in the 2nd season, when both root systems were more similar, was similar in the weed fallow and the sesbania fallow. Their nitrogen uptake in this season, see Tables 4.24, was higher than the values for the first season of a fallow mentioned by Wielemaker and Boxem (1982). Phosphorus uptake in the first season of the fallow systems, presented in Table 4.25, was however much lower than the average yield after the first season presented by Wielemaker and Boxem (1982). This lower uptake can be an indication of the phosphorus limitation at the site.

Nitrogen uptake by maize was also much lower than could be expected under non-limiting nutrient circumstances. Phosphorus deficiency at Ochinga farm can have had a large effect on the nitrogen uptake, leading to low nitrogen uptake compared to literature values. The maize grain to stover ratio's were low, indicating poorly filled cobs, confirming the phosphorus deficiency. On average a nitrogen uptake of 60.3 kg Nha^{-1} was measured. Without correction for losses the uptake would be 37.3 kg Nha^{-1}, which is in coincidence with literature values for limiting circumstances. Phosphorus uptake in maize was a bit higher than the values presented by Shepherd et al. (1993), but was lower than the average phosphorus uptake in the Kisii area.

Table 4.24: Nitrogen uptake per season per treatment after corrections for plant nutrient losses

	maize	weed fallow	sesbania fallow
2nd season	59.79	72.36	65.42
between seasons	0	18.04	58.07
3rd season	64.9	128.7	110.3
between seasons	0	29.4	8.14
4th season	55.88	120.23	94.63

Table 4.25: Phosphorus uptake (in kg Pha^{-1}) corrected for biomass losses per treatment per season

	maize	weed fallow	sesbania fallow
2nd season	4.372	3.156	3.255
between seasons	0	0.304	0.895
3rd season	5.292	8.401	6.938
between seasons	0	0.869	0.368
4th season	4.539	8.940	4.008

4.2.1.5 Root production

Background information:

Initial root development seems to be largely under genetic control. Later the complex array of environmental factors appear to have the strongest influence (Fogel, 1985). Very loose soil negatively affects root penetration through incomplete root-soil contact (Noordwijk et al., 1991). Most of the times, however, downward penetration of roots is limited by mechanical impedance (Stone and Kalisz, 1991). This is the reason that old root channels are important for root penetration (Noordwijk et al. (1991)). This may become important for maize growth in the 5th season when residual effects are measured.

Root distribution with depth of tree species related to sesbania was found to have the same rooting pattern as maize (Jonsson et al., 1988; Dyani et al., 1990). This would be an disadvantage in alley cropping (because competition would be expected), but becomes an advantage in improved fallows (because old root channels can be expected).

Based on a review of literature Santantonio and Grace (1987) conclude that root production estimates vary widely: $1.4\text{-}11.5*10^3$ $kgha^{-1}yr^{-1}$. Total root production estimates for weed fallows in temperate regions are given in literature: Hansson and Andrén (1986) present $3.6*10^3$ $kgha^{-1}$ for a grass fallow and Steen (1989) presents $2.4*10^3$ $kgha^{-1}$ for a red clover. Paustian et al. (1990) found in fallow systems a higher root production than in a crop.

Results:

Root distribution at Ochinga farm is presented in Figure 4.21 (Data K.Mekonnen, in press). Root production was measured during the 4th season (see Appendix VI.4). With the use of root distribution data, root production in the complete profile could be calculated, because the same method for root extraction was used in both studies.

Root production is presented in Table 4.26. The average root production is the equal to the numeric average because the samples were representative for areas equal in size. Root production was found to be significantly influenced by treatment and relative distance from the plant ($P<0.05$). Average measured root production was 30.9 kg d.w.ha^{-1}day^{-1} for maize and 73.01 kgha^{-1}day^{-1} for sesbania. Total root production for the fourth season was calculated by multiplying the average root production per treatment by the number of days in the season. Total root production per season in the weed fallow, being 5.9*10^{3} kgha^{-1}, is higher than the root production for weed fallows given in temperate regions given in literature. Root production in the sesbania fallow (9.9*10^{3} kgha^{-1} per season) was even higher. In the fallows a higher root production was found than in the crop (in which a root production of 4.4*10^{3} kgha^{-1} was measured per season) as already found by Paustian et al. (1990).

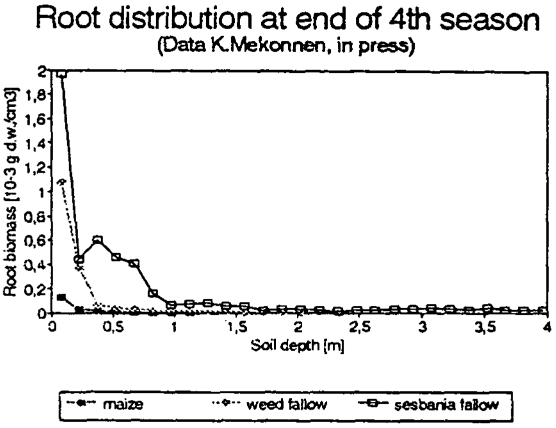


Figure 4.21: Root distribution with depth at Ochinga farm (November 1994) (Data K. Mekonnen, in press)

Table 4.26: Root production rate (in kgha^{-1}day^{-1}) and relative root production rate (in day^{-1}) for the three treatment having a canopy as a function of distance from the plant row (in m)

	distance	production rate	rel. production rate
maize	0.125	32.02	0.04145
	0.25	33.43	0.07857
	0.375	27.24	0.07135
sesbania fallow	0.25	66.14	0.00914
	0.50	83.66	0.02129
	0.75	82.87	0.02080
	1.00	59.36	0.03010
weed fallow	-	42.74	0.01284

In the 2nd and 3rd season, root production rates however will have been lower, because there was less biomass. The root ingrowth core estimates could not be used directly for those seasons. It is however known that plants strive after a constant aboveground/belowground ratio under constant nutrient conditions determined by the offer of nutrients (Brouwer, 1962; Hunt, 1978). This leads to a similar growth curve for roots as already measured for the aboveground biomass. For this growth curve parameter a, mentioned in eq. 11, is the only parameter changing and this parameter can be calculated from measured root biomass data at maturity and the known parameters b and c in equation 11.

Parameter a, the relative root growth rate, is also presented in Table 4.26. Relative root production was also found to be significantly influenced by treatment and relative distance from the stem.

Root production is the derivative of the growth curve, by definition, and is described by:

$$Production = rgr * biomass * (1 - \frac{biomass}{biomass_{max}})$$

In which rgr relative growth rate (=parameter a of eq. 11)

All parameters at the right hand side are known and the production in the 2nd and 3rd season could be calculated from the known root growth curve.

Maize production would be 32 kg d.w.ha^{-1}day^{-1} based on this calculation at day 75 (the average day of the incubation of the ingrowth root cores). This calculated growth rate is similar to the average root production measured with the root ingrowth cores. Average production rates per period based on this derivative per day per season are presented in Table 4.27. The average production estimates for maize become slightly lower than the estimates based on the root ingrowth core, because a lower growth rate occurs at the beginning of the season and there is not corrected for with the root ingrowth cores. For the other treatments root production rates for the 4th season were quite similar to those estimated with the root ingrowth cores.

le 4.27: Mortality rates, production rates and net production rates (all in kg d.w.ha^{-1}day^{-1}) period per treatment

	mortality rate			total production rate			net production rate		
	maize	sesbania	weed	maize	sesbania	weed	maize	sesbania	weed
season	27.5	2.346	1.374	27.5	37.21	12.21	0	4.86	10.84
ween seasons	0	20.48	11.87	0	37.76	22.84	0	17.48	10.97
season	28.21	65.01	37.42	28.21	67.80	39.25	0	2.79	1.83
ween seasons	0	76.66	44.88	0	76.94	45.02	0	0.28	0.14
season	28.93	76.66	44.88	28.93	76.72	44.91	0	0.06	0.03

In this table average root mortality rates (per day) are also presented based on the seasonal estimates presented in Table 4.27 (see section 4.2.1.7). This allowed to estimate net production rates (being the difference in root mortality and root production). These values are also presented in Table 4.27. For maize the net production per season was zero, because everything died at harvest.

Total mortality, root production and root net production per season for sesbania are presented in Figure 4.22. The weed fallow shows a similar trend: Root production increased in time due to an increasing living biomass. Because of the development of mortality (due to die-off of the same root biomass), net production decreased to zero. With net production rates becoming zero, root biomass stabilised at a constant value.

Seasonal root production values based on the growth curve are presented in Table 4.28. For the fourth season, the estimates are similar to those measured with the root ingrowth cores.

With the use of measured nutrient contents in living roots (presented in Table VI.4.3 and Table VI.4.1 in Appendix VI.4) it is possible to convert the biomass production to nutrient uptake for root growth (by multiplication). These seasonal uptake values are presented in Chapter 5 and were used in the calculations of the seasonal budgets.

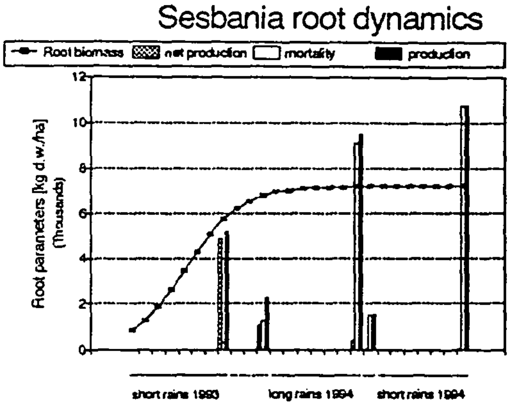


Figure 4.22: Mortality, root production and root net production and root biomass per season in the sesbania fallow

Table 4.28: Seasonal root production (in kg d.w.ha^{-1}) per period for the various vegetations

	maize	sesbania fallow	weed fallow
2nd season	3862.1	5208.9	1709.4
between seasons	0	2265.7	1370.3
3rd season	3954.8	9492.0	5495.5
between seasons	0	1538.8	900.5
4th season	4094.6	10740.9	6286.9

4.2.1.6 Leaf mortality

Sesbania leaf mortality

Background information:

Litter productivity for an oak forest amounted 27 kg Nha^{-1}yr^{-1} (Jackson et al., 1990) and Hart et al. (1991) found a production of 24 kg Nha^{-1}yr^{-1}. No data were found in literature concerning phosphorus losses due to litter mortality.

Results:

Litter fall (=leaf mortality) in the sesbania plots for Ochinga farm was measured during the 3rd season (presented in Braun (1995)) and during the 4th season (presented in Appendix VI.6). Results are shown in Figure 4.23. Nutrient contents of the litter is presented in Table 4.30.

Differences in leaf mortality between the replicates were significant at $P<0.05$. These differences were however caused by differences in LAI amounts. The replicates were not significantly different after dividing all data by its LAI, yielding litter fall per leaf area. These corrected values are shown in Figure 4.24 together with average climate circumstances. Statistical analysis of the influence of climatic circumstances on litter fall dynamics is presented in Table 4.29. Climatic circumstances were only of significant influence (at $P<0.05$) if the combined effects of average humidity and maximum temperature are used;

only the two parameter model was significant.

Seasonal litter fall is presented in Table 4.38. Nitrogen and phosphorus leaf mortality can be calculated from the seasonal leaf mortality with the use of the nitrogen and phosphorus contents presented in Table 4.30.

Table 4.29: Probabilities (and r^2) of the two and one parameter models given for the best fits of the multiple regression analysis of litterfall per unit of LAI. Minimum relative humidity, rainfall and average temperatures were not significant (at P<0.05). The intercept is significant (P<0.05) for both models.

model	r^2	P-model	P-humidity$_{ave}$	P-T$_{max}$
1	0.262	0.0259	0.0266	0.0394
2	0.045	0.3671	0.3671	

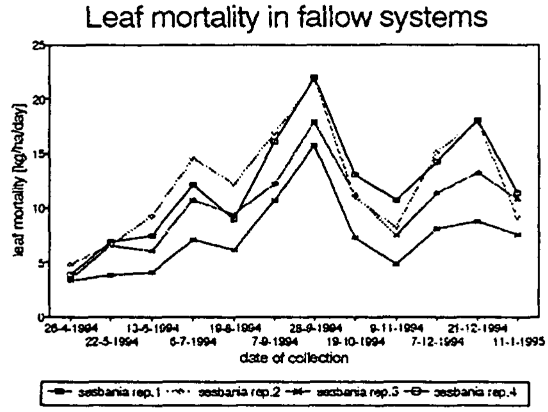


Figure 4.23: Litter fall in sesbania fallows during the 3rd and the 4th season of the experiment

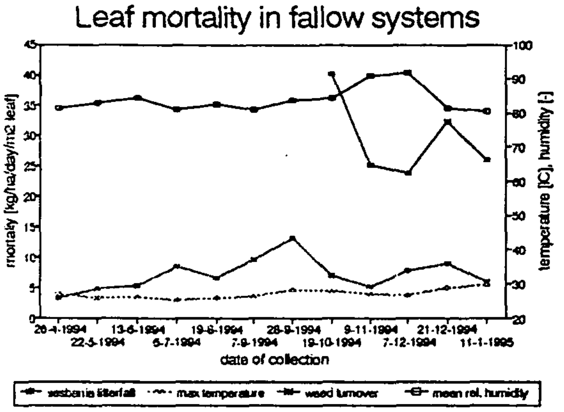


Figure 4.24: Litter fall and weed turnover (corrected for LAI) and their determining parameters, maximum temperature and average humidity during the 3rd and 4th season of the experiment

Weed mortality

No literature was found on this subject, so that no comparisons can be made with other data. Weed mortality was measured during the 4th season, short rains 1994. Data collected are presented in Appendix VI.6. No significant difference in weed mortality between the replicates was found. Average weed mortality as a function of time is presented in Figure 4.24. Nutrient contents of dead weed litter is presented in Table 4.30. Nitrogen and phosphorus weed mortality can be calculated out of the weed mortality (presented on a seasonal basis in Table 4.38 in section 4.2.1.8) times the nitrogen and phosphorus contents in weed litter presented in Table 4.30.

Table 4.30: nutrient contents (in %) for sesbania litter and weed litter

	nitrogen (%)	phosphorus (%)
sesbania litter	2.24	0.065
weed litter	1.01	0.104

Influence of climatic circumstances on weed turnover is presented in Table 4.31. Climatic circumstances were only of significant influence (at $P<0.05$) if the combined effects of average humidity and maximum temperature are used; only the two parameter model was significant (at $P<0.05$). This means that, similar to litter fall, a combination of low humidity and high temperature caused weed mortality. Seasonal weed turnover is presented in Table 4.38.

Table 4.31: Probabilities (and r^2) of the two and one parameter models given for the best fits of the multiple regression analysis of weed mortality. Minimum relative humidity, rainfall and average temperatures were not significant (at $P<0.05$). The intercept is significant ($P<0.05$) for both models.

model	r^2	P-model	P-humidity$_{ave}$	P-T$_{max}$
1	0.544	0.0013	0.0005	0.0015
2	0.159	0.0818	0.0818	

4.2.1.7 Root conversion

Background information:

Root turnover is the complex of root secretion, root exudation and dying roots (root mortality) which converse subsequently (root conversion). Conversed roots potentially can decompose or mineralise directly. Only root conversion was measured directly and will be emphasized in this section. With the use of the root production it is possible to calculate root mortality, which will be done later in this section. This estimate of root mortality is necessary to calculate seasonal root conversion losses. The position of the root dynamics in the total organic matter dynamics is presented in Figure 4.20. This root dynamics is of great importance for nutrient cycling as will be shown in Chapter 5.

Most of the root conversion occurs within the rhizosphere or is catalysed by the rhizosphere. The rhizosphere is the small volume around roots directly influenced by roots. Within the rhizosphere the conditions are different from the conditions outside the rhizospere. Due to the higher pH, the abundance of more organic matter and the availability of oxygen and soil moisture the conditions are more favourable for soil micro organisms. Most of the turnover of organic material will therefore take place within this rhizospere, giving it a crucial position in the organic matter dynamics.

Root dynamics is crucial in nutrient cycling in those ecosystems in which the nutrient cycles are closely coupled to organic matter (Fogel, 1985). In a mature forest root mortality is equal to root production (Santantonio and Grace, 1987). Also in these mature systems root dynamics becomes crucial in nutrient cycling. In many forest ecosystems, growth, death and conversion of fine roots constitute a major pathway of carbon and nutrient cycling. Roots undergo multiple cycles of growth, death and displacement during the year (Santantonio and Grace, 1987).

This occurs, because fine roots converse very fast. The amount of fine roots is in trees larger than in annual crops (Szott et al., 1991). Leguminous species tend to have high conversion rates, probably because of their nutrientrich fine roots and fine roots tend to converse very fast. Total root biomass was measured in a grassland and in forest by Jackson et al. (1990) and amounted 2500 kg d.w./ha and 3000 kg d.w./ha respectively. Fine root biomass measured, was about 1150 kg d.w./ha in a forest (Hart et al., 1991). Frankenberger and Abdelmagid (1985) found conversion rates for roots of leguminous species of 330 kg $Nha^{-1}yr^{-1}$. Vogt et al. (1986) presented a fine root turnover of 20-140 kg $Nha^{-1}yr^{-1}$.

Root turnover rates can be 10-20 % of the plant production. (Rovira et al., 1983) These losses include exudation (excelerated by soil organisms) and secretion, which occurs mostly at root tips (Anderson and Ingram, 1993). According to Fogel (1985) the contribution of exudation is 0.5-1.4% of the total root losses leading to an underestimation of root production. This amount falls within sampling uncertainties of the experiment and is assumed to be absent.

Frankenberger and Abdelmagid (1985) mention a conversion rate of tree roots with a of k_c=0.0157 day^{-1}. Lower conversion rates are mentioned by Santantonio and Grace (1987) and Ruark (1993), but those data were determined at lower soil temperatures in temperate regions.

Results:

A root conversion study using naturally died roots was carried out during the 4th season with a mesh bag experiment. The data are presented in Appendix VI.6. For this study dead roots were collected along a trench. This led to an average sample per treatment of naturally died matured roots. Separate species and specific age could therefore not be distinguished. Some characteristics of the substrate is presented in Table 4.32.

Table 4.32: Some characteristics of the root substrate used in the root conversion study.

	total nitrogen (%)	total phosphorus (%)	ash content (%)
sesbania roots	1.54	0.080	21.1
weed roots	1.44	0.066	12.8
maize roots	0.90	0.056	41.4

In Figure 4.25 the course of root conversion (corrected for ash contents) in the mesh bag experiment is shown. The root conversion is decribed with an one-exponential decay curve:

$$\frac{Y_t}{Y_0}=e^{-k_c*time} \qquad (31)$$

For such description it must be assumed that changes in substrate quality during the experiment do not affect root conversion. This seems to be a reasonable assumption, because the roots are not woody (Santantonio and Grace, 1987). Results of the analysis are shown in Table 4.33.

The regression analysis was carried out, using the model

$$\ln\left(\frac{Y_t}{Y_0}\right)=k_c*time+\varepsilon \qquad (32)$$

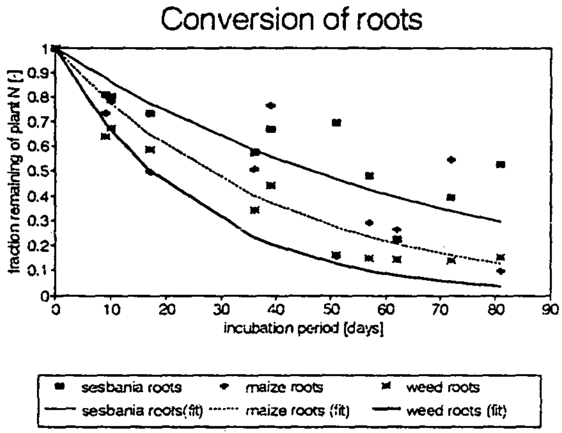


Figure 4.25: Root conversion as a function of time, determined with meshbags. Each point in the graph is averaged over all samples for this sampling time.

Treatment effects were significant (P<0.01) for all measured parameters: Substrate has a significant influence on conversion rates. Conversion rates of sesbania roots are in the range with the k=0.0157 day^{-1} mentioned by Frankenberger and Abdelmagid (1985).

To estimate total root conversion per season, it is necessary to know inputs of organic matter. For maize this input is known, since this input only occurs at harvest (as no dead roots were found with the root ingrowth study). Maize root biomass at maturity was measured (see 4.2.1.5) and could be used as an input.

Table 4.33: Statistical analysis of root conversion rates for three treatments and three components. P-model (and P-time) are significant (P<0.0001).

		sesbania	weeds	maize
dry weight	k_c (d^{-1})	0.0115	0.0345	0.0249
	r^2	0.918	0.875	0.850
P	k_c (d^{-1})	0.0145	0.0382	0.0271
	r^2	0.876	0.937	0.824
N	k_c (d^{-1})	0.0150	0.0407	0.0255
	r^2	0.84	0.971	0.835

In the weed fallow and the sesbania fallow a continuous input of dead roots occured. Mortality started at the very end of the second season of the experiment in the sesbania fallow and weed fallow. This is known, because no dead roots were found in the root ingrowth cores (see 4.2.1.5), meaning that no mortality occurred during this incubation period. Out of the known growth curve presented in section 4.2.1.5 follows, that a constant biomass was achieved during the fourth season. This means that in this season root mortality is equal to root production; the fallow systems have become mature. Root production was measured (see 4.2.1.5), so mortality in this season is known. For the third season mortality increases linearly leading to the smoothening of the curve as measured. Now mortality is known for all treatments for all seasons.

Out of the inputs of dead roots per period of three weeks (being mortality, Y_0) it is possible to calculate root conversion during this period, with the measured k_c values (see Table 4.33):

$$Decomposition=Y_0*(1-e^{-k_c*(t-t_0)}) \tag{33}$$

Table 4.34: Seasonal mortality and seasonal root conversion per season per treatment in kg d.w.ha^{-1}

	mortality			conversion		
	maize	sesbania fallow	weed fallow	maize	sesbania fallow	weed fallow
2nd season	3862.1	328.5	192.3	0	0	0
between seasons	0	1216.8	712.3	2750.0	143.7	158.1
3rd season	3954.8	9101.6	5328.3	1089.8	4879.4	4322.6
between seasons	0	1533.2	897.5	1619.5	1206.6	903.2
4th season	4094.6	10732.1	6282.8	2297.0	9737.5	6286.0

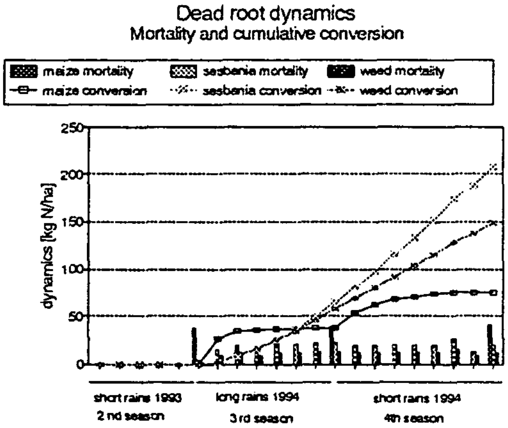


Figure 4.26: Mortality and cumulative conversion of roots per treatment

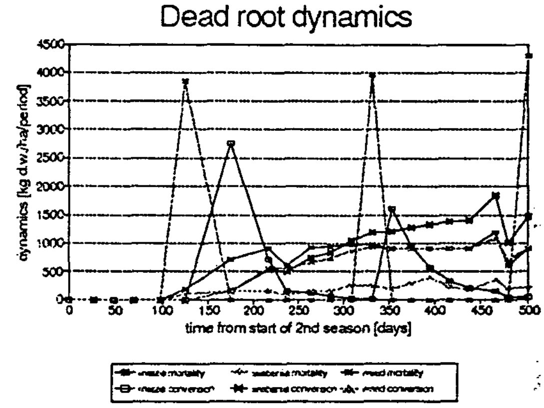


Figure 4.27: Root mortality and root conversion per period

The length of each calculation time interval was three weeks to allow comparison with the litter conversion data. After each calculation interval (t) the root conversion is calculated per Y_0 (as created at t_0) and summed for all different inputs of dead roots per time interval. The sum is equal to the total conversion for that interval. Seasonal mortality and seasonal root conversion are presented in Table 4.34.

The development of mortality and conversion is shown in Figure 4.26. It shows very clearly that conversion followed mortality with some retardation. Cumulative conversion, presented in Figure 4.27 shows more about the dynamics of the root conversion. For maize roots, all roots conversed in one season. Root conversion in the weed fallow and the sesbania fallow followed a similar course possibly leading to an increase in organic matter during the experiment. Data on organic nitrogen and organic phosphorus are presented in Appendix VII. In Chapter 5 will be returned to this issue.

The nitrogen and phosphorus amounts released by root conversion can be calculated from the root biomass converted, as calculated above. The turnover of nitrogen and phosphorus due to root mortality and root conversion is simply the nitrogen and phosphorus content of the dead root biomass, presented in Table 4.27, times the biomass converted. These data will not be presented in this section, but will be used in Chapter 5 for further calculations on nitrogen and phosphorus dynamics.

4.2.1.8 Litter conversion

Background information:

Litter quality is lower at less fertile sites (Vitousek and Sanford, 1986), as is the case for Ochinga farm in Western Kenya. Quality of the substrate influences conversion rates of litter, because physical and chemical protection of soil organic matter can occur. Oglesby and Fownes (1992) mention for sesbania leaves a polyphenol content of 2.60 % and a lignin content of 14.5%. Oglesby and Fownes (1992) mention that sesbania conversion, contrary to the conversion of other tree species, was not influenced by lignin. For the conversion of legumes, Frankenberger and Abdelmagid (1985) mention an influence of C/N ratio of the plant material. They found conversion rates of 940 kg $Nha^{-1}yr^{-1}$ for foliage and 190 kg Nha^{-1} yr^{-1} for stems of leguminous trees.

A litter conversion constant of 0.04 day^{-1} is mentioned for metabolic surface litter by Parton et al. (1987). Sesbania litter converses much slower than weeds according to Young and Muraya (1990).

In this study, conversion of maize stover was not investigated, because maize stover losses from planting to harvest are generally negligible (Hansson et al., 1987). After harvest, maize stover was removed and was not left to converse. Living maize biomass literally disappeared directly by termite activity. The losses of maize stover that occurred by termites (causing an exponential decrease in maize LAI between maximum allocation and harvest, see 4.1.1.6) were not caused by natural leaf mortality (and subsequently litter conversion) as such and will not be treated here. The termite activity was proved, because the decrease in nutrient contents in maize stover was not only caused by a decrease in nutrient concentration (due to nutrient reallocation), but the total nutrient content decreased.

The maize stover biomass lost this way between biomass assessment at maximum LAI and harvest (see 4.2.1.4) was assumed to be directly incorporated in soil organic matter by the termites. This conversion by termites is described by the same model as used in the litter conversion study.

Results:

Litter conversion was measured during the 4th season, the short rains 1994. Data are presented in Appendix VI.7. For the litter conversion of weed litter, dead material from the three most abundant species within the dead material was used on an equal weight basis. These weed species are Guizotia scabra, Hibiscus aponearus and Digitaria scalarum.

At the beginning of the fourth season the portion of grasses in the dead material was quite high, while grass had been outcompeted almost completely from the living biomass. For the fallows this is a good development, because grass is not a soil improver, while Guizotia and Hibiscus are recognized by farmers as soil improvers (R. Buresh, pers. comm.). As grasses were outcompeted by last mentioned weed species, this is a good development in terms of soil fertility. Other species that increased during this season were Galinsoga Parviflora and Dichondra Repens. At the end of the 4th season almost no grasses were left, while at the end of the 2nd season grasses covered 50% of the area, see Table 4.35. In Table 4.35 it can also be seen that the weed cover in the sesbania fallows, which started one season later, developed in a similar way as in the weed fallows. It can be expected that the weed species composition in the sesbania fallow will develop in the same direction as in the weed fallow as no significant differences on weed species composition between treatments are expected, based on these results.

Table 4.35: Most abundant weed species in the sesbania fallow and the weed fallow. Data from the sesbania fallow were composed out of data collected by Braun (1995) and K.Mekonnen (in press). Data on the weed fallow were collected by Hartemink (1994). The development stage of the weeds is similar for both treatments.

Sesbania fallow (start of 4th season)		Weed fallow (first half of the 3rd season)	
Paspalum scrobiculatum (grass)	28%	Paspalum Scrobilculatum	25%
Digitaria abysscinica (grass)	29%	Digitaria Abysscinica	25%
Eragrostis Tenuiflora (grass)	11%		
Dichondra Repens	14%	Dichondra Repens	17%
Cynodon Dactylon	1%	Guizotia Scabra	1%
Ageratum Conyzoides	5%	Ageratum Conyzoides	2%
Crassophalum Rubens	2%	Galinsoga Parviflora	2%
Spilathes Mauritiana	1%	Richardia Brasiliensis	5%
Biophytum Petersianum	4%	Bidens Pilosa	2%
like sesbania	3%		
Hybiscus Aponearus	2%	Hibiscus Aponearus	22%

Polyphenols and lignin contents of the substrate used in this study are presented in Table 4.36.

Table 4.36: Quality of the substrate used in the litter conversion study indicated by percentages lignin, polyphenol, nitrogen and phosphorus (all in %)

	lignin	polyphenol	N	P
weed litter	18.9	0.3	1.21	0.104
sesbania litter	17.5	0.43	1.87	0.058

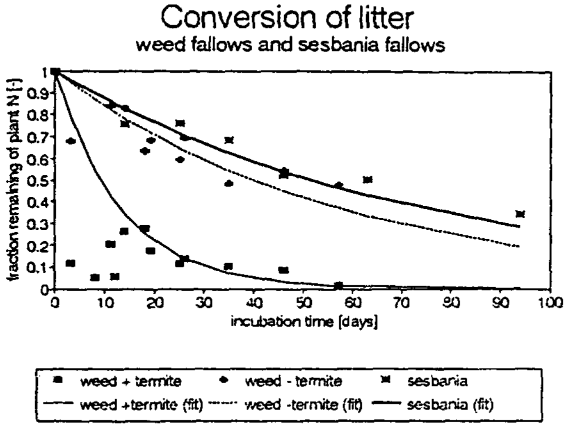


Figure 4.28: Leaf litter conversion as a function of time, determined with meshbags. Each point is averaged for all samples taken at that moment.

The course of litter conversion (corrected for ash contents) is shown in Figure 4.28. In the weed fallow termite activity had a significant influence on litter conversion rates ($P\leq 0.0001$) for all parameters investigated and litterbags with and without termite activity had to be analysed separately to avoid extreme variation. Some termite attack occurred on the sesbania litter, but this did not have large effects and occurred homogeneously spread over all samples: Termite activity did not affect litter conversion rates of sesbania significantly. For this reason sesbania litter conversion was analysed as one data set.

Treatment differences were significant for all parameters ($P<0.05$). The litter conversion is decribed with an one-exponential decay curve:

$$\frac{Y_t}{Y_0}=e^{-k_c*time} \qquad (34)$$

For such description it must be assumed that changes in substrate quality during the experiment do not affect litter conversion. Litter conversion constants were determined with the use of this analysis (see Table 4.37).

The regression analysis was carried out, using the model

$$\ln\left(\frac{Y_t}{Y_0}\right)=k_c*time+\epsilon \qquad (35)$$

In the weed fallow 47 samples were significantly influenced by termites and 48 samples were not significantly influenced (based on visual observations). Using this proportion an average true conversion constant for the weed fallow was calculated to be 0.0445 d^{-1}, while sesbania litter conversed much slower (with an average k_c of 0.0095 d^{-1}). Both are consistent with literature. Lignin and polyphenol contents did however not differ between weed litter and sesbania litter. Sesbania litter had much higher nitrogen contents than weed litter, while weed litter contained much more phosphorus. Because of the phosphorus limitation at Ochinga farm it is possible that conversion of sesbania litter was limited by its phosphorus contents, while weed litter conversion was not (due to its higher phosphorus contents).

Table 4.37: Statistical analysis of litter conversion rates for three treatments and three components. P-model (and P-time) are significant (P<0.01).

		sesbania	weeds + termites	weeds - termites
dry weight	k_c (d^{-1})	0.0095	0.0691	0.0112
	r^2	0.987	0.962	0.963
P	k_c (d^{-1})	0.0088	0.0868	0.0207
	r^2	0.906	0.947	0.969
N	k_c (d^{-1})	0.0134	0.0759	0.0174
	r^2	0.970	0.958	0.840

To come to seasonal estimates of litter conversion, not only conversion rates are needed, but also total input of dead litter. This input (=litter mortality) was measured in the weed fallow during the 4th season and in the sesbania fallow during the 3rd and the 4th season (see 4.2.1.6). During the 4th season weed mortality was a constant multiple of the sesbania mortality. This constant ratio was used to extrapolate weed mortality to the 3rd season. During the 3rd season sesbania mortality increased linearly. From this linear relationship (having a r^2 of 0.767 and being significant at P<0.05) extrapolation shows that no mortality occurred until the end of the 2nd season. The same conclusion would have been drawn if the growth curves for aboveground biomass and belowground biomass, which are similar, would have been considered. For roots, mortality neither started before the end of the 2nd season (as shown in the root ingrowth study).

Out of the calculated litter mortality, total litter conversion could be calculated with the use of eq. 29. For the calculations it was possible to use dry weights, because nutrients contents were constant and equal for litter (as presented in section 4.2.1.6) and the litter used in this conversion study. For the calculations a time interval of three weeks was chosen, because this was the time interval between the measurements of litter mortality. This was also done to have comparable errors (due to using discontinuous equations for continuous processes) as for root conversion.

For each time interval (t) litter conversion is calculated per measured (or calculated) litter mortality, Y_0 (as created at t_0) and summed for all different inputs of litter (remaining from earlier time intervals) per time interval. The sum is equal to the total litter conversion during that interval, see Figure 4.29. Seasonal mortality and litter conversion are presented in Table 4.38. Seasonal nutrient litter conversion is the seasonal biomass conversion times the nutrient contents (presented for nitrogen and phosphorus in Table 4.30). These seasonal conversion values are presented in Chapter 5.

Table 4.38: Seasonal litter mortality and seasonal litter conversion (in kg d.w.ha^{-1}) for sesbania fallow and weed fallow

	mortality		conversion	
	sesbania fallow	weed fallow	sesbania fallow	weed fallow
2nd season	109.4	397.9	0	0
between seasons	157.5	624.7	41.3	354.9
3rd season	1023.5	5636.9	500.1	4546.1
between seasons	232.6	1200.4	139.5	986.6
4th season	1831.6	8555.4	1409.1	8722.1

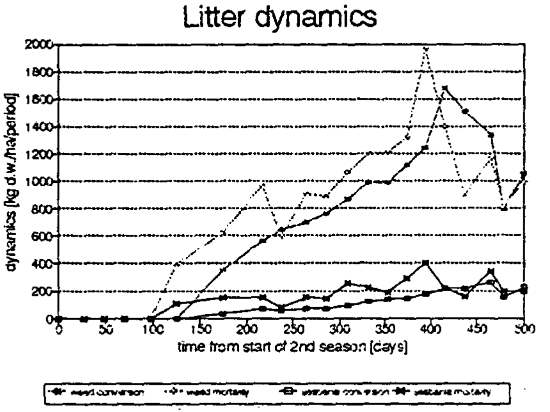


Figure 4.29: Litter mortality and litter conversion development during the experiment for the sesbania fallow and weed fallow

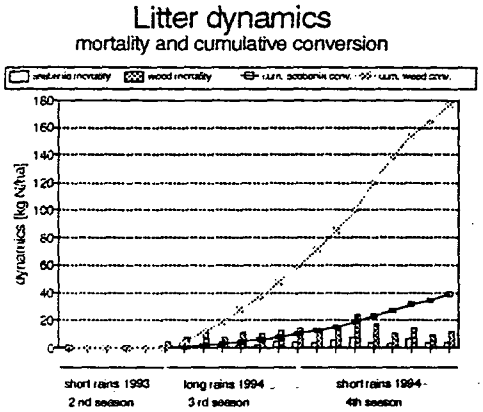


Figure 4.30: Litter mortality and cumulative conversion for the sesbania fallow and weed fallow

From Figure 4.29 it follows that in the weed fallow litter conversion developed much faster than in the sesbania fallow, due to the much higher conversion rates. These higher conversion rates lead to a completely other organic matter regime in the weed fallow than in the sesbania fallow, as can be seen in Figure 4.30. In the weed fallow everything is conversed quite fast, whereas in the sesbania fallow litter conversion is limited leading to a slow release of organic plant matter. In the weed fallow all inputs of litter disappear almost directly, while in the sesbania fallow a layer of non-conversed litter on top of the soil develops. This litter is very slowly released to the soil. This will be used as inputs for the organic nitrogen dynamics, treated in Chapter 5.

4.2.1.9 Soil organic matter mineralisation

Background information:

Soil mineralisation is a very complex process and is influenced by many factors. With each sampling for soil mineralisation measurement the system is disturbed and soil mineralisation rate is affected (Raison et al., 1987). Polglase et al. (1992) found with an anaerobic laboratory incubation ten times as high mineralisation rates as with an in-situ incubation. No universal method for determination of soil mineralisation rates has been developed yet. A number of possible methods have been given by Serna et al. (1992), Raison et al (1987) and Anderson and Ingram (1993). To avoid direct soil mineralisation measurements it has been tried to correlate chemical features of soil (Serna et al., 1992; Powers, 1980) and plant (Oglesby et al., 1992) with mineralisation rate. But neither of these gave satisfactory results.

Soil mineralisation is fastest in well-drained soils high in basic cations. Soil mineralisation is influenced by the C/N-ratio of the soil organic matter or the quality of the organic matter in general. Frankenberger and Abdelmagid (1985) found a high correlation between mineralisation rates and %N, while a correlation with carbon was absent. Powers (1980) describes that soil mineralisation rates decreased fast with depth, probably caused by a decrease in easily extractable organic matter (Powers, 1980). Soil mineralisation rates are also influencd by temperature, pH and by the form of organic nitrogen,; $NH4^+$ is preferred (Brady, 1985). Soil moisture content, which must be optimal for heterotrophic bacteria, has also large influences. Linn and Doran (1984) describe an experiment in which soil mineralisation is determined as a function of water filled pore space (WFPS). They found a soil moisture optimum value for soil mineralisation of 60%, while soil mineralisation rates decreased fast if moisture contents deviated from this optimum value. Patrick (1982) found that soil mineralisation rates at optimum soil moisture content were 2 to 3 times as high as under anaerobic conditions.

Soil mineralisation is stimulated near roots due to the vicinity of microbial biomass and because mineralised nitrogen is directly removed from the soil system by plant uptake (yielding lower immobilisation) (Paustian et al., 1990). For all these reasons a large variability in mineralisation rates can be found within a season and between systems. In fallows a continuous presence of roots exists, leading to higher mineralisation rates in fallows. Mineralisation rates of 147 kg $Nha^{-1}yr^{-1}$ (for a nitrogen fixing fallow) and 214 kg $Nha^{-1}yr^{-1}$ (for a weed fallow) was found, compared to 80 kg $Nha^{-1}yr^{-1}$ in barley (Paustian et al., 1990).

Immobilisation

If the circumstances are not ideal, then the opposite of mineralisation (immobilisation) occurs. This immobilisation can be a large sink. The mean residence time for nitrogen in a forest floor was found to be 2.5 times as large as the mean residence time of the total organic matter in the forest floor, which shows the effect of immobilisation (Hart et al., 1991). The plants and the microbes compete for the available mineral-N, which is turned over into organic-N by the microbes; immobilisation. This incorporation can occur at a very fast rate to above 50% in one day. Microbes tend to compete more effectively for the ammonia. This makes nutrient availability controlled by microbial dynamics.

A more extensive review of plant-microbial competition and the role of spatial and temporal variability in this competition is given by Schimel et al.(1989a,b) and Jackson et al. (1988).

Ammonification

Ammonification is the precursor of nitrification and is the transformation of organic matter to NH_4^+ by chemical or (micro-)biological processes. Chemically it can be described as:

$R-NH_2 + H_2O <-> R-OH + NH_3 + Energy$

$2NH_3 + H_2CO_3 <-> (NH_4)_2CO_3 <-> 2\ NH_4^+ + CO_3^{2-}$

It is common use to make an division into different organic matter pools for the calculation of ammonification rates. In the slower ammonificating pools the nitrogen can be stored and is out of circulation (Osmond et al., 1992).

The amount of mineralisable N has been estimated to be 31 kg Nha^{-1} for grasslands, 47 kg Nha^{-1} for forest and 40 kg Nha^{-1} for bare soil (Jackson et al., 1990). Net ammonification rates of 540 kg d.w.ha^{-1}yr^{-1} (Javid et al., 1991), 300 kg Nha^{-1}yr^{-1} (Serna et al., 1992) and 13-16 kg Nha^{-1}yr^{-1} (Hart et al., 1991) for forests were mentioned.

Nitrification

Nitrification is the transformation of NH_4^+ to NO_3^- by microbes. It can be described as (Brady, 1985):

$NH_4^+ + 5O_2 ->$ (by nitrosomonas o.a.) $2H_2O + 4NO_2^- + 4H^+ ->$ (by nitrobacter o.a.) NO_3^-

Nitrification can be very fast under ideal circumstances: enough available NH_4^+, good aeration, optimal temperature ($27^0C < T < 32^0C$), enough available water and the abundance of exchangable cations (Brady, 1985). At pH higher than 7.5, inhibition of nitrification occurs (Serna et al., 1992). Javid et al. (1991) mention a nitrification rate of about 300 kg Nha^{-1}yr^{-1}. For oak forest floor a low net nitrification rate was found: 12 kg Nha^{-1}yr^{-1} (Hart et al., 1991). These examples show clearly the high variability.

Net soil mineralisation rates were measured with four methods in the 4th season. Data of all methods are presented in Appendix VI.8. Laboratory experiments will be treated before the field methods. Results of each method separately will be presented first (section 1-4), before the methods are combined to come to seasonal estimations of soil mineralisation under field conditions per treatment (section 5).

1) aerobic incubation

Using an extensive experiment with undisturbed soil cores it was tried to determine the relationship between soil moisture contents (indicated by water filled pore space (WFPS)) and soil mineralisation rates. Samples were collected in the bare fallow. The bare fallow had lowest absolute rates from all treatments (see Figure 4.36), but was less complicated to investigate due to the absence of dead root biomass.

An investigation of the determining parameters combining the data of both experimental runs (see Figure $4.32_{a,b,c,d,e}$) indicated the great complexity of the soil system. Due to this complexity a direct interaction between soil mineralisation rates and WFPS led to a very large variability (with a C.V. of 50-150%), indicating the importance of other factors. The relationship is presented in Figure 4.32_b and was further investigated with a statistical analysis (see Tables 4.39 and 4.40).

Soil mineralisation was measurd as the appearance rate of NH_4^+. This is only appropriate if immobilisation and nitrification are absent. Immobilisation is determined by total inorganic nitrogen available. Some samples, with a low amount of available nitrogen, had a decrease in NH_4^+. In these cases immobilisation can have occurred. The effects will however be low, because immobilisation is a slow process. In all other samples immobilisation did not seem to occur.

Nitrification is a strongly aerobic process and is already inhibited at low oxygen shortages. Nitrification can be a fast process, leading to low concentrations of ammonia under field conditions. During the incubation ammonia was a substantial part of total inorganic nitrogen. This means that nitrification was inhibited strongly. The five samples (out of the 84 samples) in which nitrate increased during the incubation were left out of the analysis, because in those samples the assumption that nitrification was negligible is falsified. For the analysis it was necessary to include more factors. High variation in other relevant factors could have caused this high variation. The higher complexity resulting from this exercise was needed to be able to extract the relationship between moisture content and soil mineralisation, the objective of this study.

The amount of ammonia at t=0 ($NH_{4,0}^+$) was highly variable. Although ammonia is a product of mineralisation, it is an indication of available soil organic matter and soil mineralisation potential, because it can only be produced by soil mineralisation. Initial ammonia therefore indicates the amount of initial organic matter at the microsite, indicating the history of the site, and is more sensitive to changes than average total organic nitrogen or total carbon. Using ammonia will correct directly for the high heterogenity within the soil organic matter. The amount of initial ammonia was therefore used as a distinguishing variable in the analysis next to average organic nitrogen. The graph between mineralisation rates and ammonia at time 0 (Figure 4.32_d) shows this relationship well: Easily extractable soil nitrogen available at the site (measured by initial ammonia contents) probably determined mineralisation rates to a high extent.

A decrease in easily extractable soil nitrogen occurred with with depth, leading to a decrease in quality of the organic matter. At depth lower amounts of organic matter are found, with a higher C/N-quotient and the organic matter is usually more stabilised. This means that less organic matter is available for mineralisation. This is underlined by change in ratio of soil mineralisation to total soil nitrogen with depth: Old organic matter will be slower mineralised leading to a lower ratio (meaning lower relative mineralisation rates). In the lower layers the fraction of old organic matter is larger than in the top layers, because of the lack of fresh organic matter at depth. Easily decomposable organic matter has already disappeared from this older material. This leads a decrease in relative mineralisation.

The relationship between %C and mineralisation rates is however not significant at $P<0.05$ (see Figure $4.32_{d,e}$): The functional relationship is between %N in organic matter and mineralisation rates and not between %C and mineralisation rates:

Soil nitrogen seems to be more limiting than carbon, in accordance with Frankenberger and Abdelmagid (1985). This relationship could be proved, because the C/N ratio of soil organic matter changed with depth. The high correlation between average %N per layer and soil mineralisation (see Figure 4.32$_a$) and the relationship between initial ammonia and total nitrogen (see Figure 4.32$_c$) endorses the nitrogen limitation. The conclusion still has to be taken with some caution, because not all samples were analysed for total nitrogen and organic carbon.

All this indicates that easily extractable soil nitrogen (indicated by initial ammonia and the quality of organic matter) determines soil mineralisation rates to a large extent. The statistical analysis (see Tables 4.39 and 4.40) confirmed the relationships shown graphically in Figure 4.32. No threshold values could be distinguished.

Table 4.39: Probabilities (and r^2) of the five,four, three, two and one parameter models given for the best fits of the multiple regression analysis of soil mineralisation rates determined with the aerobic incubation experiment. The intercept was significant ($P<0.05$) in all models.

model	r^2	P-model	P-$NH_{4,0}^+$	P-$WFPS^2$	P-%N	P-WFPS	P-%C
1	0.620	0.0001	0.0001	0.1356	0.2833	0.1433	0.3175
2	0.533	0.0001	0.0001	0.2246	0.0776	0.2854	
3	0.550	0.0001	0.0001	0.0022	0.0267		
4	0.551	0.0001	0.0001	0.0036			
5	0.477	0.0001	0.0001				

The best fit is given by the equation (with WFPS in %, NH_{40}^+ in mg/kg and the mineralisation rate in mgkg^{-1}day^{-1}):

$$MineralisationRate=0.0451*NH^{+}_{4,0}+2.21*\%N-8.65*10^{-5}*WFPS^{2}+0.534 \tag{36}$$

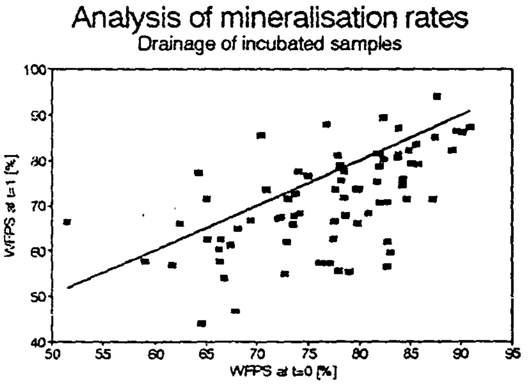


Figure 4.31: Analysis of the moisture regime within the samples used in the mineralisation incubation experiment

Some drainage of the samples occurred during the experiment (see Figure 4.31). For this reason average WFPS was used in the analysis. This can have been another reason for the high variability in the study. For this reason only those samples of which WFPS did not change more than 5% during the incubation were included in Figure 4.32$_b$.

Not a complete equilibrium was achieved during the experiment. The samples were quite wet, making an equilibrium hard to achieve. All samples were that wet, that no moisture shortage could be expected, but some oxygen shortage might have occured. Mineralisation decreased with increasing WFPS in the range of moisture contents investigated. The decrease in mineralisation rates was highest at high WFPS values, see Figure 4.32$_b$. This is also indicated by the negative coefficient in eq. 36. Mineralisation was inhibited mostly at very high WFPS, as indicated by the significant influence of WFPS^2. However still some soil mineralisation occurred under anaerobic circumstances. At the lowest moisture contents with a WFPS of 50-55%, the highest mineralisation (of about 1.1 mg Nkg^{-1}day^{-1}) was reached. This is a bit lower than the optimum value mentioned by Linn and Doran (1984). The ratio of soil mineralisation rates under optimum soil moisture conditions and soil mineralisation under anaerobic conditions was around 4, similar to the ratio found by Patrick (1982).

The higher complexity by including ammonia, total nitrogen and organic carbon was necessary to reach the original objective. The relationship between soil moisture contents and soil mineralisation could now be determined. The relationship found can be quite specific for the bare fallow, but that was not investigated.

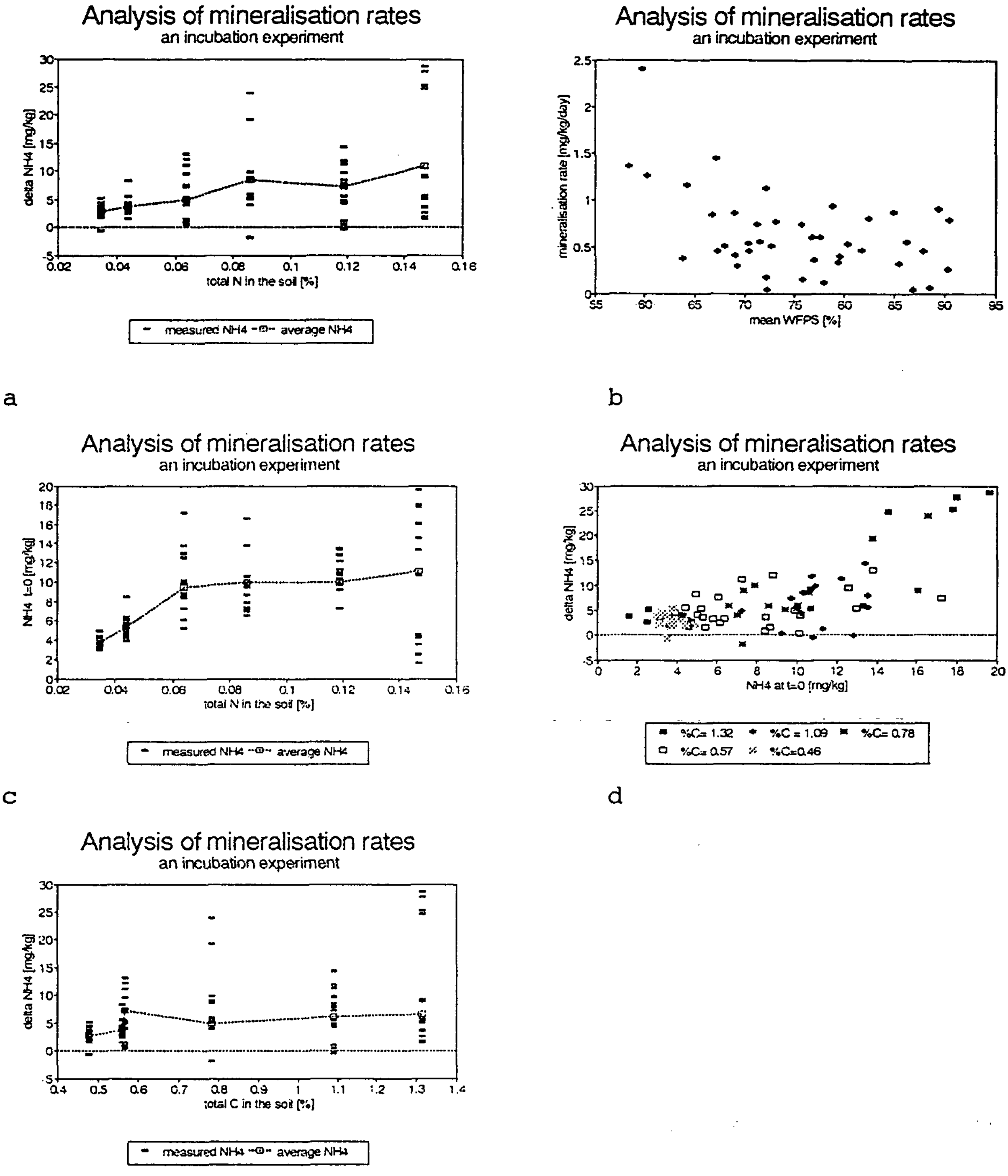
Table 4.40: Probabilities (and r^2) of the five, four, three, two and one parameter models given for the best fits of the multiple regression analysis of relative soil mineralisation rates (being the mineralisation rate per percentage of organic nitrogen) determined with the aerobic incubation experiment. The intercept was significant (P<0.05) in all models.

model	r^2	P-model	P-$NH_{4,0}^+$	P-%N	P-WFPS^2	P-%C	P-WFPS
1	0.300	0.0001	0.0001	0.1286	0.3312	0.3751	0.3794
2	0.291	0.0001	0.0001	0.0841	0.0943	0.2947	
3	0.283	0.0001	0.0001	0.0001	0.0926		
4	0.257	0.0001	0.0001	0.0004			
5	0.187	0.0009	0.0009				

The best fit for relative soil mineralisation is given by equation:

$$RelativeMineralisationRate=7.837*NH_{4,0}^{+}-607.5*\%N+64.57 \qquad (37)$$

The applicability of using relative mineralisation can be small, as already indicated by the very low r^2. Total nitrogen was not determined for each sample, while total nitrogen determines to a large extent relative soil mineralisation rates. This relationship will therefore not be used in further calculations.



a

b

c

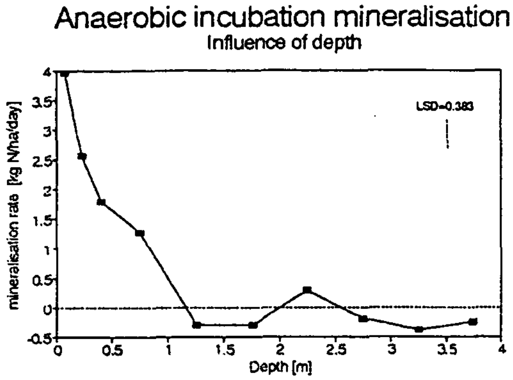
d

e

Figure 4.32$_{a,b,c,d,e}$: Analysis of mineralisation, using an aerobic incubation experiment. Analysis of potential influencing parameters; water filled pore space, amount of NH_4^+ at t=0, total soil nitrogen and soil organic carbon

2) anaerobic incubation

Under anaerobic conditions soil mineralisation rates will be about 4 times as low as under optimal moisture conditions due to oxygen deficiency, as shown above. Generally a laboratory incubation can only reveal potential rates and relationships. The method can however reveal the relationship of soil mineralisation with depth.


Anaerobic incubation mineralisation
Influence of depth

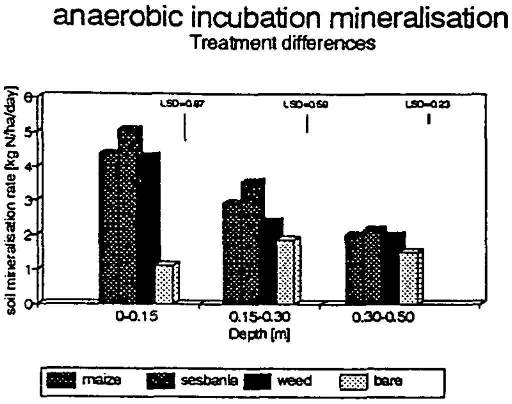

anaerobic incubation mineralisation
Treatment differences

Figure 4.33: Mineralisation as influenced by soil depth, measured with an anaerobic incubation

Figure 4.34: Mineralisation as influenced by treatment, measured with an anaerobic incubation

The relationship between soil mineralisation rates and depth is presented in Figure 4.33. Soil mineralisation rates decrease fast with depth. Probably this is caused by the decrease is easily extractable organic matter (Powers, 1980). This can be seen in Figure 4.35, in which the relationship between soil mineralisation and organic carbon is presented. This relationship is not linear, while that is expected if no change in quality of organic matter occurs with depth. The fact that the change in mineralisation rate with a change in organic matter decreased with depth could indicate that the quality of organic matter decreased and only young organic matter was mineralised. This means that what was decomposed was mineralised soon after. At depth new organic matter can be formed by root mortality (see section 4.2.1.7). The absolute rates of this relationship are only valid for an anaerobic incubation.

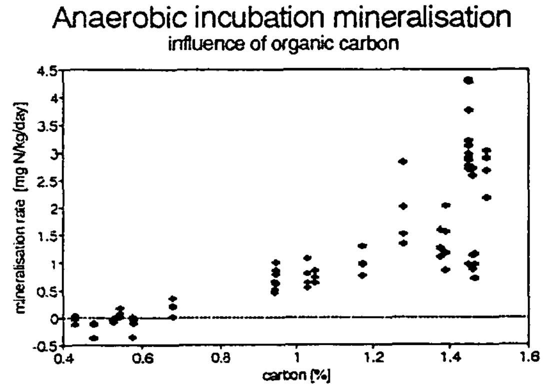

Anaerobic incubation mineralisation
influence of organic carbon

Figure 4.35: Relationship between mineralisation rates and the amount of organic matter, indicated by %C.

The relationship between soil mineralisation rate, treatment and depth is presented in Figure 4.34. The influence of treatment on soil mineralisation rates was significant at P<0.05. Soil mineralisation rates of the bare fallow are similar to the values measured in the top layer of the bare fallow with the aerobic incubation study (see Figure 4.32$_b$). Soil mineralisation rates measured in the weed fallow were however not significantly different (at P<0.05) from soil mineralisation rates in maize. Relative mineralisation rates (defined as the mineralisation rate per unit of organic nitrogen). were also significantly influenced by treatment (at P<0.05): treatment differences in organic nitrogen were not clearly present (see Chapter 5). Data on organic nitrogen can be found in Appendix VII.

3) field core mineralisation

This method potentially gives the most realistic estimates of mineralisation per treatment at constant moisture contents and is used as basis of the calculation of seasonal mineralisation. Moisture contents during the incubation are indicated in Table 4.41. Results are presented in Figure 4.36. A high variation occurred in the study. Soil mineralisation rates were however also in this study significantly different per treatment ($P<0.05$). Soil mineralisation rates in the weed fallow were however not significantly different (at $P<0.05$) from rates measured in maize (see also the LSD-value). No roots growed in the cores in the three weeks of the experiment, so that can't have caused the treatment differences.

Table 4.41: Soil moisture contents and average soil mineralisation rates (kg $Nha^{-1}day^{-1}$) and their LSD- (Least Significant Difference) values during the field core incubation study on soil mineralisation rates. Soil moisture contents are expressed as a percentage of WFPS to be facilitate data comparison. The period between two sampling moments was 21 days. The cores were inserted to a depth of 15 cm.

treatment	t=0	average t=0 - t=1	t=1	average soil min.
maize	42.74	44.28	45.82	0.414
sesbania fallow	43.77	45.14	46.50	0.642
weed fallow	48.04	50.09	52.15	0.183
bare fallow	40.52	42.74	44.96	0.014
LSD	4.43		3.74	0.290

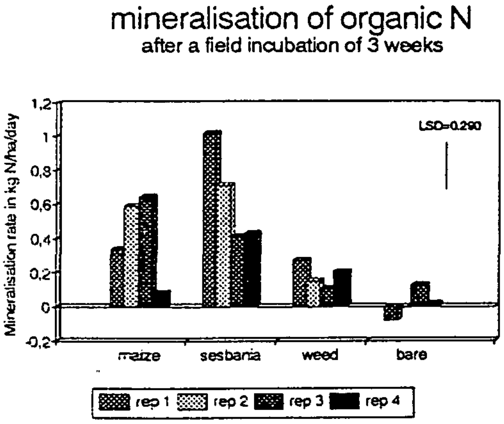


Figure 4.36: Mineralisation as influenced by treatment, measured with a field core experiment (Each bar consists of an average of three cores.).

Moisture contents slightly increased during the study. All cores were covered, so no direct rainfall could enter the cores (avoiding leaching). The heavy rainfall during the incubation can however have caused some capillary rise leading to higher moisture contents. Moisture contents in the bare fallow were lowest and clearly beneath optimum values. Whether this caused the low values in the bare fallow can't be said with certainty. Moisture contents in the weed fallow were significantly higher than those in maize and can have overestimated soil mineralisation for the weed fallow compared to maize. The diffences in soil mineralisation caused by this effect will be rather small, because differences in WFPS are small and the WFPS of the weed fallow is near the optimum for soil mineralisation (see the aerobic incubation study). Changes in soil mineralisation with WFPS around this optimum are small. Differences in soil mineralisation rates are caused by treatment effects and are no artefact of soil moisture conditions. A possible explanation for these treatment differences will be presented in Chapter 5, when presenting the complete organic nitrogen balance.

4) tent mineralisation

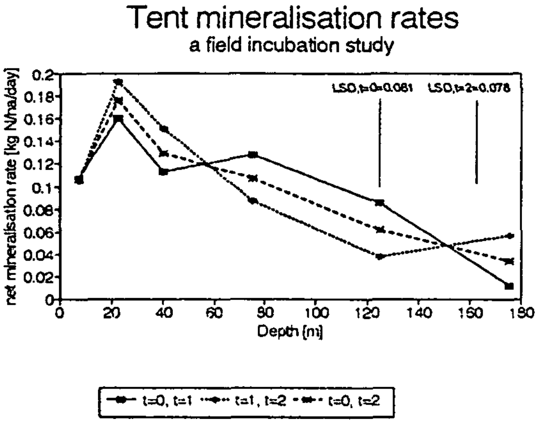


Figure 4.37: Mineralisation as influenced by soil depth, measured with the tent mineralisation

No soil mineralisation was found with the field core mineralisation method in the bare fallow, as no new inputs of organic matter occurred in this treatment. With the tent mineralisation it was tried to measure soil mineralisation rates in the bare fallow very accurately at constant soil moisture content. Soil evaporation could however not be avoided completely (see Table 4.42). Average soil moisture contents were therefore corrected for dynamics in soil evaporation to account for rapid initial moisture losses: Soil evaporation is proportional to the square root of time (Tanner and Jury, 1976, see Appendix III). This means that changes in soil moisture become inversely related to the square root of time, because evaporation is the only loss of soil moisture possible. The curve with this characteristic was fitted between two successive sampling points and soil moisture was calculated for each day using this relationship. The average soil moisture over all days between two successive sampling moments is presented in Table 4.42. This is of course not equal to the average moisture content of two sampling moments. Changes in soil moisture contents only occurred in the upper three layers.

The relationship between mineralisation rates and depth is presented in Figure 4.37. Soil mineralisation rates were indeed very low, but not completely absent. Some old organic nitrogen was also mineralised. The experiment also revealed that some soil mineralisation, though very small, occurred at depth. Soil mineralisation rates in the lower three layers can even be slightly underestimated, because some denitrification occurred above a WFPS-value of 73% (see 4.2.1.13). Denitrification was however still very low under these circumstances. Soil mineralisation at depth might also have been caused because other microorganisms are active under anaerobic conditions than under aerobic conditions leading to other relationships with depth.

In the top layer mineralisation rates were lower than in the second layer, while potential soil mineralisation rates in the top layer should be higher. This was probably caused by moisture stress; mineralisation rates decrease fast if moisture contents decrease below a WFPS of 60% (Linn and Doran, 1984). Moisture contents in the upper three layers were significantly lower than the moisture content in the lower three layers (at P<0.05). The upper three layers became significantly different from each other during the experiment due to evaporation.

With the anaerobic mineralisation study no treatment effects were found below layer 2 (see its LSD values in Figure 4.34). Probably the mineralisation rates found below the 2nd layer with the tent method can be used for all treatments, while soil mineralisation rates in the upper two layers were specifically for the bare fallow. Using the values of the upper two layers for other treatments would lead to an underestimation of mineralisation, because the mineralisation in the bare fallow was lowest of all treatments, see Figure 4.36.

Table 4.42: Soil moisture contents during the tent mineralisation study. Moisture contents were expressed as a percentage of WFPS (water filled pore space) to be able to compare the data between layers and with literature. The period between two sampling moments was 42 days. The LSD (Least significant difference is also presented.

layer	t=0	average t=0 - t=1	t=1	average t=1 - t=2	t=2
0-15 cm	52.49	46.00	41.55	38.81	36.93
15-30 cm	63.93	56.89	54.85	51.52	49.85
30-50 cm	67.95	64.74	63.22	60.76	58.30
50-100 cm	77.91	77.51	77.31	75.12	73.52
100-150 cm	74.66	74.66	74.66	73.31	71.76
150-200 cm	73.26	73.85	74.04	73.07	72.10
LSD	5.60		7.71		10.08

5) calculations on the mineralisation rates

To come to an integral seasonal estimate potential corrections should include temperature effects, depth and moisture changes over the season. The four methods mentioned were used to include these corrections. Dynamics of moisture and inorganic nitrogen, disturbances and losses all have large influences on the results leading to a high variation. The field core mineralisation was used as a basis for the calculations of seasonal mineralisation, because the field core mineralisation was able to determine mineralisation rates under field conditions per treatment. By combining the other studies with the field studies (being field core mineralisation and tent mineralisation) as basis and correction for depth and moisture with laboratory studies (being anaerobic incubation and aerobic incubation, respectively) it was possible to come an integral estimate.

Mineralisation rates can be corrected for temperature with Q_{10} values. Temperature within the canopy is about 2°C lower than the temperature outside the canopy, while it is at maximum about 3°C higher during nighttime (Jacobs et al., 1992). On average per day temperature at soil surface hardly differs from temperature outside the canopy. This means that no significant treatment effect of temperature on soil mineralisation rates will occur. The average day temperature only changes around 2°C within a season and has therefore hardly any effect on mineralisation rates. Temperature during the field core incubation was not different from normal temperatures, so temperature influences were assumed to be absent.

To extend the measured mineralisation values of the top soil to two meter deep, the relationship of soil mineralisation with depth was needed. The tent mineralisation could not be used to obtain this relationship because in that study an interaction of moisture contents occurred. The soil mineralisation rate in the 0-15 cm layer was around 43% of the total soil mineralisation, as determined by the anaerobic incubation study under constant moisture contents. This ratio was corrected for differences in moisture content between depths afterwards. For this last correction the data obtained with the aerobic incubation study were used. This gave corrections for WFPS values above 50%. For WFPS below 50% the corrections given by Linn and Doran (1984) were used.

Using these corrections seasonal values could be calculated. For the bare fallow, not the results of the field core study were used, but the results obtained with the tent mineralisation, after some moisture corrections. The tent mineralisation study measured mineralisation rates in the bare fallow very accurately and had much less variation than the field core study. Results are shown in Table 4.43. When the increase in total inorganic nitrogen in the bare fallow (as presented in 4.2.1.10) was used as an indication of mineralisation in the bare fallow, the results were similar. The presented soil mineralisation rates are higher than those presented by Paustian et al. (1990) for temperate regions.

Table 4.43: Soil mineralisation rates (in kg Nha^{-1}) per treatment per season as determined by combining several mineralisation studies. In the last column some estimate of seasonal mineralisation using changes in total inorganic nitrogen in the bare fallow is presented.

	bare fallow	maize	sesbania fallow	weed fallow	bare fallow (based on ΔN)
2nd season	71.20	100.24	140.97	77.28	60.81
between seasons	29.56	57.84	81.63	45.12	23.63
3rd season	67.20	128.34	196.98	114.12	58.63
between seasons	9.52	18.96	27.92	14.82	8.31
4th season	68.36	130.84	220.46	120.92	63.36

The seasonal estimates are uncertain, because the techniques induced a large variability in the results. Some implications of this high variability will be presented in Chapter 5. In future studies it should be tried to decrease variation to a much larger extent.

Although field core mineralisation is a very helpful tool to determine mineralisation rates per treatment, it is also an inducer of large variation. With the field cores soil mineralisation rates were determined rather fast and for all treatments under field conditions. The only ways to decrease the variability is to take more cores (while already 12 cores per treatment per sampling moment were taken) to deal with the very high variability in inorganic nitrogen per plot. The same cause of variation played a role in the aerobic incubation.

Whereas changes in moisture contents only played a minor role in the field core mineralisation, it had a large impact on the aerobic incubation. Changes of over 10% were not uncommon, leading to a high variation in measured mineralisation rates. This can only be decreased if water potential is kept constant more strictly in future experiments. Changes in moisture contents also played some role in the tent mineralisation. Evaporation can be decreased by having an extra cover directly on top of the soil, but in that case temperature should be kept under control more strictly. The tent mineralisation still is the most accurate tool, because it takes composite samples from a large area for a long period. It gives however only good results if plant uptake is absent. It is therefore only useful for either short periods after removing plant cover or for longer periods in bare fallows.

The anaerobic incubation does not have the problems of changing moisture contents, but due to the anaerobic conditions it only indicates potential mineralisation rates. These potential mineralisation rates can reveal treatment and depth effects.

Soil mineralisation of phosphorus was derived out of nitrogen mineralisation data. Phosphorus mineralisation is not directly related to the organic nitrogen/organic phosphorus ratio of the soil as also the nitrogen/phosphorus ratios of the mineralising micro organisms determine the efficiency in which phosphorus can be mineralised. Assuming a N/P ratio of 10 for the micro organisms, then phosphorus mineralisation will be relative slower than the nitrogen mineralisation if the N/P ratio of the mineralisable material is larger than 10. Part of the phosphorus will be immobilised by the microorganisms in that case.

The N/P ratio of the soil organic matter is around 3.5, but that is not the material that is mineralised, because only new material was mineralised, as shown above. The N/P ratio of this new organic matter, consisting of litter and roots, was higher than 10. A correction for phosphorus immobilisation should therefore be made. A simple approach was used.

First of all, the average N/P, C/N and C/P ratio of the new soil organic matter was calculated from N/P, C/N and C/P ratio's of litter and roots and the known conversed amounts per season. Further more, it was asssumed that 2/3 of the carbon was mineralised and 1/3 of the carbon was assimilated by the micro organisms. With the knwon nitrogen mineralisation rates and assumed fixed C/N and C/P ratio's for the micro organisms of 10 and 100, respectively, phosphorus mineralisation could be calculated from:

$$P_{\min}=N_{\min}\frac{(1.5\,(C/N)_{o.m.}-5)}{(1.5\,(C/P)_{o.m.}-50)} \qquad (38)$$

Results for each treatment and each period are presented in Table 4.44. These rates are much lower than the rates if no immobilisation would have taken place. The results change less than 10% if a C/P ratio of 50 is assumed for the micro organisms. This is within the determined confidence intervals.

Table 4.44: Phosphorus mineralisation (in kg Pha^{-1}) per treatment per season as derived from nitrogen mineralisation data

	maize	sesbania fallow	weed fallow	bare fallow
2nd season	6.001	5.102	4.891	6.797
between seasons	1.770	3.324	2.468	2.794
3rd season	4.023	8.101	6.395	6.448
between seasons	0.570	1.114	0.868	0.913
4th season	4.092	8.707	7.129	6.560

4.2.1.10 Inorganic nitrogen storage

Results:

Inorganic soil nitrogen is the resultant of many processes occurring within the soil and can be used to estimate the reliability of the process estimates, as already shown in section 4.2.1.9 for the soil mineralisation in the bare fallow. Inorganic soil nitrogen (in the forms of ammonia and nitrate) was determined for 19 sampling rounds spread over three seasons. Part of these data has already been presented by Hartemink (1994) and Braun (1995). Data collected during the 4th season are presented in Appendix VI.9. Results are presented in Figure $4.38_{a,b,c}$.

At the start of the 2nd season no significant differences (at $P<0.05$) between treatments were found (Hartemink, 1994). At the start of the 3rd season there were significant differences (at $P<0.05$) and these differences increased with time. The weed fallow and the sesbania fallow were not significantly different, maize had significantly higher amounts of nitrogen and the bare fallow had significantly higher amounts than maize (all at $P<0.05$) (Braun, 1995). The bare fallow showed a significant increase in nitrogen in March 1994, which was followed by a significant decrease in nitrogen in April 1994. The increase in the bare fallow in January 1995 was also significant (at $P<0.05$). The changes in nitrogen before and after heavy rainfall in the bare fallow and the high nitrogen amounts in bare fallow and maize at depth may indicate a large susceptibility of these treatments for leaching of nitrogen.

The significant lower amounts of nitrogen (also at depth) in sesbania fallow and weed fallow and the absence of built up of nitrogen in the weed fallow and the sesbania fallow are probably caused by continuous nitrogen uptake in these treatments. As already indicated in 4.1.1.2 both weed fallow and sesbania fallow were able to have some continuous uptake from depth. The remarkable similarity between the sesbania fallow and the weed fallow patterns may indicate that both were equally able to retrieve nutrients from depth and to avoid leaching to depth. This stresses the importance of ground cover also between seasons to avoid leaching.

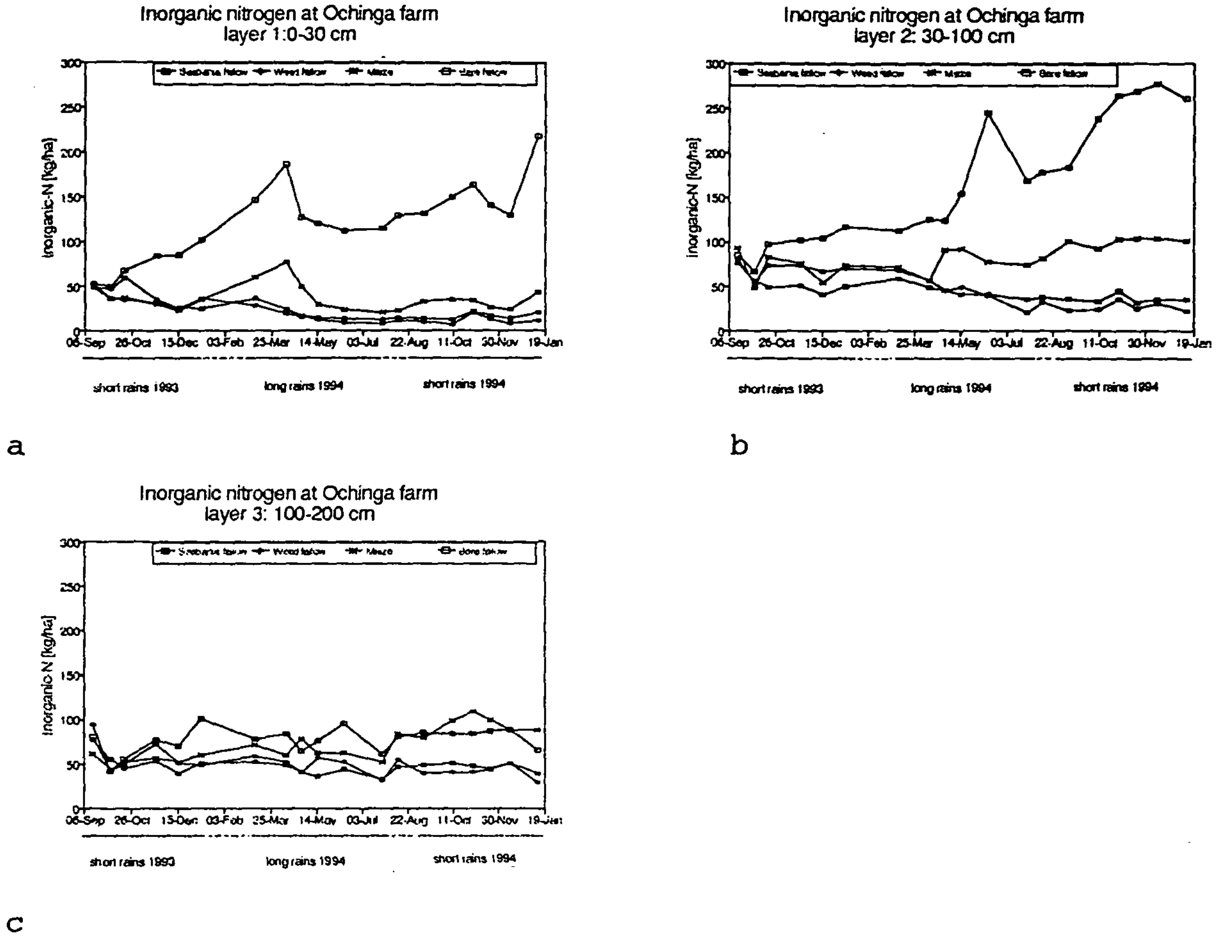


Figure 4.38$_{a,b,c}$: Soil inorganic nitrogen changes in the 2nd, 3rd and 4th season of the experiment for three soil layers

As soon as plant uptake of nitrogen stopped (which already occurred around three weeks before the end of the season in maize, because from that moment on only reallocation of nutrients took place) nitrogen amounts in the top soil increased due to mineralisation. This built up of nitrogen was especially visible between two seasons. As soon as rains started again, this nitrogen was susceptible to leaching. An indication that this actually occurred is the fact that the peak found in the top soil of the bare fallow at the end of March 1994 returned in the 30-100 cm layer in May 1994, probably caused by movement of nitrogen. While moisture changes in the top layer could be seen directly in the 30-100 cm layer, this did not occur with nitrogen. Nitrogen movement was retarded. This could have been caused by nitrogen adsorption (see 4.2.2.3). Most of the losses occurred during the rainy seasons, when moisture contents were high. Also the bare fallow had high moisture contents, increasing the likelihood of leaching. Birch (1958) attributed the nitrogen flush to fragmentation of organic matter during the dry period, which would be mineralised during the rainy period.

ble 4.45: Inorganic nitrogen (log-transformed) in the layers 0-30, 30-100 and 100-200 cm for four nd-use systems (LUS) at Ochinga.

ason	Sampling date	Inorganic N (log kgNha^{-1}*10^{2}) in 0-30 cm layer				Inorganic N (log kgNha^{-1}*10^{2}) in 30-100 cm layer				Inorganic N (log kg Nha^{-1}*10^{2}) in 100-200 cm layer			
		Sesbania fallow	Weed fallow	Maize	Bare fallow	Sesbania fallow	Weed fallow	Maize	Bare fallow	Sesbania fallow	Weed fallow	Maize	Bare fallow
	16 Sep	169	169	172	172	188	190	194	191	189	196	175	190
	04 Oct	156	167	157	169	175	171	166	182	173	162	161	161
	19 Oct	155	177	157	183	169	186	190	197	166	169	169	173
	22 Nov	150	154	146	192	170	186	187	200	173	184	173	187
	16 Dec	141	139	135	192	162	182	171	199	160	170	172	182
	10 Jan	139	151	153	200	170	184	186	206	171	169	177	197
	08 Mar	156	145	178	217	176	181	185	205	172	176	185	189
	11 Apr	138	128	189	227	168	175	175	209	168	172	178	192
	28 Apr	123	119	169	210	164	164	195	209	161	160	188	181
	17 May	115	112	145	208	160	168	195	218	156	174	180	187
	14 Jun	113	100	138	205	161	159	189	237	164	172	179	197
	26 Jul	110	96	131	205	154	130	185	221	150	150	171	177
	12 Aug	118	108	137	211	158	149	190	225	166	173	191	189
	09 Sep	115	101	152	210	154	135	200	226	168	159	189	191
	11 Oct	112	93	154	216	151	138	196	236	170	161	199	192
	03 Nov	134	128	153	220	164	155	199	242	166	161	203	191
	22 Nov	124	110	143	214	149	139	200	242	165	165	191	194
	13 Dec	115	98	138	209	153	148	199	243	166	171	194	193
	13 Jan	130	105	164	233	154	136	200	241	159	146	194	181

	0-30 cm layer	30-100 cm	100-200 cm
comparing LUS means ame sampling date (df = 9):	6.137 (LSD = 14)	5.913 (LSD = 12)	7.716 (LSD = 17)
comparing sampling date means ame LUS (df = 54):	6.720 (LSD = 13)	7.879 (LSD = 18)	7.791 (LSD = 16)

Statistical analysis of the total inorganic nitrogen was carried out on the log-transformed values to overcome the skewed distribution, because the data were not normally distributed. The log-transformed data and its SED (standard error of difference) and its LSD (Least significant difference are presented in Table 4.45.

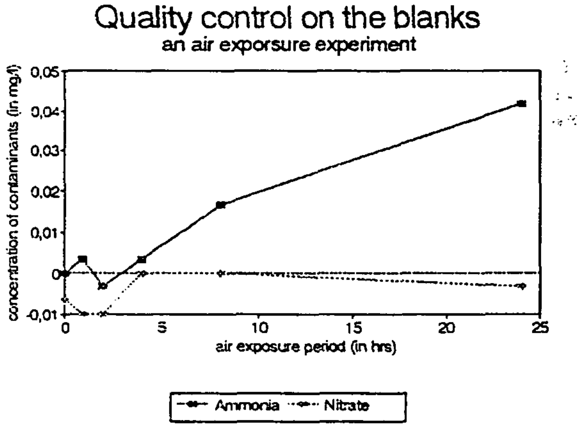


Figure 4.39: Control on the quality of the blanks, while soil extracting: an air exposure experiment

Some quality control was carried out on the samples. The data obtained by an extraction with KCl was compared with the data obtained by an extraction with distilled water. This was carried out because in several simulation programs an input of nitrogen in the soil solution is asked, which could be different from the amount of nitrogen determined by KCl extraction. Total inorganic nitrogen in the solution was however not significantly different for the two methods(at $P<0.05$) in the top layers. This may be not the case in the lower layers for which this relationship was not tested, because sorbed nitrate increased with depth (see 4.2.2.3). KCl extraction may remove sorbed nitrate and water extraction not, leading to higher concentrations of nitrate in the KCl extraction. This could not be proved.

The second quality control was an check on contamination of the ammonia samples due to deposition during air exposure (see Figure 4.39). Nitrate contamination was negligible. The contamination was negligible during the first two hours of air exposure. The samples were never opened for a longer period than those two hours.

Outputs:

4.2.1.11 Runoff water

Results:

Total phosphorus, ammonia, nitrate and total nitrogen in the runoff water were analysed a couple of times (see Appendix VI.10). Total nitrogen was better correlated to runoff losses and includes all losses (including organic losses of nitrogen) in runoff water. For these reasons further analysis was done on total nitrogen and total phosphorus only. Nutrient contents decreased with increasing runoff losses (see Figure 4.40). Nutrient contents were analysed after some runoff had taken place, but only the last millimeters of runoff water were actually sampled. When runoff starts, first easily available nutrients will be lost. After a while this stock becomes depleted, releasing less and less nutrients.

To calculate all nutrients lost during the runoff event, the losses during the runoff event have to be integrated. For this reason a fit was made describing the relation between runoff and nitrogen contents in runoff water. The following functions were tried (with nutrient contents in mgm^{-2} and runoff in mm):

$$\int NutrientLosses = \int a * runoff^{b} \tag{39}$$

$$\int NutrientLosses = \int \frac{a}{runoff^{2}} + b \tag{40}$$

$$\int NutrientLosses = \int b * e^{a * runoff} \tag{41}$$

$$\int NutrientLosses = \int a + b * e^{\frac{-runoff}{c}} \tag{42}$$

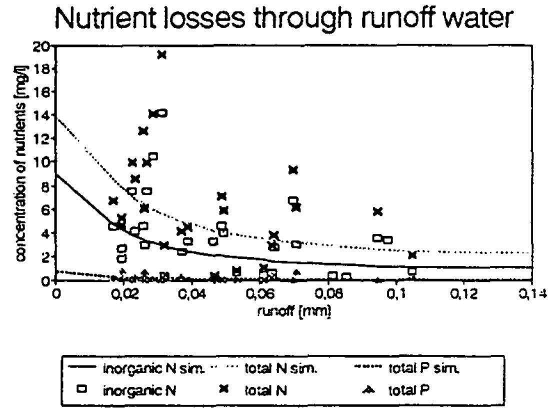


Figure 4.40: Nutrient contents in runoff water in relation to the amount of runoff before sampling

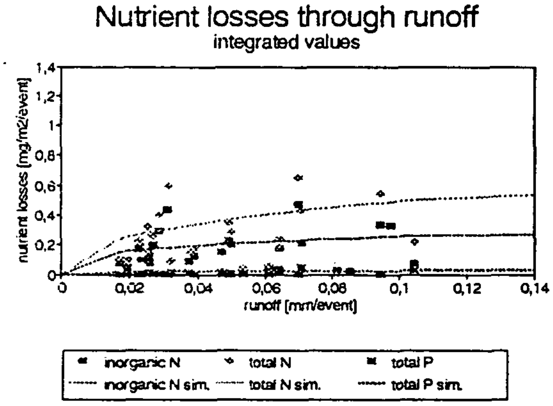


Figure 4.41: Nutrient losses in runoff water per runoff event

The best fit was given by eq. 39. This revealed for the nitrogen losses a a=0.4985 and b=-0.5991 for nitrogen losses at a r^2 of 0.367, which is still poor. For phosphorus losses the fit was even poorer (r^2= 0.167) and a= 0.01282 and b=-0.7393. The integrated values are shown in Figure 4.41 and can be calculated with:

$$NutrientLosses = \frac{a}{b+1} * runoff^{b+1} \tag{43}$$

No significant difference was found between nutrient losses in runoff water from weed fallows and runoff water from sesbania fallows (at $P<0.05$). Total losses become different per treatment, due to the different amounts of runoff. Seasonal phosphorus losses in the runoff water were very small and are presented in Table 4.46. Seasonal losses of nitrogen are presented in Table 4.47.

Table 4.46: Seasonal losses of phosphorus due to runoff (in kg Pha^{-1}) per treatment

	bare fallow	sesbania fallow	weed fallow	maize
2nd season	0.0023	0.0018	0.0011	0.0021
between seasons	0.0015	0.0010	0.0008	0.0013
3rd season	0.0029	0.0022	0.0016	0.0025
between seasons	0.0017	0.0011	0.0010	0.0015
4th season	0.0025	0.0012	0.0009	0.0022

Table 4.47: Seasonal losses of nitrogen due to runoff (in kg Nha^{-1}) per treatment

	bare fallow	sesbania fallow	weed fallow	maize
2nd season	0.136	0.087	0.041	0.115
between seasons	0.069	0.035	0.026	0.058
3rd season	0.185	0.126	0.080	0.155
between seasons	0.084	0.043	0.036	0.071
4th season	0.149	0.048	0.030	0.127

4.2.1.12 Eroded sediments

Background information:

With runoff also some soil is lost; erosion. Erosion will accelerate losses of organic matter (and nitrogen with organic matter) (Parton et al., 1987). Luckily under normal circumstances in Western Kenya majority of the rain showers occurs when there is a cover of crops. This is however not the case for the bare fallow. The quantity of soil lost can be calculated with the universal soil loss equation (USLE). This equation states (Young and Muraya, 1990; Wischmeier and Smith, 1978) (with erosion in kgha^{-1}yr^{-1}):

$$Erosion_{USLE}=R*K*LS*C \qquad (44)$$

In which for the Maseno situation the factors are estimated as follows:

R	Rainstorm parameter	This numerical measure of the erosive potential of the rainfall is given as a function of intensity (I) and maximum intensity (I_{max}) both in cm/hr yielding R in ton d.w./ha

$$R=I_{max}*(2.1+0.89*\log(I)) \qquad (45)$$

K	Erodibility factor	0.04 was given as a reasonable value for a stable soil like those in Western Kenya according to Shepherd et al. (1993). With the use of monograph in Wischmeier and Smith (1978) a value

		of 0.08 was calculated and this last value was used in the calculations.
LS	slope factor	Shepherd et al. (1993) gave a value of 0.56 for an average farm in Western Kenya. With the use of monograph in Wischmeier and Smith (1978) a value of 0.31 was calculated and this last value was used in the calculations.
C	Crop factor	The crop factor depends on crop and crop management. With the use of the conversion tables presented by Wischmeier and Smith (1978) the factors were estimated as follows: 1.0 (bare fallow), 0.65 (maize, with a low productivity), 0.30 (sesbania fallow) and 0.07 (weed fallow). The presence of weeds under the sesbania greatly helped to reduce this crop factor, as was already shown in Figure 4.8.

Stoorvogel and Smaling (1990) mention an annual loss of 30 ton d.w.ha^{-1} for maize in the sub-sahara. To calculate losses of nitrogen and phosphorus on the basis of erosion (in $kgha^{-1}yr^{-1}$), Stoorvogel and Smaling (1990) and Gachene (1989) mention that a enrichment factor should be included. This enrichment factor is similar for both nutrients:

$$Erosion_N = 1.5 * FractionN_{soil} * erosion_{USLE} \tag{46}$$

$$Erosion_P = 1.5 * FractionN_{soil} * Erosion_{USLE} \tag{47}$$

Shepherd et al. (1993) presented erosion losses of 11 kg $Nha^{-1}yr^{-1}$ for maize in Western Kenya with the use of the USLE and the equation mentioned above.

Results:

Based on the estimates mentioned above, it was possible to calculate sediment losses, see Table 4.48.

Table 4.48: Sediment losses at Ochinga farm in ton d.w.ha^{-1} per season for each treatment calculated with the universal soil loss equation

	bare fallow	weed fallow	sesbania fallow	maize
2nd season	10.03	0.60	3.01	6.52
between seasons	1.34	0.08	0.40	0.87
3rd season	15.87	0.95	4.76	10.32
between season	2.09	0.13	0.68	1.36
4th season	7.14	0.43	2.14	4.64
total loss	36.48	2.19	10.94	23.71

In the weed fallow and the sesbania fallow erosion losses were also measured during the 4th season allowing a comparison with the estimates using the USLE and allowing extrapolation of the data to the bare fallow and maize.

The data collected are presented in Appendix VI.11. As a first approach the sesbania and the weed fallow were statistically analysed together. The relationship between the sediment losses and runoff for both treatments together is presented in Figure 4.42. For this analysis the data collected by Braun (1995) were also included. Results are shown in Table 4.49.

Table 4.49: Probabilities (and r^2) of the three, two and one parameter models given for the best fits of the multiple regression analysis of sediments in runoff water. The intercept was significant ($P<0.05$) in all models.

model	r^2	P-model	P-rainfall	P-runoff	P-intensity
1	0.353	0.0005	0.0002	0.2511	0.4343
2	0.343	0.0002	0.0001	0.2549	
3	0.321	0.0001	0.0001		

Only rainfall had a significant influence on erosion losses. To analyse why runoff had no significant influence on erosion losses both treatments were analysed separately (see Table 4.50 and Table 4.51).

Table 4.50: Probabilities (and r^2) of the three, two and one parameter models given for the best fits of the multiple regression analysis of sediments in runoff water in the sesbania fallow. The intercept was significant ($P<0.05$) in all models.

model	r^2	P-model	P-rainfall	P-runoff	P-intensity
1	0.558	0.0026	0.0016	0.0282	0.0851
2	0.471	0.0033	0.0064	0.0239	
3	0.292	0.0114	0.0114		

The best equation for the sesbania fallow is the two parameter model (with erosion losses in $kgha^{-1}$ per event and runoff and rain both in mm per event):

$$Sediment_{sesbania}=26.39*runoff+o.527*rain-18.83 \qquad (48)$$

Table 4.51: Probabilities (and r^2) of the three, two and one parameter models given for the best fits of the multiple regression analysis of sediments in runoff water in the weed fallow. The intercept was significant ($P<0.05$) in all models.

model	r^2	P-model	P-rainfall	P-runoff	P-intensity
1	0.417	0.0001	0.0001	0.2845	0.9071
2	0.417	0.0001	0.0001	0.2775	
3	0.409	0.0001	0.0001		

Model 3 is the most significant for the weed fallow (with erosion in kg d.w.ha^{-1} per event and rain in mm per event):

$$Sediment_{weed}=1.481*rain-64.73 \qquad (49)$$

The weed fallow had a much lower runoff than the sesbania fallow (see 4.1.1.5). Runoff in the weed fallow became more or less constant during the trial and had no significant influence anymore. In the sesbania fallow, runoff differed much more with time leading to a significant influence of runoff. Two separate models were used to describe the two fallow systems.

The regression equations were used to calculate seasonal sediment losses in the weed fallow and the sesbania fallow. The regression equation of the sesbania fallow was also used to extrapolate the data to the bare fallow and maize. In the bare fallow and in maize runoff was also high (see section 4.1.1.5 for its calculation) and runoff was assumed to have also a significant influence on these treatments. Sediment losses in the bare fallow and maize could, therefore, be calculated with the use of calculated runoff in these treatments. The results are presented in Table 4.52.

Table 4.52: Sediment losses at Ochinga farm in ton d.w.ha^{-1} per season for each treatment determined with the collected data and the regression analysis results following out of the collected data

	bare fallow	weed fallow	sesbania fallow	maize
2nd season	10.48	0.66	3.64	6.97
between seasons	1.92	0.07	0.37	1.26
3rd season	22.69	1.47	8.96	13.74
between season	3.19	0.15	0.65	2.09
4th season	13.35	0.87	1.06	8.96
total loss	51.64	3.22	14.68	33.03

The annual erosion losses for maize are about 24 ton d.w.ha^{-1}, which is quite similar to the estimates mentioned by Stoorvogel and Smaling (1990) for the sub-sahara. The results using the data are also quite similar to the results using the USLE, giving extra confidence in the calculations. Only the crop factor differs between treatments. This facilitates a relative comparison between treatments. Because the crop factor of the bare

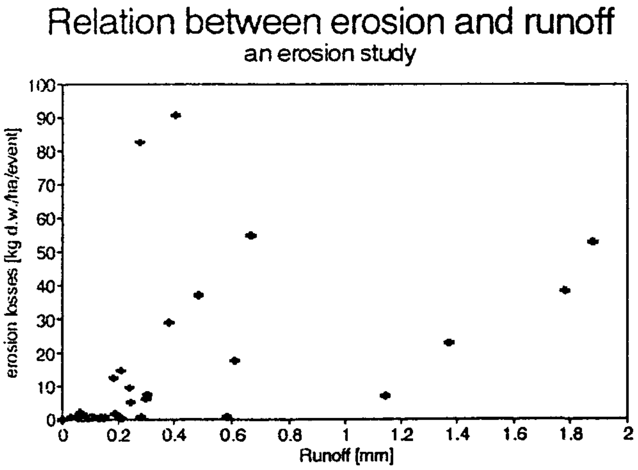


Figure 4.42: The relationship between sediment losses and runoff independent of treatment

fallow is always 1.0 by definition, it is possible to calculate the crop factors of the other treatments: 0.601 (for maize), 0.284 (for sesbania fallow) and 0.062 (for the weed fallow). These estimates approximate the crop factors calculated based on Wischmeier and Smith (1978). This means that also relative erosion losses, comparing treatments mutually, is estimated well. The assumption that the same regression equation for sesbania fallow could be used in maize and the bare fallow is not falsified.

To calculate nutrient losses on the basis of erosion estimates (in $kgha^{-1}yr^{-1}$) with the USLE, Stoorvogel and Smaling (1990) and Gachene (1989) mention that an enrichment factor should be included. In this case it was not necessary to include such a factor, because total nitrogen and phosphorus were measured directly in the sediment samples. The average total nitrogen content in the sediment samples was 0.711% and average phosphorus content was 0.119% (see Appendix VI.11). This leads to seasonal nitrogen and phosphorus losses due to erosion, as presented in Table 4.53 and 4.54, respectively. These losses are much higher than the nitrogen losses presented by Shepherd et al. (1993).

Table 4.53: Nitrogen losses in kg Nha^{-1} through erosion based on total sediment losses per season as calculated with the use of measured data

	bare fallow	weed fallow	sesbania fallow	maize
2nd season	74.52	4.69	25.87	49.58
between seasons	13.66	0.48	2.60	8.97
3rd season	161.4	10.48	63.71	97.71
between season	22.73	1.09	4.66	14.83
4th season	94.93	6.15	7.57	63.72
total loss	367.2	22.89	104.40	234.8

Table 4.54: Phosphorus losses through erosion based on total sediment losses per season as calculated with the use of measured data

	bare fallow	weed fallow	sesbania fallow	maize
2nd season	12.472	0.785	4.329	8.299
between seasons	2.285	0.081	0.436	1.502
3rd season	27.005	1.754	10.663	16.35
between season	3.804	0.182	0.780	2.483
4th season	15.888	1.029	1.266	10.67
total loss	61.45	3.83	17.47	39.30

4.2.1.13 Denitrification

Background information:

Denitrification is the most important gaseous loss of nitrogen. Grimme and Juo (1985) state that leaching and denitrification are the most important causes of nitrogen inefficiency in the humid tropics. Denitrification is carried out by facultative anaerobic microorganisms and depends therefore on soil moisture content. Linn and Doran (1984) mention a threshold value of 60-70%. Additionally, these microorganisms need a carbon source and nitrate to denitrify. Denitrification can be described as:

$2NO_3^- \rightarrow 2NO_2^- \rightarrow 2\ NO \rightarrow N_2O \rightarrow N_2$

Denitrification is higher in tropical regions than in temperate regions and increases with disturbance as microorganisms are more active under such conditions. The rhizosphere may enhance denitrification (Anderson and Ingram, 1993), because at those places organic carbon, moisture, nitrate and transport of nitrogen (a limiting factor for denitrification (van Veen and Frissel, 1983)) are least limited. Continuous presence of roots can increase denitrification (Paustian et al., 1990). Problems measuring denitrification using acetylene inhibition are discussed by Anderson and Ingram (1993).

Denitrification is estimated to be 5 % of the inorganic N by Young and Muraya (1990). Stoorvogel and Smaling (1990) estimated denitrification to be 17 kg $Nha^{-1}yr^{-1}$ and Shepherd et al. (1993) estimated 22 kg $Nha^{-1}yr^{-1}$ (for a crop) and 39 kg $Nha^{-1}yr^{-1}$ (for an improved fallow). Smaling and Stoorvogel (1990) give a transfer function for denitrification:

$$\mathit{Denitrification}=12+2.5*\mathit{fertilizer}-0.1*\mathit{uptakeN} \qquad \textbf{(50)}$$

Other gaseous losses are caused by Nitrosomonas, producing also small amounts of N_2O during ammonia oxidation but that is not of practical importance. Neither is the chemical denitrification (via urea) (Brady, 1985). Nitrate respiring bacteria can reduce nitrite to ammonia, which must not be confused with denitrification. But this process is neither of practical importance (Anderson and Ingram, 1993). All those gaseous losses were assumed to be absent.

Results:

Denitrification is not a continuous process as it depends on soil moisture content. At Ochinga farm it was measured with two methods during the short rains of 1994, the 4th season (see Appendix VI.12):

1) Aerobic incubation

With an extensive experiment with undisturbed soil cores it was tried to determine the relationship between soil moisture contents (indicated by water filled pore space (WFPS)) and denitrification rates, determined as the rate of disappearance of nitrate. In the cores leaching, uptake and nitrification were also assumed to be absent. The five samples for which this assumption was falsified were left out of the analysis. The analysis of the determining parameters (see Figure $4.43_{a,b,c,d,e}$) indicated the great complexity of the soil system. Due to this complexity a direct relationship between denitrification rates and WFPS led to a very large variability (with a C.V. of 50-150%), see Figure 4.43_b. The variability is partly created by changes in moisture content during the experiment (for this reason only those samples of which the change in soil moisture was less than 5% were used in Figure 4.43_b). Initial nitrate is also highly variable, due to its microsite variability. This makes movement of nitrogen important for the denitrification process under field conditions. The relationship between denitrification and moisture content could be determined in a statistical analysis (see Tables 4.55 and 4.56), similar to the analysis of mineralisation rates.

The amount of nitrate at time 0 is the amount of available substrate at the site. Figure 4.43_d clearly shows the dependance of the micro organisms on this nitrogen sustrate. The relationship between %C (the carbon substrate) and denitrification rates is not significant at P<0.05 (see Figure $4.43_{d,e}$); Nitrogen (see Figure 4.43_a) seems to be more limiting than carbon. The high correlation between average %N per layer and denitrification and the relationship indicated in Figure 4.43_c underline that the functional relationship is given by %N and not by %C. The relationships shown grafically were also analysed statistically (in Tables 4.55 and 4.56).

Table 4.55: Probabilities (and r2) of the five, four, three, two and one parameter models given for the best fits of the multiple regression analysis of denitrification rates determined with the aerobic incubation experiment.

model	r2	P-model	P-NO3,0-	P-WFPS2	P-WFPS	P-%N	P-%C
1	0.706	0.0001	0.0001	0.1998	0.2216	0.1275	0.2320
2	0.924	0.0001	0.0001	0.0011	0.0015	0.0049	
3	0.890	0.0001	0.0001	0.0220	0.0355		
4	0.885	0.0001	0.0001	0.0023			
5	0.858	0.0001	0.0001				

The best fit was obtained if all parameters, except %C, were used (with WFPS in %, NO3,0- in mgkg-1 and denitrification in mg kg-1day-1):

$$Denitrification=-3.4*\%N-0.25*WFPS+0.0017*WFPS^2+0.071*NO^-_{3,0}+9.2 \quad (51)$$

In the top layers nitrate and total nitrogen were high and both decreased with depth. The influence of nitrate on denitrification rates was higher than the influence of total nitrogen. Although total nitrogen has a negative sign in the equation, denitrification is highest in the top soil. The positive sign on $WFPS^2$ indicates that denitrification increases more than linear with increasing WFPS.

From equation 51, it can be calculated that below a WFPS value of about 73% (independent of depth) no denitrification occurred, which is comparable to values mentioned in literature. Denitrification increased fast with increasing WFPS up to saturation, in accordance with literature (Linn and Doran, 1984).

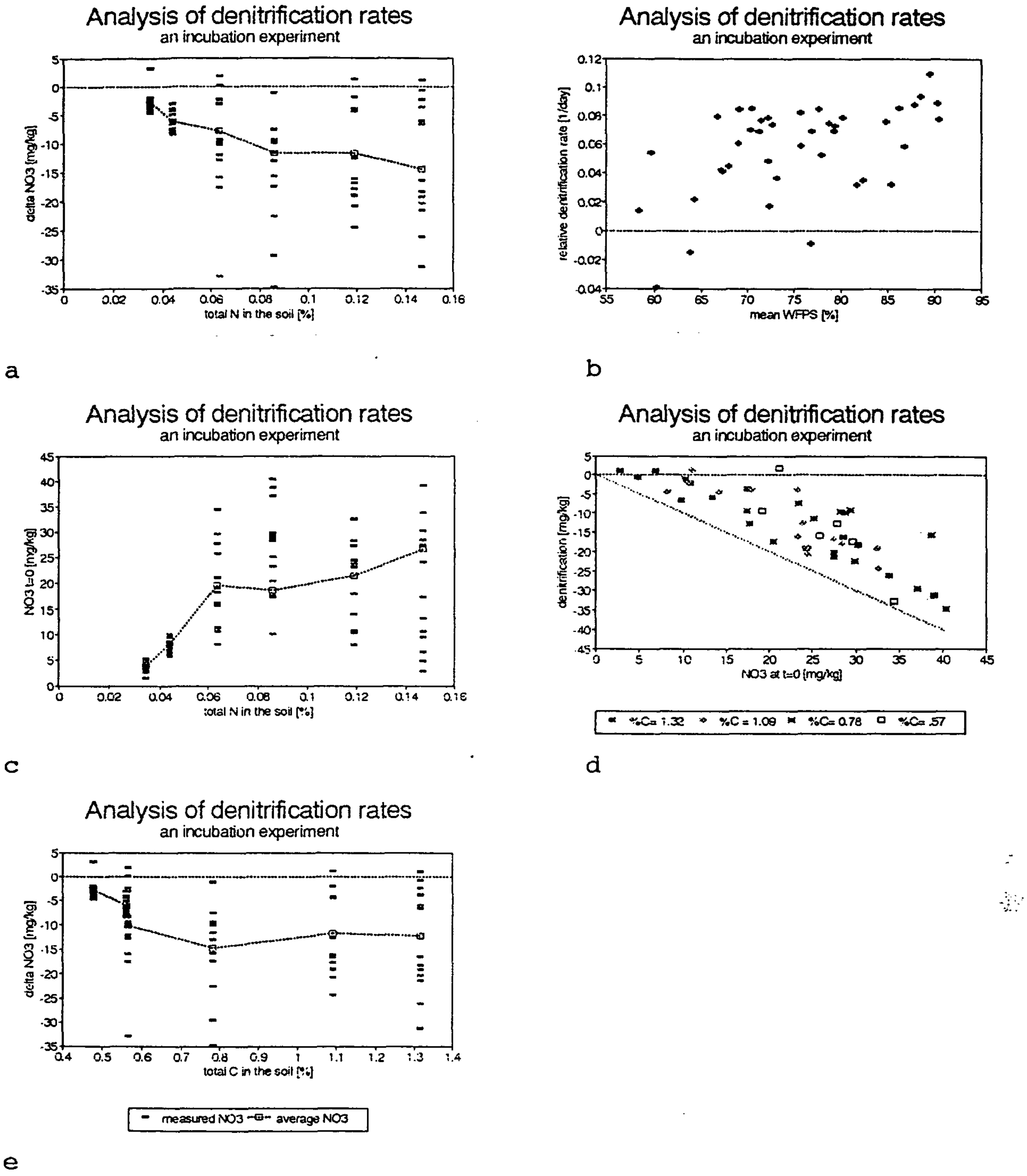


Figure 4.43$_{a,b,c,d,e}$: Analysis of denitrification, using an aerobic incubation experiment. Analysis of potential influencing parameters; amount of NO_3^- at t=0, total soil nitrogen and soil organic carbon. The line through 4.28$_d$ indicates complete denitrification.

Table 4.56: Probabilities (and r^2) of the five, four, three, two and one parameter models given for the best fits of the multiple regression analysis of relative denitrification rates determined with the aerobic incubation experiment.

model	r^2	P-model	P-$NO_{3,0}^-$	P-%N	P-$WFPS^2$	P-WFPS	P-%C
1	0.357	0.0202	0.0040	0.0127	0.1425	0.0829	0.2558
2	0.342	0.0001	0.0008	0.0001	0.0205	0.0306	
3	0.338	0.0001	0.0026	0.0001	0.0769		
4	0.357	0.0001	0.0001	0.0001			
5	0.419	0.0001	0.0001				

Only carbon did not have a significant influence on measured relative denitrification (R.D.), the change in denitrification rate per unit of nitrate:

$$R.D.=1.7*10^{-4}*WFPS^2-0.44*\%N-2.7*10^{-2}*WFPS-2.1*10^{-3}*NO^-_{3,0}+1.08 \tag{52}$$

Literature suggests that denitrification depends on carbon, nitrate and moisture contents. Results suggest that carbon was sufficient for nitrate to disappear, presumably by denitrification. Nitrate was also abundant, especially in the upper 50 cm. Nitrate disappeared at WFPS above about 73%. Soil water, especially in the lower layers, exceeds 73% WFPS frequently. For these reasons, denitrification is likely to occur under the field conditions of Ochinga farm. The assumption of Hartemink (1994) used earlier in this experiment, that denitrification at Ochinga is negligible should no longer be hold.

2) *anaerobic incubation*

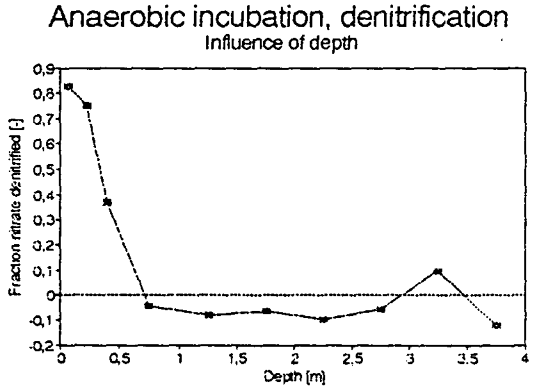


Figure 4.44: Denitrification, as the fraction initial nitrate disappeared, as influenced by soil depth

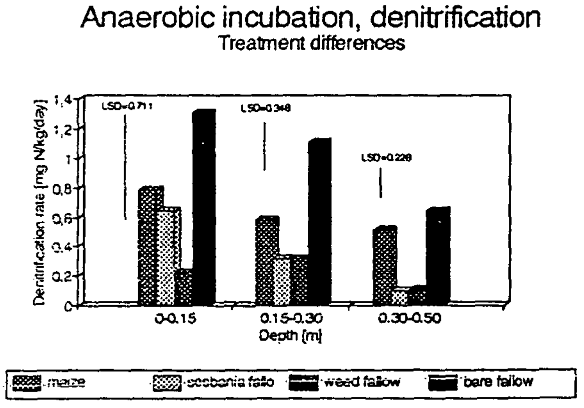


Figure 4.45: Denitrification rates as influenced by treatment and soil depth

The relationship between denitrification losses (presented as the fraction of initial nitrate lost by denitrification) and depth is shown in Figure 4.44. Most denitrification occurred in the top soil, probably because denitrifying populations are most dense at these places (Payne, 1991). Denitrification was not significantly different from zero (at $P<0.05$) at a depth below 50 cm, where nitrate is low, but still available. Besides, carbon may have played a limiting role at these depths. Some root inputs in fallow systems may have led to some limited denitrification at depth, but this could not be proved.

In Figure 4.45 the relationship between denitrification, depth and treatment is shown. Denitrification was significantly different between treatments (at $P<0.05$). These differences in denitrification were only caused by differences in initial nitrate, because if denitrification was expressed as the fraction of initial nitrate disappaered, as presented in Figure 4.44, then denitrification was not significantly different per treatment (at $P<0.05$). The bare fallow had the highest nitrate concentrations and thus highest denitrification rates.

Based on soil nitrate, the relationship between denitrification and moisture and the relation between denitrification rates and treatment (as determined in the anaerobic incubation) seasonal losses for denitrification were estimated. Results are presented in Table 4.57.

Table 4.57: Seasonal estimates on denitrification in kg Nha^{-1} per treatment

	bare fallow	sesbania fallow	maize	weed fallow
2nd season	27.18	18.72	27.53	21.68
between seasons	0	0	0	1.44
3rd season	35.48	18.05	30.89	15.04
between seasons	4.28	2.84	5.56	1.78
4th season	47.34	17.78	30.48	10.42

4.2.2 Estimated processes

Inputs:

4.2.2.1 Biological nitrogen fixation

Nitrogen can be fixed non-symbiotically and symbiotically.

Non-symbiotic fixation

Background information:

Nitrogen fixation can be described as:

$N_2 + 6\ H^+ + 6e^- > 2\ NH_3$

Non-legumes, associated with free living bacteria, fix about 8 kg $Nha^{-1}yr^{-1}$ in woodlands and in grasslands the fixation is about 15 kg $Nha^{-1}yr^{-1}$ according to Brady (1985). Young et al. (1990) estimate non-symbiotic fixation as 1 kg $Nha^{-1}yr^{-1}$. Stoorvogel and Smaling (1990) mention a base fixation of 5 kg $Nha^{-1}yr^{-1}$. Osmond et al. (1992) mention an indigenous nitrogen fixation in the tropics of 10 kg $Nha^{-1}yr^{-1}$.

Results:

Based on these literature estimates the following fixation-estimates were used for Ochinga farm: For sesbania 8 kg $Nha^{-1}yr^{-1}$ non-symbiotic fixation, 15 kg $Nha^{-1}yr^{-1}$ for the weed fallow and 10 kg $Nha^{-1}yr^{-1}$ for maize and bare fallow. Nitrogen fixation costs energy. The nitrogen fixed will therefore be considered to enter the soil organic nitrogen pool, because the fixed nitrogen is directly stored in bacterial biomass.

Symbiotic nitrogen fixation
Background information:

Rhizobia, symbiotically associated with legumes in nodules, can (if the soil is not acid and the supply of P, K and S is good) fix up to 140 kg $Nha^{-1}yr^{-1}$. Nitrogen fixed in this way will be directly transformed into proteins as the process costs energy. Fixed nitrogen is therefore assumed to be incorporated directly as organic N in the plant tissue. Young et al. (1990) estimate symbiotic fixation to be 100 kg $Nha^{-1}yr^{-1}$. Stoorvogel and Smaling (1990) mention that 60% of the nitrogen uptake in plants is fixed symbiotically. Lena Stahl (ICRAF, pers. comm.) states that 30-40% of the nitrogen in plants was fixed in Sesbania Sesban. The fixation is however extremely variable and ranges between 0-60%.

Results:

At the experiment active nodules were found, so there is at least some nitrogen fixation. In the first analysis a default percentage of 35% is assumed. In Chapter 5 a sensitivity analysis will be presented in which the influence of different fixation rates will be tested ranging from 0-50%.

Internal:

4.2.2.2 Weathering of rocks

Results:

Rocks and other unweathered material contain small amounts of phophorus. Through weathering this phosphorus is released. Hingston (1977) estimated the input from weathering of minerals 0.1 kg $Pha^{-1}yr^{-1}$.

Outputs:

4.2.2.3 Leaching

Background information:

NO_3^- is highly mobile. Leaching of nitrogen tends to be highest when soil mineralisation is highest and when nitrogen uptake is low (for example because of a phosphorus deficiency). Leaching is assumed to be a major cause of nitrogen losses in tropical areas, especially in oxisols where the rainfall exceeds evapotranspiration. Field data on leaching losses in Africa are however scarce (Arora and Juo, 1982). A good rooting system (temporarily and spatially) is required to minimize leaching.

Bypass flows, determined by the pore system, reduce leaching of nitrogen (but can increase leaching of water), because in those cases only part of the water contributes to the downward flow of nitrate (van Veen and Frissel, 1983). Bypass flows use the larger transmission pores (> 50 µm), allowing little time to equilibrate with the soil solution in the smaller (storage) pores and will contain only small amounts of nitrogen (Grimme and Juo, 1985). These small amounts of solute can be transported well ahead of the main solute front (Edwards et al., 1993).

Leaching is also affected by adsorption of nitrate (made possible by the existance of AEC (Arora and Juo, 1982)), increasing the retention time. A evaluation of the CERES model indicated that if nitrate adsorption is not taken into account, this can lead to underestimations of leaching of nitrogen (Bowen et al., 1993). Jemison et al. (1994) come to the same conclusion in their evaluation of the LEACHM model. Hartemink (1994) measured adsorption curves for Ochinga farm using the methodology described in Cahn et al. (1992). The adsorption curve for nitrate is presented in Figure 4.46. Out of this measurement a retention factor of 2.4 (meaning that about 60% is adsorbed) could be estimated. Under agricultural conditions the supply of nitrogen will exceed the adsorption capacity at the start of the season and leaching will occur (Noordwijk, 1989). Deep roots will retrieve this nitrogen in the second part of the season. Also fallows have the possibility to retrieve lost nutrients. Under the conditions at Ochinga farm (nitrate sorption being high enough to compensate leaching conditions caused by a rainfall surplus) this retrieval is theoretically possible (based on calculations presented by Noordwijk, 1989). Continuous roots will however be needed to use the nitrogen efficiently.

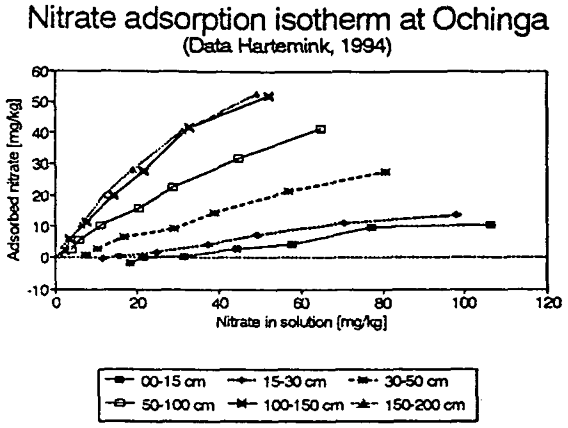


Figure 4.46: Nitrate adsorption isotherm for the experiment as measured by Hartemink (1994)

Stoorvogel and Smaling (1990) present a transfer function based on rainfall, fertilizer and uptake to estimate leaching (with all parameters in kg $Nha^{-1}yr^{-1}$, except for rain which is in $mmyr^{-1}$):

$$Leach_N = 2.3 + 0.0028 * rain + 0.3 * fertilizer_N - 0.1 * uptake_N \quad \textbf{(53)}$$

Complicated computer models, like LEACHN (Wagenet and Hutson, 1989) have been developed to estimate nitrogen leaching losses. Seyfried & Rao (1991) give for perennial systems a leaching loss of 1 kg $Nha^{-1}yr^{-1}$ and for maize a leaching loss 57 kg $Nha^{-1}yr^{-1}$. Shepherd et al. (1993) estimate 39 kg $Nha^{-1}yr^{-1}$ (for maize) and 69 kg $Nha^{-1}yr^{-1}$ (for a fallow).

Results:

Leaching at Ochinga farm were tried to estimate with LEACHW (for leaching of water) and LEACHN (for leaching of nitrogen). The problems with LEACHN are that LEACHN has a weak denitrification component and symbiotic fixation, nitrate adsorption and bypass flow are not taken into account.

At Maseno some bypass flow might have occurred through termite activity. According to James Kinyangi (ICRAF, pers. comm.) only one species was active. Termite activity was quite randomly distributed in the soil, horizontally and vertically (see figure 4.47). No clusters of channels were found. Termites were encountered alive to a depth of 3-4 m (as also stated by Wielemaker and Boxem, 1982). Their channels were however not continuous, root channels were only small (and had under all

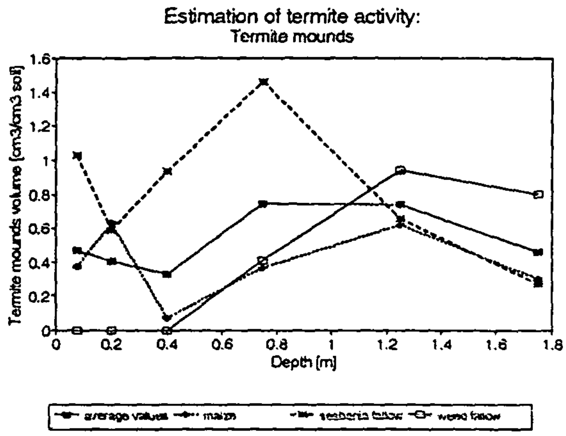


Figure 4.47: Distribution of termite channels with depth.

circumstances tight contact with the soil) and the rest of the soil was very homogeneous. Because of this soil structure, bypass flow was unlikely. While the activity of termites tended to be high (no quantification of termite activity was available), bypass flow will be assumed to be absent.

Due to the shortcomings of the LEACHN program, so far no good results could be obtained. Other ways to calculate leaching of nitrogen were therefore sought.

With the use of the results of LEACHW, a first estimation of leaching of nitrogen could be made. Inorganic nitrogen concentrations were known and rather constant in the lower layers. In one sampling round (in November 1994) soil sampling took place up to 4m deep. This sampling round yielded inorganic nitrogen concentrations below the profile investigated, because the soil profile was taken up to 2 m depth, as explained in Chapter 2. Multiplying the nitrogen concentrations with the moisture leaching losses gives seasonal leaching losses for nitrogen (see Table 4.58), as all nitrogen transported below 2 m deep is considered as leaching.

Table 4.58: Seasonal leaching losses of nitrogen in kg Nha^{-1} calculated with the use of moisture leaching losses and nitrogen concentrations below the profile

	maize	bare fallow	sesbania fallow	weed fallow
2nd season	37.83	67.33	13.53	22.07
between seasons	6.82	23.79	1.58	2.93
3rd season	38.54	64.44	21.82	19.24
between seasons	5.84	13.81	2.11	2.12
4th season	66.86	75.00	18.57	24.56

The bare fallow had a high nitrate concentration below the profile, while the weed fallow and sesbania fallow contained much lower amounts of nitrogen at depth. In those fallows occurred therefore much less leaching of nitrogen.

Results obtained with the transfer function presented by Stoorvogel and Smaling (1990) are presented in Table 4.59.

Table 4.59: Seasonal leaching losses of nitrogen in kg Nha^{-1} calculated with the transfer function presented by Stoorvogel and Smaling (1990).

	maize	bare fallow	sesbania fallow	weed fallow
2nd season	25.51	31.49	24.95	24.26
between seasons	5.77	5.77	-0.04	3.97
3rd season	60.41	66.90	54.03	55.87
between seasons	9.48	9.48	8.67	6.54
4th season	34.84	40.43	30.97	19.85

The results presented in Table 4.58 and 4.59 are in the same range as the seasonal losses presented in literature. In Chapter 5 the average values of the two approaches will be used for calculations.

Part III: Seasonal modeling, synthesis

Chapter 5: Seasonal budgets

In Chapter 4 the processes occurring were determined. With the use of a small timestep applied per process it was possible to calculate the fluxes for each process per season. Some of those seasonal fluxes are already presented in Chapter 4. The processes will however interact with each other, as already indicated in Chapter 4. Runoff amounts will for example influence the amounts of moisture and nitrogen available for leaching. For this reason answers for each process can't be used independently.

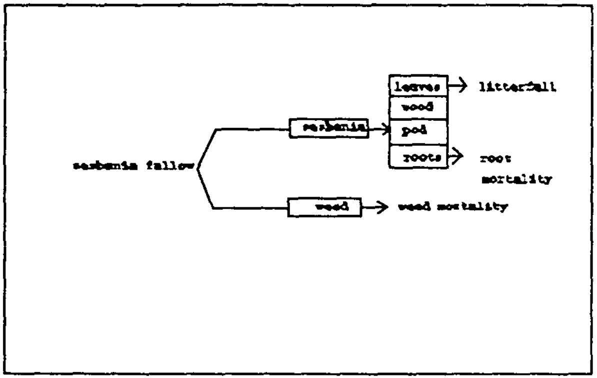


Figure 5.1$_a$: Basic flow diagram for organic material in the sesbania fallow

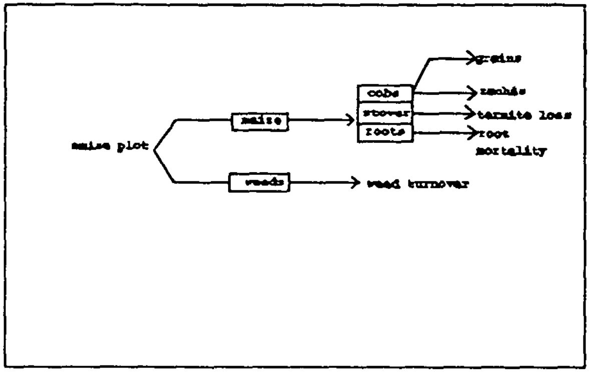


Figure 5.1$_b$: Basic flow diagram for organic material within the maize plot.

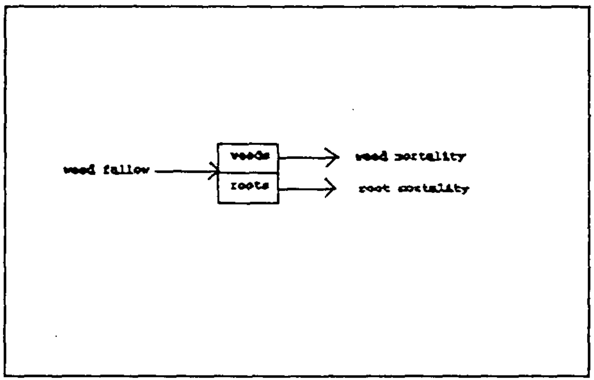


Figure 5.1$_c$: Basic flow diagram for organic material in the weed fallow

Because of these interactions, the total system has to be considered to come to the answers on the objectives mentioned in Chapter 1. The difficulty is that the variability increases when summing different processes, because the variability of each process has to be summed also. The confidence interval of the results will therefore increase (making treatment differences less clear), but this is still the only way to deal with the total agroforestry system. The confidence intervals are very important. For this reason each seasonal balance will be presented with its coefficient of variation (C.V.). With the use of the seasonal balance the net balance for nitrogen and phosphorus will be calculated. Differences in net balance between treatments will be tested on their significance by calculating the confidence interval with the help of the C.V.-values. This will also reveal which processes have an important influence on the net balance.

With the use of the processes and their interactions it is possible to compose total seasonal balances for water, nitrogen and phosphorus. Contrary to Chapter 4 the time step applied in this chapter will be only seasonal.

In sections 5.2 and 5.3 some diagrams of plant material in the 4th season will be presented as part of the organic matter dynamics per treatment. The basic diagrams (with indications of processes occurring) of these major pathways are presented in Figure 5.1_a (for sesbania fallow), Figure 5.1_b (for maize) and Figure 5.1_c (for weed fallow). The pools in these diagrams (the boxes) represent the net production of biomass in the 4th season. The arrows represent the distribution of produced plant biomass among the possible outputs.

5.1 Water balance

5.1.1 pools

Soil moisture contents measured during the 19 sampling rounds in the 2nd season (Hartemink, 1994), in the 3rd season (Braun, 1995) and in the 4th season (section 4.1.1.2) were converted to mm. Moisture contents in the total profile are presented in Figure 5.2. Moisture contents at the beginning and at the end of each season and their changes are presented in Table 5.1. These changes are again used in table 5.$2_{a,b,c,d}$ for comparison of measured changes in soil moisture with calculated changes in soil moisture using the separate processes, as indicated in Table 5.$2_{a,b,c,d}$.

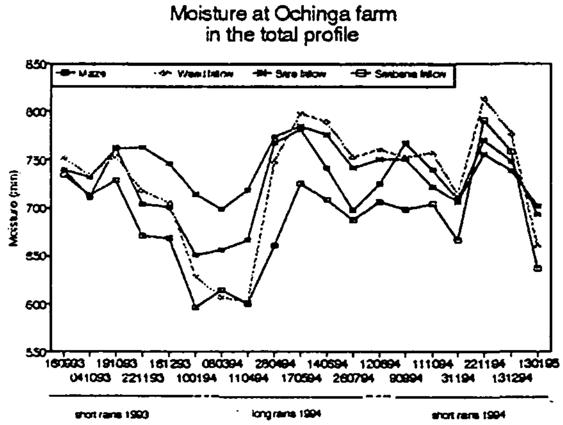


Figure 5.2: Total moisture (in mm) in the soil profile during the experiment

The calculated changes in moisture storage were not significantly different from the measured changes, although the differences are sometimes very large. Especially the differences in the weed fallow at the end of the 3rd season and at the end of the 4th season and in maize at the end of the 3rd season are large. This is caused by the large variability in runoff measurements (and consequently infiltration) and in evapotranspiration calculations (see the C.V. values in table 5.$2_{a,b,c,d}$). Also an underestimation of the evapotranspiration may have caused the large differences. Leaching losses don't seem to contribute to the difference because the coincidence between observed and predicted values was large (see 4.1.2.2). The assumptions mentioned in Chapter 2 on which the water balances are based are not falsified.

Soil moisture was significantly higher in the bare fallow during the 2nd season and the first half of the 3rd season. Soil moisture in the weed fallow was significantly higher during the rainy periods in the 3rd and the 4th season, due to the low runoff. During these periods soil moisture in the sesbania fallow was significantly lower, due to the combined effects of large evapotranspiration and runoff.

Table 5.1: Soil moisture and the changes in soil moisture (both in mm) over the profile per treatment per season

	2nd season		3rd season		4th season	
	begin	end	begin	end	begin	end
sesbania fallow	734.1	596.7	614.1	705.7	697.8	636.7
Δstorage		-137.4	17.4	91.6	-7.9	-60.1
maize	739.3	651.1	656.7	724.9	767.4	692.4
Δstorage		-88.2	5.6	68.2	42.5	-75.0
weed fallow	751.3	628.6	605.7	760.0	752.7	660.0
Δstorage		-122.7	-22.9	154.3	-7.3	-97.7
Bare fallow	739.3	713.2	698.5	749.5	749.9	701.8
Δstorage		-26.1	-14.7	51.0	0.4	-48.1

5.1.2 processes on a seasonal basis

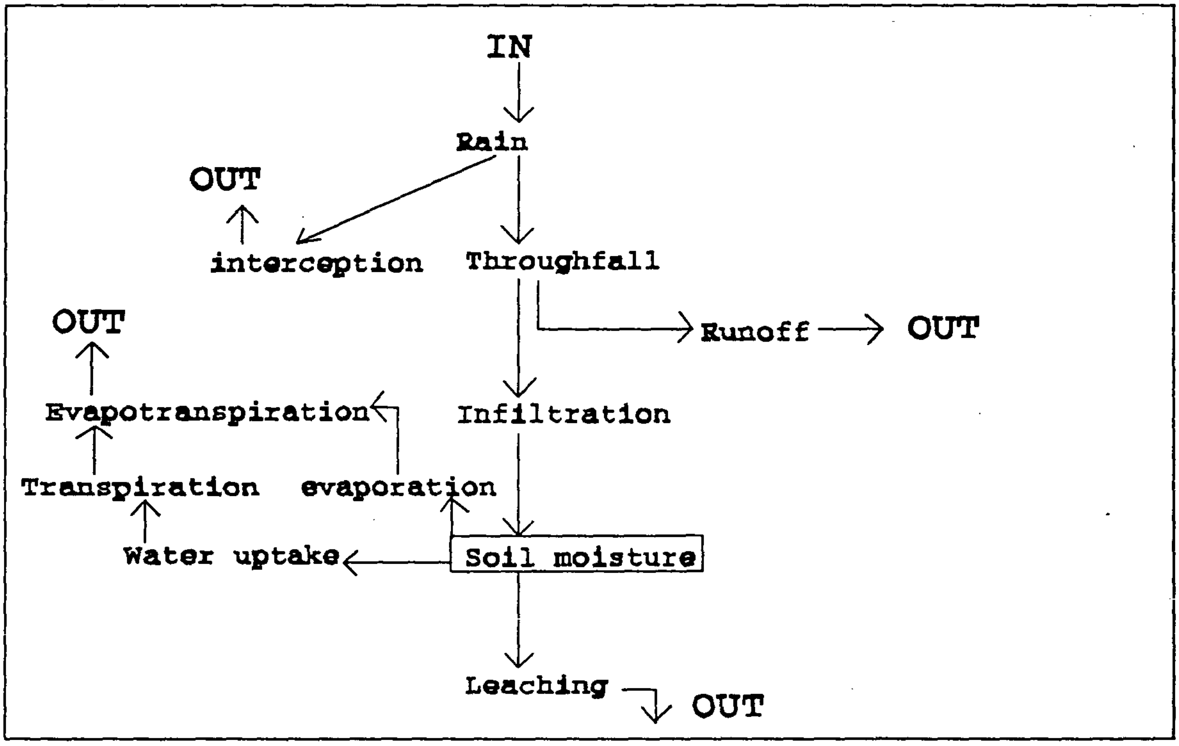


Figure 5.3: Functional flow diagram of water flows

All measured and calculated processes were discussed in section 4.1. The functional relationship between all processes is presented in Figure 5.3. With the use of interception and rainfall it is possible to calculate throughfall and out of throughfall and runoff it is possible to calculate infiltration and water storage could also be calculated with the use of a mass conservation equation. For each treatment the seasonal balance was calculated and presented in Table $5.2_{a,b,c,d}$ (together with the C.V.).

The water balance (and changes in water balance) were similar in the weed fallow and the sesbania fallow. Cumulative losses in maize were smaller than in above mentioned treatments. This was particularly caused by the low evapotranspiration, especially in between the seasons. This period therefore played an important role in terms of water conservation, although due to the bareness of this period, runoff was higher in the beginning of the growth season. Cumulative losses in the bare fallow were larger than in the other fallows, because of its very large runoff, eventhough evapotranspiration was very low.

Leaching, runoff and evapotranspiration were the most important processes in the water model, as we can conclude from Table $5.2_{a,b,c,d}$. Moisture storage changes reacted most sensitively on those parameters. Especially runoff was of crucial importance, due to its high variability caused by differences in slope and growth performance in the different replicates. A multiple regression was carried out on the data to deal with this variability. In soil conservation and soil fertility practices large emphasis should be paid to these slope aspects, because they determine (for a large part) the total water balance. A good runoff control becomes crucial for a good water conservation practice, as can be concluded from the large losses in the bare fallow. The runoff also had its influence on the nitrogen and phosphorus balance as we will see in sections 5.2 and 5.3.

Due to the large quantities of water lost by evapotranspiration, the total water balance potentially reacts very sensitively on changes in evapotranspiartion. With the extensive evapotranspiration calculations presented in Appendix III, it was possible to restrain the variability in its estimate.

The variation in leaching estimates was tested with the LEACHW-program. The high coincidence between observed and the moisture contents calculated by LEACHW indicates that variability in this estimation was reasonably small. This variability could however not be quantified. Variability in rainfall, interception and throughfall was also quite small and was not very crucial for the sensitivity of the total water balance.

Table 5.2$_a$: Water flows (in mm) to, inside and from the sesbania fallow on a seasonal basis

	2nd season	between seasons	3rd season	between seasons	4th season	C.V (%)
Inputs:						
Rainfall	489.0	89.6	1038.8	147.2	627.8	2
Internal flows:						
Interception	59.4	11.3	153.2	24.6	133.7	7
Throughfall	429.6	78.3	885.6	122.6	494.1	7
Infiltration	300.8	65.5	576.1	100.0	465.6	24
Outputs:						
Runoff	128.8	12.8	319.5	22.6	28.5	71
Evapotranspiration	332.6	97.5	314.0	45.3	338.9	17
Leaching	137.0	16.1	221.0	21.4	188.0	n.d
Δstorage[1]	-137.4	17.4	91.6	-7.9	-60.1	6
ΔStorage[2]	-168.8	-48.1	41.1	33.3	-61.3	

1) as measured during soil sampling

2) as calculated from inputs and outputs of soil moisture:
Δstorage =infiltration - evapotranspiration - leaching

Table 5.2$_b$: Water flows (in mm) to the weed fallow, inside the weed fallow and out of the weed fallow on a seasonal basis

	2nd season	between seasons	3rd season	between seasons	4th season	C.V (%)
Inputs:						
Rainfall	489.0	89.6	1038.8	147.2	627.8	2
Internal flows:						
Interception	63.6	11.6	135.0	19.1	81.6	7
Throughfall	425.4	80.0	903.8	128.1	546.2	7
Infiltration	405.7	73.9	799.5	113.6	537.5	24
Outputs:						
Runoff	19.7	6.1	104.3	14.5	8.7	76
Evapotranspiration	355.4	89.8	347.8	55.7	350.9	17
Leaching	160.5	21.3	139.9	15.4	178.6	n.d
Δstorage[1]	-122.7	-22.9	154.3	-7.3	-97.7	3
ΔStorage[2]	-110.2	-37.1	311.8	42.5	8.0	

1) as above

2) as above

Table 5.2$_c$: Water flows (in mm) to the bare fallow, inside the bare fallow and out of the bare fallow on a seasonal basis

	2nd season	between seasons	3rd season	between seasons	4th season	C.V (%)
Inputs:						
Rainfall	489.0	89.6	1038.8	147.2	627.8	2
Internal flows:						
Interception	0	0	0	0	0	
Throughfall	489.0	89.6	1038.8	147.2	627.8	7
Infiltration	100.9	17.9	198.9	28.3	133.7	24
Outputs:						
Runoff	388.1	71.7	839.9	118.9	494.1	24
Evapotranspiration	4.9	1.8	4.1	0.6	5.1	17
Leaching	172.1	60.8	164.7	35.3	191.7	n.d
Δstorage$_1$	-26.1	-14.7	51.0	0.4	-48.1	3
ΔStorage$_2$	-76.1	-44.7	30.1	-7.6	-63.1	

1) as above
2) as above

Table 5.2$_d$: Water flows (in mm) to the maize plot, inside the maize plot and out of the maize plot on a seasonal basis

	2nd season	between seasons	3rd season	between seasons	4th season	C.V (%)
Inputs:						
Rainfall	489.0	89.6	1038.8	147.2	627.8	2
Internal flows:						
Interception	9.8	0	20.8	0	12.6	7
Throughfall	479.2	89.6	1018.0	147.2	615.2	7
Infiltration	224.0	42.9	475.8	70.4	287.5	24
Outputs:						
Runoff	255.2	46.7	542.2	76.8	327.7	24
Evapotranspiration	215.8	1.8	128.1	0.6	151.0	17
Leaching	112.1	20.2	114.2	17.3	198.1	n.d
Δstorage$_1$	-88.2	5.6	68.2	42.5	-75.0	2
ΔStorage$_2$	-103.9	29.1	233.5	49.6	-61.6	

1) as above
2) as above

5.2 Nitrogen balance

5.2.1 pools

All nitrogen data were converted to kg Nha^{-1}. Soil inorganic nitrogen was sampled in 19 sampling rounds in the 2nd season (see Hartemink (1994)), in the 3rd season (see Braun (1995)) and in the 4th season (see 4.2.1.10). Inorganic nitrogen for the total profile is presented in Figure 5.4. Inorganic nitrogen contents at the beginning, at the end of each season and their changes within the season are presented in Table 5.3 to come to a seasonal balance. These changes are again used in Table 5.8$_{a,b,c,d}$ for comparison of measured changes in soil inorganic nitrogen with calculated changes in soil inorganic nitrogen using the separate processes.

Table 5.3: Inorganic nitrogen and the changes in inorganic nitrogen (both in kgha^{-1}) over the profile per treatment per period

	2nd season		3rd season		4th season	
	begin	end	begin	end	begin	end
sesbania fallow	202.88	126.07	147.95	99.80	98.11	95.07
Δstorage		-76.81	21.88	-48.15	-1.69	-3.04
maize	208.34	169.07	203.15	188.50	212.29	233.50
Δstorage		-39.27	34.08	-14.65	23.79	21.21
weed fallow	225.55	155.36	155.37	98.61	72.37	63.65
Δstorage		-70.19	0.01	-56.76	-26.24	-8.72
Bare fallow	220.67	321.08	336.85	388.24	401.55	543.94
Δstorage		100.41	15.77	51.39	13.31	142.39

The calculated changes in inorganic nitrogen storage in the soil, as indicated in Table 5.8 were not significantly different from the measured changes, although the differences are sometimes quite large. This is caused by the large variability in mineralisation (with a C.V. of 320% in the bare fallow!) and to a minor extent by the variability in inorganic soil nitrogen and plant uptake. This high variation led to a large confidence interval. The assumptions presented in Chapter 2, on which the processes in the balances are based were not falsified.

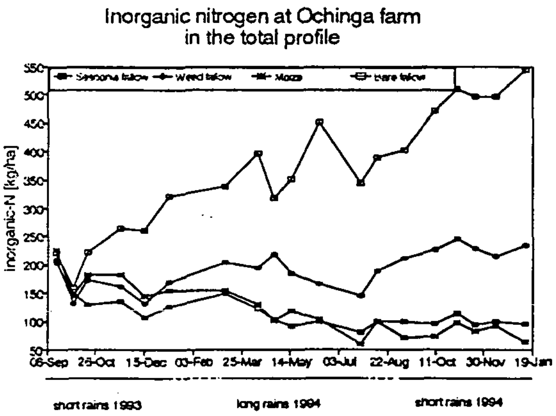


Figure 5.4: Total inorganic soil nitrogen in the profile during the experiment

In the sesbania fallow an additional source of variation, symbiotic fixation, was distinguished. The variability and uncertainty in symbiotic fixation led to an enormous variation. The differences between calculated and measured inorganic nitrogen changes could be explained from the variation of symbiotic fixation alone in all seasons, except for the 2nd season by assuming a symbiotic fixation of 27%, 48%, 31% and 61% for between seasons, the 3rd season, between seasons and the 4th season respectively.

At the beginning of the experiment differences in soil inorganic nitrogen were not significantly different. During the experiment significant differences between treatments developed due to the treatment differences in the process invloved.

Contrary to inorganic nitrogen, organic nitrogen was not significantly different between the treatments (Data are presented in Appendix VII.): The LSD (Least Significant Difference) for the initial soil sampling for comparing treatments at constant depth is $0.1*10^4$ kg Nha^{-1}. For the final soil sampling the LSD for comparing treatments at constant depth is $0.1*10^4$ kg Nha^{-1}. Only organic nitrogen in the weed fallow is significantly higher than organic nitrogen in the sesbania fallow in layer one and higher than organic nitrogen levels in the bare fallow in layer one and three. For the total profile no significant differences could be found. Organic nitrogen did not change significantly during the experiment either. This does not change when total nitrogen levels in the 0-5 cm layer and the 5-15 layer are compared. The data on nitrogen in the 0-5 cm and the 5-15 cm layer are also presented in Appendix VII. Total organic nitrogen for the total profile at the beginning of each season, at the end each season (if measured) are presented in Table 5.4.

Table 5.4: Organic nitrogen (in $kgha^{-1}$) over the profile per treatment per season

	2nd season		3rd season		4th season	
	begin	end	begin	end	begin	end
sesbania fallow	$1.8*10^4$	n.d.	n.d.	n.d.	$1.8*10^4$	$1.9*10^4$
maize	$1.8*10^4$	n.d.	n.d.	n.d.	$1.8*10^4$	$2.0*10^4$
weed fallow	$1.7*10^4$	n.d.	n.d.	n.d.	$1.7*10^4$	$1.9*10^4$
Bare fallow	$1.7*10^4$	n.d.	n.d.	n.d.	$1.6*10^4$	$1.7*10^4$

The calculated changes in organic nitrogen are also indicated in Table $5.8_{a,b,c,d}$. Paustian et al. (1990) found an increase in organic soil nitrogen in a weed fallow and a tree fallow. The calculated changes in this experiment indicate a decrease in organic nitrogen in all treatments except for the weed fallow. In the weed fallow an increase in organic soil nitrogen was calculated as soon as turnover of organic material started. No significant difference could be proved from direct measurements of organic soil nitrogen.

The treatment differences in calculated organic nitrogen amounts were, however, significant for the 4th season, although variation was high. This high variation was mainly caused by variability in soil mineralisation data and to a minor extent in mortality and plant uptake data.

The significant differences in nitrogen dynamics between the sesbania fallow and the weed fallow indicate a completely other scenario for the sesbania fallow and weed fallow in nitrogen dynamics. The organic nitrogen dynamics is of primary importance in the distinction between the two fallow systems. This dynamics will be presented in section 5.2.2.

5.2.2 processes on a seasonal basis

All measured and calculated processes were discussed in section 4.2. The functional relationship between all processes is presented in Figure 5.5. The complex of processes is the seasonal balance for nitrogen for this experiment. General models for carbon and nitrogen balances are also presented in literature, like CENTURY (Parton et al., 1987) and SCUAF (Young and Muraya, 1990).

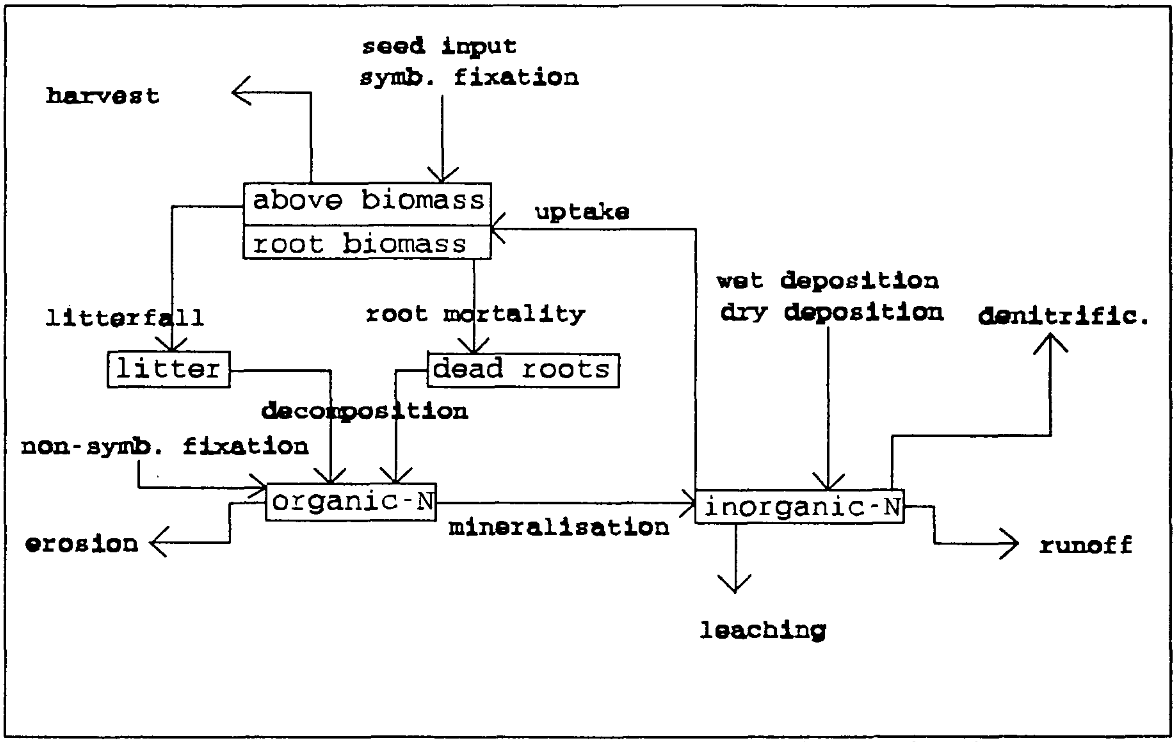


Figure 5.5: Functional flow diagram of organic and inorganic nitrogen flows

Note: 1) Wet deposition is not significantly different from nitrogen found in throughfall. This means that no plant interaction occurs. Plant leaching is therefore not drawn.

2) Adsorption and desorption of inorganic nitrogen are not drawn separately, but they influence leaching as indicated in 4.2.2.2.

Another type of model is described by Wolf et al. (1989). They describe a model in which the depletion during cropping years, while accumulation occurs during the fallow period. All these models are however less useful when it comes to a specific situation as this case. For this reason only measured (and estimated) data were used for the calculation of the seasonal balance for nitrogen. For each treatment the seasonal balance was calculated and is presented in Table $5.8_{a,b,c,d}$ (together with the C.V.).

In Table 5.8_a nitrogen uptake from the soil was assumed to be 65% of the total nitrogen uptake calculated in section 4.2.1.4. Symbiotic fixation was assumed to contribute 35% of the total nitrogen uptake. A sensitivity analysis using symbiotic fixation levels varying between 0-50% will be presented below.

The net balance

For the total system it is important to know the net balance (=the difference between inputs and outputs). Both inorganic and organic dynamics play a role in this net balance. The net balance per season in all treatments is presented in Table 5.5. As both inputs and outputs differ per treatment, the ratio of outputs to inputs is also included, see Table 5.6.

Table 5.5: Average net balance for nitrogen (in kg Nha^{-1}) for each treatment per season. For the sesbania fallow a range of estimates of symbiotic fixation is included

	symb. fix.	2nd season	between seasons	3rd season	between seasons	4th season
sesbania fallow	0%	-55.67	-1.58	-109.98	-11.54	-193.74
	15%	-45.86	7.40	- 93.43	-10.32	-179.55
	35%	-32.77	19.01	- 71.38	-8.69	-160.62
	50%	-22.96	27.73	- 54.83	-7.47	-146.32
weed fallow		-40.61	-2.53	- 50.74	-5.49	- 28.71
bare fallow		-144.45	-26.38	-252.17	-31.46	-192.02
maize		-138.04	-13.19	-232.02	-26.63	-167.73

Table 5.6: Relative net balance, meaning the amount of outputs divided by the inputs, for nitrogen. All data above 1 indicate a negative balance.

	symb. fix.	2nd season	between seasons	3rd season	between seasons	4th season
sesbania fallow	0%	5.30	1.72	14.00	10.02	18.40
	15%	3.01	0.30	5.22	5.34	26.86
	35%	1.91	0.15	2.84	3.29	15.52
	50%	1.50	0.11	2.12	2.55	14.13
weed fallow		5.53	1.88	6.47	5.10	4.76
bare fallow		21.5	13.4	24.9	31.8	24.6
maize		19.1	7.19	21.9	18.9	20.3

The nitrogen balances found are in the same range as those reported in literature: Smaling et al. (1993) found a nitrogen balance for the Kisii area of -112 kg Nha^{-1}yr^{-1}. Shepherd et al. (1993) calculated a balance of -86 kg Nha^{-1}yr^{-1} for a crop and -70 kg Nha^{-1}yr^{-1} for improved fallows. Shepherd et al. (in draft) calculated -89 kg Nha^{-1}yr^{-1} for a crop and -86 kg Nha^{-1}yr^{-1} for an improved fallow. Paustian et al. (1990) found a net loss in crop and weed fallow and a net gain in a nitrogen fixing fallow. From this study it follows that the average balance for the sesbania fallow and the weed fallow is higher than the net balance for maize and bare fallow.

The inputs were small. Wet deposition and non-symbiotic fixation were the most important inputs. Only the sesbania fallow had a substantial input when symbiotic fixation is assumed to be active. This symbiotic fixation was the only reason why the net balance in the sesbania fallow, became higher than the net balance in the weed fallow. The most important losses were erosion, leaching and denitrification.

Leaching and denitrification estimates were highly variable and contributed largely to the variability of the outputs. Erosion was the most important loss in both bare fallow and maize, as is also indicated by Shepherd et al. (1993). The large influence of erosion on the net balance stresses the important influences of soil conservation practices on soil fertility. It is important that erosion is counteracted or taken into account in soil fertility studies.

Table 5.7: Range in which the net balance for nitrogen (in kg Nha^{-1}) for each treatment per season can occur. This range is calculated with the use of the C.V. values, as explained in the text. For the sesbania fallow a range ofestimates of symbiotic fixation is included

	symb. fix.		2nd season	between seasons	3rd season	between seasons	4th season
sesbania fallow	0%	min	- 78.17	- 2.84	-147.76	-16.32	-240.80
		max	- 33.11	- 0.32	- 72.21	- 6.76	-147.15
	15%	min	- 68.36	5.87	-131.21	-15.10	-226.61
		max	- 23.30	8.39	- 55.65	- 5.54	-132.93
	35%	min	- 55.27	18.48	-109.60	-13.47	-207.68
		max	- 10.21	21.00	- 34.04	- 3.91	-114.00
	50%	min	- 45.46	26.20	- 92.60	-11.77	-193.48
		max	- 0.40	28.72	- 17.05	- 3.17	- 99.80
weed fallow		min	- 53.15	- 4.45	- 67.14	- 7.44	- 38.91
		max	- 28.07	- 0.61	- 34.98	- 3.53	- 18.06
bare fallow		min	-201.89	-33.78	-339.39	-41.75	-284.41
		max	- 87.31	-18.98	-166.00	-21.30	-108.61
maize		min	-183.90	-16.72	-298.84	-34.43	-220.12
		max	- 92.15	- 9.76	-165.21	-18.83	-131.63

It is necessary to know whether the differences in net balance between treatments are significant. The C.V.'s were used for this analysis. With the use of C.V.'s the minimum and maximum value per process could be calculated as average ± (average* C.V./100). The minimum value constisted of the maximum output + minimum input and the maximum value was obtained from the minimum output + maximum input. With the use of these minimum and maximum values the range, in which the net balance can occur, was calculated. Treatments were significantly different if the range had no coincidence. The results are presented in Table 5.7. For this analysis the symbiotic fixation in the sesbania fallow was analysed separately, because of its extreme influence on the net balance.

The high variability in possible symbiotic fixation rates is the main reason why no significant difference between the sesbania fallow and weed fallow was found as the actual symbiotic fixation was not known. The differences in net balance between bare fallow and maize were not significant. The differences in net balance in the sesbania fallow and weed fallow on one side and the net balance in the bare fallow and maize on the other side were however significant. This means that fallow systems are important out of soil fertility point of view to decrease the rate of soil depletion. The absolute values of the net balance were however negative, meaning that still soil fertility was lost. The periods between the seasons had the lowest net balance and are therefore very important to improve the soil fertility status, because during those periods erosion and denitrification, the most important losses, are small.

Table 5.8$_a$: Nitrogen flows (in kg Nha^{-1}) to, within the sesbania fallow and from the sesbania fallow

	2nd season	between seasons	3rd season	between seasons	4th season	c.v (%)
Inputs:						
Seed input	6.65	0	0	0	0	2
Wet deposition	3.25	0.59	6.90	0.95	4.17	13
Dry deposition	0	0.06	0	0.02	0	30
Non-symb. fixation	3.05	1.18	2.94	0.42	3.16	26
Symbiotic fixation	22.90	20.32	38.60	2.85	33.12	76
Internal flows:						
Mineralisation	140.97	81.63	196.98	27.92	220.46	55
Root mortality	4.27	15.82	118.32	19.93	139.51	38
Root conversion	0	1.87	63.43	15.68	126.59	13
Litter mortality	2.05	2.95	19.14	4.35	41.03	27
Litter conversion	0	0.77	9.35	2.61	26.35	18
Plant uptake (above)	42.52	37.75	71.70	5.29	61.51	48
Plant uptake (below)(1)	67.72	29.45	123.40	20.00	139.63	38
Outputs:						
Biomass removal(2)	4.71	0	0	0	150.9	17
Erosion	25.87	2.60	63.71	4.66	7.57	16
Runoff	0.08	0.04	0.13	0.04	0.05	40
Denitrification	18.72	0	18.05	2.84	17.78	32
Leaching	19.24	0.77	37.93	5.39	24.77	53
Δinorganic N(3)	-72.81	21.88	-48.15	-1.69	-3.04	54
Δinorganic N(4)	-1.01	26.77	-44.49	-0.37	-15.85	
Δorganic N(5)	-166.84	-54.38	-122.25	-4.98	-1.6	

(1) The plant uptake for below ground biomass is equal to root production

(2) Biomass removal is the sum of weeding, thinning and harvest.

(3) as measured during soil sampling

(4) as calculated from differences between inputs and outputs in the soil inorganic nitrogen pool:
Δstorage= mineralisation + wet deposition + dry deposition + non-symbiotic fixation - runoff -denitrification - leaching - total uptake

(5) as calculated from differences between inputs and outputs in the organic nitrogen pool:
Δstorage= total conversion - mineralisation - erosion

Table 5.8$_b$: Nitrogen flows (in kg Nha^{-1}) to, within and from the weed fallow

	2nd season	between seasons	3rd season	between seasons	4th season	C.V (%)
Inputs:						
Seed input	0	0	0	0	0	
Wet deposition	3.25	0.59	6.90	0.95	4.17	13
Dry deposition	0	0.06	0	0.02	0	30
Non-symb. fixation	5.71	2.22	5.51	0.78	5.92	26
Symbiotic fixation	0	0	0	0	0	
Internal flows:						
Mineralisation	77.28	45.12	114.12	14.82	120.92	52
Root mortality	2.46	9.12	67.05	11.49	80.42	25
Root conversion	0	2.02	55.33	11.56	80.46	32
Litter mortality	4.81	7.55	68.21	14.52	103.52	31
Litter conversion	0	4.29	55.01	11.94	105.54	5
Plant uptake (above)	72.36	18.04	128.7	29.4	120.23	27
Plant uptake (below)(1)	21.88	17.54	70.34	11.53	80.47	25
Outputs:						
Biomass removal	0	0	0	0	0	
Erosion	4.69	0.48	10.48	1.09	6.15	15
Runoff	0.04	0.03	0.08	0.04	0.03	40
Denitrification	21.68	1.44	15.04	1.78	10.42	18
Leaching	23.16	3.45	37.55	4.33	22.20	26
Δinorganic N(3)	-70.19	0.01	-56.76	-26.24	- 8.72	61
Δinorganic N(4)	-51.88	7.49	-68.12	-30.51	-46.88	
Δorganic N(5)	-63.33	-16.76	42.80	15.00	119.39	

(1) as above
(3) as above
(4) as above
(5) as above

Table 5.8$_c$: Nitrogen flows (in kg Nha^{-1}) to the bare fallow, within the bare fallow and out of the bare fallow

	2nd season	between seasons	3rd season	between seasons	4th season	C.V (%)
Inputs:						
Seed input	0	0	0	0	0	
Wet deposition	3.25	0.59	6.90	0.95	4.17	13
Dry deposition	0	0.06	0	0.02	0	30
Non-symb. fixation	3.81	1.48	3.67	0.05	3.95	26
Symbiotic fixation(6)	0	0	0	0	0	
Internal flows:						
Mineralisation	71.20	29.12	67.20	9.52	68.36	320
Root mortality	0	0	0	0	0	
Root conversion	0	0	0	0	0	
Litter mortality	0	0	0	0	0	
Litter conversion	0	0	0	0	0	
Plant uptake (above)	0	0	0	0	0	
Plant uptake (below)	0	0	0	0	0	
Outputs:						
Biomass removal	0	0	0	0	0	
Erosion	74.52	13.66	161.40	22.73	94.93	18
Runoff	0.14	0.07	0.19	0.08	0.15	40
Denitrification	27.18	0	35.48	4.28	47.34	203
Leaching	49.41	14.78	65.67	5.39	57.72	30
Δinorganic N(3)	100.41	15.77	51.39	13.31	142.39	28
Δinorganic N(4)	1.53	16.40	-23.57	-0.79	-28.73	
Δorganic N(5)	-110.12	-28.22	-195.00	-27.49	-129.11	

(3) as above
(4) as above
(5) as above
(6) The weed fallow did not contain Leguminosae

Table 5.8$_d$: Nitrogen flows (in kg Nha^{-1}) to, within and from the maize plot

	2nd season	between seasons	3rd season	between seasons	4th season	c.v (%)
Inputs:						
Seed input	0.55	0	0.55	0	0.55	1
Wet deposition	3.25	0.59	6.90	0.95	4.17	13
Dry deposition	0	0.06	0	0.02	0	30
Non-symb. fixation	3.81	1.48	3.67	0.52	3.95	26
Symbiotic fixation	0	0	0	0	0	
Internal flows:						
Mineralisation	100.24	57.84	128.34	18.96	130.84	82
Root mortality	37.46	0	38.36	0	39.72	29
Root conversion	0	26.68	10.57	15.71	22.28	33
Litter mortality	0	0	0	0	0	
Litter conversion$_{(7)}$	23.07	0	8.65	0	24.66	35
Plant uptake (above)	59.79	0	64.90	0	55.88	35
Plant uptake (below)$_{(1)}$	37.46	0	38.36	0	39.72	29
Outputs:						
Biomass removal$_{(2)}$	36.72	0	64.9	0	31.22	35
Erosion	49.58	8.97	97.71	14.83	63.72	18
Runoff	0.12	0.06	0.16	0.07	0.13	40
Denitrification	27.53	0	30.89	5.56	30.48	58
Leaching	31.67	6.29	49.48	7.66	50.85	21
Δinorganic N$_{(3)}$	-39.27	34.08	-14.65	23.79	21.21	27
Δinorganic N$_{(4)}$	-29.27	53.62	-44.88	6.64	4.32	
Δorganic N$_{(5)}$	-96.63	-11.21	-142.66	-8.60	-82.2	

(1) as above
(2) as above
(3) as above
(4) as above
(5) as above
(7) Litter conversion is in this case equal to stover loss due to termites

Plant dynamics

Before the organic nitrogen dynamics is analysed, a more detailed view on the plant dynamics is needed. The functional diagrams, as presented in Figure $5.1_{a,b,c}$ with the specific conservions, are presented for the nitrogen dynamics in the 4th season in Figure $5.6_{a,b,c}$. The shortcut from above ground plant biomass to organic matter due to termite activities in the maize plots was not drawn in the Figure 5.5, but is mentioned in Figure 5.6_b.

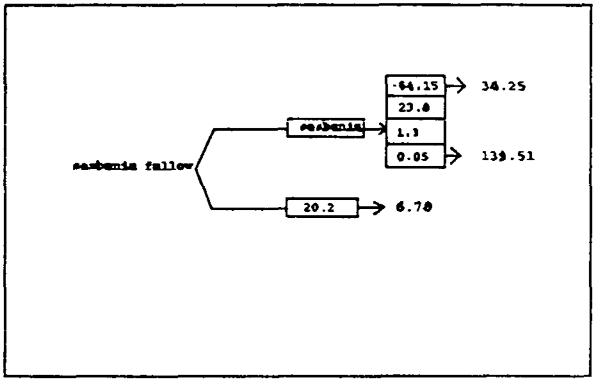


Figure 5.6_a: Main pathways of nitrogen through organic material in the sesbania fallow

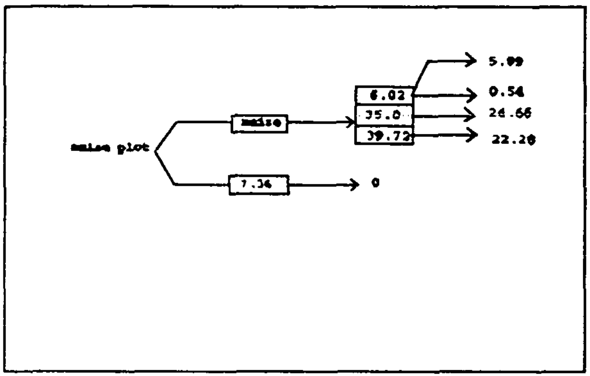


Figure 5.6_b: Main pathways of nitrogen through organic material in the maize plot

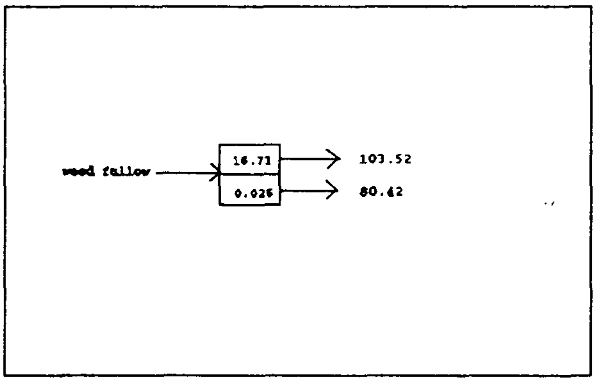


Figure 5.6_c: Main pathways of nitrogen through organic material in the weed fallow

Figure $5.6_{a,c}$ show that biomass had reached maturity in the 4th season as no increase in biomass was found. Mortality was developed fully in that season. In the maize plots termite losses contributed for 35% to the biomass losses of maize stover. Due to this very fast turnover of organic nitrogen and due to the rather fast conversion rates of maize roots (almost all roots are conversed within one season) decreases in organic nitrogen were lower in the maize plots than in the bare fallow and were similar to the changes in the sesbania fallow. In Tables 5.9 to 5.11 the recycling of nitrogen per treatment is analysed.

Table 5.9: Plant dynamics for maize (all data in kg Nha^{-1})

		2nd season	between seasons	3rd season	between seasons	4th season
removed from the plots	stover	17.75		2.04		9.93
	grain	8.16		24.4		5.89
	rachis	1.85		1.5		0.54
	weeds	5.12		13.8		7.36
	thinning	3.84		4.8		7.50
	TOTAL	36.72	0	64.50	0	31.22
returned to the plots	roots	37.46		38.36		39.72
	termite losses	23.07		8.65		24.66
	TOTAL	60.53	0	47.01	0	64.38

Nitrogen removed by grain was 26% of the total removed nitrogen. This percentage can be increased up to 48% if stover would be returned to the soil. Stover would then contribute for (on average) 22% to the total recycled nitrogen, a considerable amount. A lot of biomass was lost due to termite consumption in the ripening phase. This decreased maize yields, but helped to maintain soil fertility. Stover that would be removed otherwise, is returned to the soil, maintaining the soil fertility status.

Note that the production of stover indicated in Figure 5.6_b is not equal to the sum of stover and termite losses in Table 5.9. This is because of the reallocation of nitrogen from maize stover to the grains.

Table 5.10: Plant dynamics for the weed fallow (all data in kg Nha^{-1})

		2nd season	between seasons	3rd season	between seasons	4th season
removed	**TOTAL**	0	0	0	0	0
returned to the plots	leaf mortality	4.81	7.55	68.21	24.52	103.52
	root mortality	2.46	9.12	67.05	11.49	80.42
	weed harvest					86.61
	roots					31.22
	TOTAL	7.27	16.67	135.26	26.01	301.77

Everything from the weed fallow is returned to the soil. Aboveground biomass is a little bit more than the belowground biomass.

Table 5.11: Plant dynamics for the sesbania fallow (all biomass data in kg Nha^{-1})

		2nd season	between seasons	3rd seasons	between seasons	4th season
removed	wood					150.9
returned	leaves					64.1
to the	weeds					26.7
plots	weed mortality					6.78
	leaf mortality	2.05	2.95	19.14	4.35	34.25
	pods					3.4
	roots					82.35
	root mortality	4.27	15.82	118.32	19.93	139.5
	TOTAL	6.32	18.77	137.46	24.28	357.1

The weeds contributed considerably to the nitrogen dynamics of the sesbania fallow. 11% of the stored nitrogen in aboveground biomass was stored in weed biomass. The contribution of weeds to the recycled nitrogen was even larger: 28% of the recycled biomass comes from weeds.

Organic nitrogen dynamics: a boxcar train

Different dynamics of nitrogen from uptake up to inorganic nitrogen will lead to different residual effects. This was investigated for the sesbania fallow and the weed fallow with the use a boxcar train description (Leffelaar, 1993). Nitrogen flows from one boxcar to another while the boundaries of each boxcar (≈ pool) is kept fixed. The rate of movement is equal to the transfer rate, while each boxcar has its own retardation time. The boxcars distinguished are plant biomass, litter and organic matter nitrogen. The processes (causing each specific retardation) are mortality, converion and soil mineralisation respectively. In these processes lies the crucial difference in nitrogen dynamics for these two fallow systems.

Both sesbania fallow and weed fallow pumped nitrogen from depth, keeping nitrogen in the system. Part of the nitrogen was pumped upwards. Another part was stored in the root biomass and was freed at the same depth by conversion of the roots. In this sense fallowing retarded nitrogen leaching. Total root conversion was in both systems about the same. Root conversion rates were lower in the sesbania fallow, but this was compensated by higher mortality amounts. During conversion plant nitrogen was humified and immobilised by micro organisms and mineralised after immobilisation. In reality both processes occurred simultaneously. In these processes lies the crucial difference in nitrogen dynamics for these two fallow systems.

In the weed fallow a high turnover of plant material was found. Mortality and conversion were equally fast (see Figure 5.7), due to an improved phosphorus dynamics. This means that almost no accumulation of dead roots or litter occurred. This is coherent with visual observations.

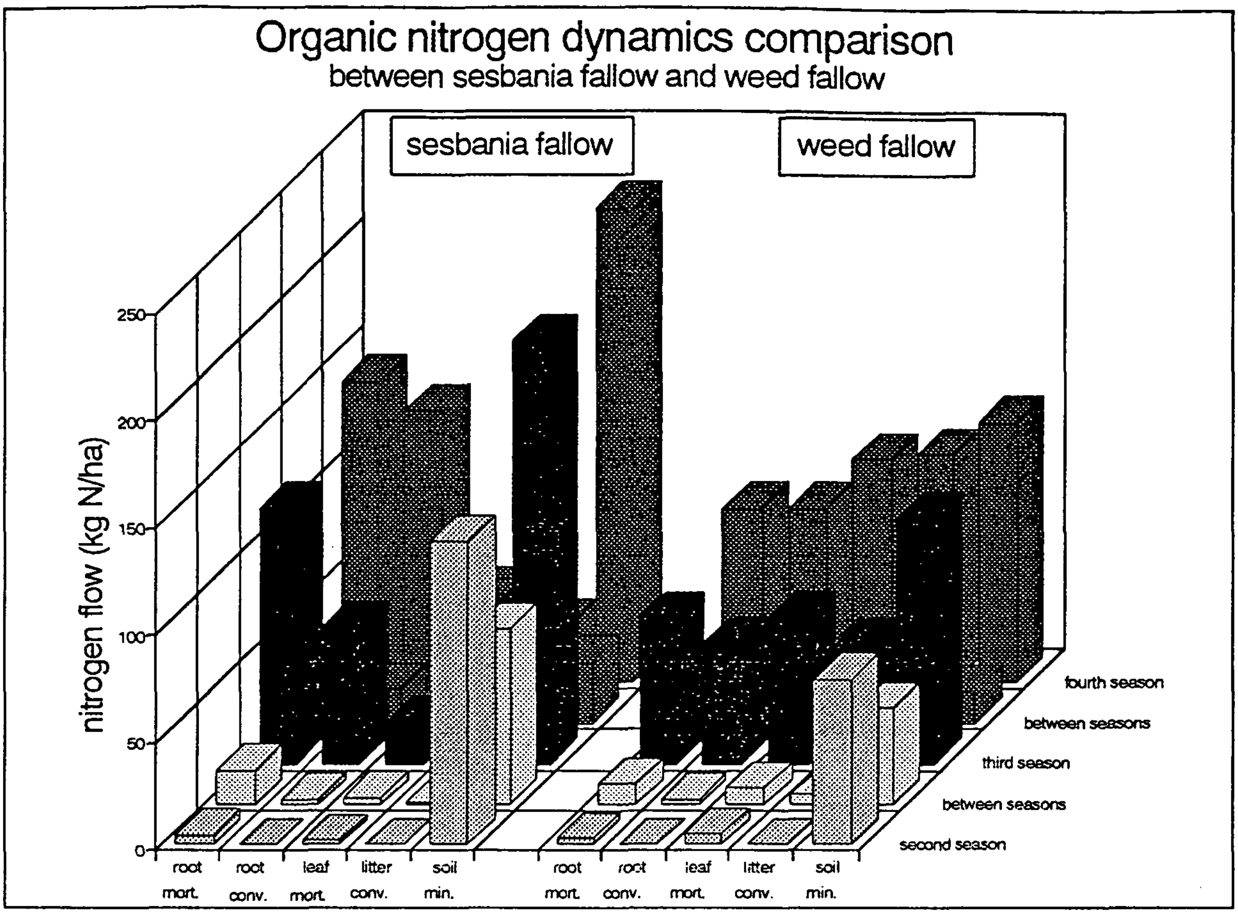


Figure 5.7: Organic nitrogen dynamics per period for sesbania fallow and weed fallow

After the 3th season of the experiment direct litter mineralisation developed in the weed fallow. A minimum of litter mineralisation was calculated as the difference between conversion and mineralisation using the assumption that no old organic nitrogen was mineralised. For the 4th season a litter mineralisation of 60% was calculated for the weed fallow. The fast turnover, inducing a fast decrease in C/N, contributed to this. The vicinity of roots and the occurrence of this litter mineralisation could have caused the significant treatment differences found in the soil mineralisation experiments.

Due to the very fast litter conversion, followed by direct litter mineralisation of nitrogen, considerably less nitrogen flew into the soil organic nitrogen pool. The result of this litter mineralisation was that less nitrogen flew into the soil organic nitrogen pool. Soil mineralisation made use of the newly converted organic nitrogen and was for this reason lower in the weed fallow than in the sesbania fallow. Nitrogen was mineralised soon after conversion. All inorganic nitrogen, produced by soil mineralisation and litter mineralisation was directly available for plant uptake. Plant uptake rates were more or less equal to the mineralisation rates keeping inorganic nitrogen contents in the profile low. The weed fallow recycled its own nitrogen and had a scenario of short term effects on residual yields as the boxcars hardly knew any retardation.

The sesbania fallow had a different nitrogen dynamics (see Figure 5.7). Root mortality was higher in the sesbania fallow, because of a higher root biomass. Litter mortality was much slower than in the weed fallow, because most nitrogen was stored in the wood. The weeds in the sesbania fallow contributed therefore considerably to the recycled nitrogen (see above). Due to the removal of wood at the end of the fallow a lot of nitrogen was lost in the sesbania fallow. This is a large disadvantage for a fallow system, developed to improve the soil fertility. This becomes less problematic if wood is a desired product. Conversion rates in the sesbania fallow were also much lower than in the weed fallow. This could be caused by the very low phosphorus contents of sesbania leaves, while the experiment was situated at a phosphorus deficient site. Conversion of roots and litter was even slower than the mortality of roots and litter, leading to a built-up of non-decomposed dead material. After conversion the material was turned into inorganic nitrogen at a high rate, due to fast soil mineralisation rates. Soil mineralisation was even faster than the sum of mortalities. Some old organic material must have been used for mineralisation, leading to a decrease in organic nitrogen contents, as measured. Litter mineralisation could not be proved for the sesbania fallow either, probably due to high C/N and N/P coefficients in these treatments. The retardation due to a slow conversion and the absence of litter mineralisation led to a scenario of long term effects on residual yields. Old root channels can also contribute to the residual effects.

Root dynamics, here demonstrated for the sesbania fallow and the weed fallow, had a crucial role in the organic nitrogen dynamics. This is found more generally if the cycles are closely coupled to organic matter as for example in many forest ecosystems (Fogel, 1985).

Organic nitrogen dynamics and especially the soil mineralisation in maize fullfilled an intermediate position. No litter mineralisation could be proved in this treatment, but as total inputs of dead plant material were lower (due to harvest removal and low root production), lower soil mineralisation rates were found than in the sesbania fallow. Root conversion rates were fast enough to converse all roots within one season, maintaining soil fertility levels enabling plant uptake in the next season. Due to the removal of aboveground plant material, the total balance is negative. Additional measures are needed to maintain soil fertility in the maize plots. Neither the weed fallow nor the sesbania fallow will be successfull in this aspect. The weed fallow has no negative nitrogen balance, but recycles its own biomass. The sesbania fallow releases enough nitrogen for successfull residual yields, but depletes the soil in the long run due to the removal of wood. It is therefore not suitable as a fallow system, but could be used in a crop rotation system, if wood is considered to be a useful product by farmers.

5.3 Phosphorus balance

5.3.1 pools

Inorganic phosphorus was measured during three sampling rounds (see Appendix VII). Inorganic phosphorus contents available for plant uptake as measured with the P-Olsen method for the total profile at the beginning and at the end of each season and changes within the season are presented in Table 5.12. These data were used to come to a seasonal balance. These changes are again used in Table $5.14_{a,b,c,d}$ for comparison of measured changes in soil inorganic phosphorus with calculated changes in soil inorganic phosphorus using the separate processes.

Table 5.12: Inorganic phosphorus over the profile available for plant uptake (in kgha^{-1}) per treatment per season

	2nd season		3rd season		4th season	
	begin	end	begin	end	begin	end
sesbania fallow	25.613	n.d.	n.d.	n.d.	24.709	34.001
maize	25.613	n.d.	n.d.	n.d.	30.183	38.253
weed fallow	25.613	n.d.	n.d.	n.d.	31.234	34.322
Bare fallow	25.613	n.d.	n.d.	n.d.	26.546	32.751

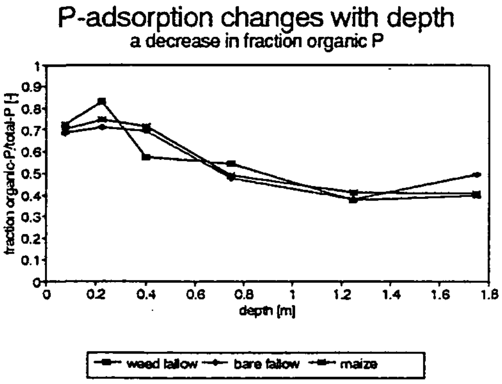


Figure 5.8: Decrease in organic phosphorus as a function of total phosphorus, indicating an increase in adsorbed phosphorus with depth.

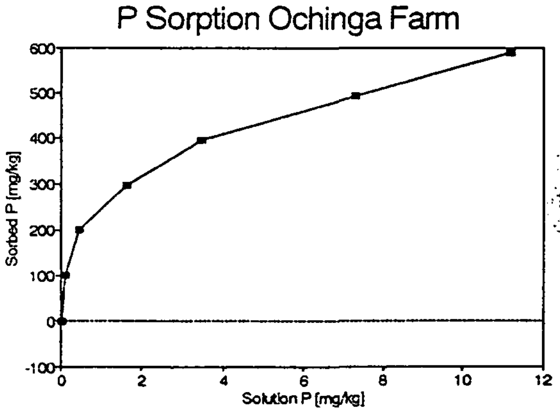


Figure 5.9: Adsorption isotherm for phosphorus at Ochinga farm

Measured available inorganic phosphorus increased significantly during the 4th season in all treatments. The calculated changes in available inorganic phosphorus in the soil were not significantly different from the measured changes, although large variabilities occurred. Especially the variability in soil mineralisation and in plant uptake were large. This high variation led to a large confidence interval.

The assumption that the net phosphorus adsorption was zero, was not falsified, although the adsorption capacity of inorganic phosphorus was very large (as presented in Figure 5.9). This adsorption capacity increased with depth: Independant measures of total phosphorus contents and organic phosphorus contents were known (see Appendix VII). The difference between total phosphorus and organic phosphorus is inorganic phosphorus. Available inorganic phosphorus was small and negligible, inorganic phosphorus in minerals was constant as soil mineralogy was constant with depth. The decrease in organic phosphorus as a fraction of total phosphorus (see Figure 5.8) therefore indicates an increase in phosphorus adsorption with depth.

Inorganic phosphorus that is produced (mainly by soil mineralisation) will not remain in the soil solution, but will be adsorbed. Most of the phosphorus is however loosely bound and still available for plant uptake. Due to plant uptake, causing desorption of phosphorus, net adsorption remained about zero.

Inorganic phosphorus (both calculated and measured) remained constant during the experiment. A significant increase was only found for the 4th season. Treatment differences were not found.

Organic phosphorus was not significantly different between treatments (Data presented in appendix VII.): This does not change when total phosphorus levels in the 0-5 cm layer and the 5-15 layer are compared. Data on phosphorus in the 0-5 cm and the 5-15 cm layer are also presented in Appendix VII. Organic phosphorus for the total profile at the beginning and at the end each season (if measured) are presented in Table 5.13.

Table 5.13: Organic phosphorus (in kgha^{-1}) over the profile per treatment per season

	2nd season		3rd season		4th season	
	begin	end	begin	end	begin	end
sesbania fallow	$4.4*10^3$	n.d.	n.d.	n.d.	$4.2*10^3$	$4.8*10^3$
maize	$4.5*10^3$	n.d.	n.d.	n.d.	$4.4*10^3$	$4.8*10^3$
weed fallow	$4.3*10^3$	n.d.	n.d.	n.d.	$4.2*10^3$	$4.8*10^3$
Bare fallow	$4.4*10^3$	n.d.	n.d.	n.d.	$4.3*10^3$	$4.5*10^3$

The calculated changes in organic phosphorus are also indicated in Table $5.14_{a,b,c,d}$. Results indicate a decrease in organic phosphorus in all treatments. The treatment differences between calculated organic phosphorus amounts are not significant, because variation is high. This high variation is mainly caused by variability in soil mineralisation estimates.

5.3.2 processes on a seasonal basis

All measured and calculated processes are discussed in section 4.2. The functional relationship between all processes is presented in Figure 5.10. For each treatment the seasonal balance for phosphorus for this experiment was calculated from the complex of processes presented together with the C.V. in Table $5.14_{a,b,c,d}$.

Table 5.14$_a$: Phosphorus flows (in kg Pha^{-1}) to, within and from the sesbania fallow

	2nd season	between seasons	3rd season	between seasons	4th season	C.V (%)
Inputs:						
Seed input	0.330	0	0	0	0	2
Wet deposition	0.352	0.064	0.747	0.106	0.451	41
Dry deposition	0	0.017	0	0.006	0	30
Rock weathering	0.038	0.015	0.037	0.005	0.039	n.d
Internal flows:						
Mineralisation	5.102	3.324	8.101	1.114	8.707	55
Root mortality	0.256	0.949	7.099	1.196	8.371	38
Root conversion	0	0.112	3.806	0.941	7.595	13
Litter mortality	0.063	0.091	0.593	0.135	1.885	27
Litter conversion	0	0.024	0.290	0.081	0.817	18
Plant uptake (above)	3.255	0.895	6.938	0.368	4.008	48
Plant uptake (below)$_{(1)}$	4.063	1.767	7.404	1.200	8.378	38
Net adsorption$_{(2)}$	0	0	0	0	0	
Outputs:						
Biomass removal$_{(3)}$	0.295	0	0	0	7.06	17
Erosion	4.329	0.436	10.663	0.780	1.266	16
Runoff	0.002	0.001	0.002	0.001	0.001	44
Δinorganic P$_{(4)}$					9.292	n.d
Δinorganic P$_{(5)}$	-1.825	0.757	-5.459	-0.338	-3.190	
Δorganic P$_{(6)}$	-9.162	2.869	0.999	1.348	15.973	

(1) The plant uptake for below ground biomass is equal to root production

(2) Net adsorption is adsorption - desorption

(3) Biomass removal is the sum of weeding,thinning and harvest

(4) as measured during soil sampling

(5) as calculated from differences between inputs and outputs in the pools:
Δstorage= soil mineralisation + wet deposition + dry deposition + rock weathering - runoff - uptake

(6) as calculated from differences between inputs and outputs in the pools:
Δstorage= total decomposition - soil mineralisation -erosion

Table 5.14$_b$: Phosphorus flows (in kg Pha^{-1}) to, within and from the weed fallow

	2nd season	between seasons	3rd season	between seasons	4th season	
Inputs:						
Seed input	0	0	0	0	0	
Wet deposition	0.352	0.064	0.747	0.106	0.451	41
Dry deposition	0	0.017	0	0.006	0	30
Rock weathering	0.038	0.015	0.037	0.005	0.039	n.d
Internal flows:						
Mineralisation	4.891	2.468	6.395	0.868	7.129	52
Root mortality	0.125	0.463	3.463	0.583	4.084	25
Root conversion	0	0.103	2.810	0.587	4.086	32
Litter mortality	0.414	0.650	5.862	1.248	8.898	31
Litter conversion	0	0.369	4.728	1.026	9.071	5
Plant uptake (above)	3.156	0.304	8.401	0.869	8.940	27
Plant uptake (below)$_{(1)}$	1.111	0.891	3.572	0.585	4.086	25
Net adsorption$_{(2)}$	0	0	0	0	0	
Outputs:						
Biomass removal	0	0	0	0	0	
Erosion	0.785	0.081	1.754	0.182	1.029	15
Runoff	0.001	0.001	0.002	0.001	0.001	44
Δinorganic P$_{(4)}$					3.088	n.d
Δinorganic P$_{(5)}$	1.013	1.368	-4.796	-0.470	-5.408	
Δorganic P$_{(6)}$	-1.409	2.881	12.450	2.259	8.889	

(1) as above
(2) as above
(4) as above
(5) as above
(6) as above

Table 5.14$_c$: Phosphorus flows (in kg Pha^{-1}) to, within and from the bare fallow

	2^{nd} season	between seasons	3^{rd} season	between seasons	4^{th} season	
Inputs:						
Seed input	0	0	0	0	0	
Wet deposition	0.352	0.064	0.747	0.106	0.451	41
Dry deposition	0	0.017	0	0.006	0	30
Rock weathering	0.038	0.015	0.037	0.005	0.039	n.d
Internal flows:						
Mineralisation	6.797	2.794	6.448	0.913	6.560	320
Root mortality	0	0	0	0	0	
Root conversion	0	0	0	0	0	
Litter mortality	0	0	0	0	0	
Litter conversion	0	0	0	0	0	
Plant uptake (above)	0	0	0	0	0	
Plant uptake (below)	0	0	0	0	0	
Net adsorption$_{(2)}$	0	0	0	0	0	
Outputs:						
Biomass removal	0	0	0	0	0	
Erosion	12.472	2.285	27.005	3.804	15.888	18
Runoff	0.002	0.002	0.003	0.002	0.003	44
Δinorganic $P_{(4)}$					6.205	n.d
Δinorganic $P_{(5)}$	2.185	2.888	7.229	1.028	7.047	
Δorganic $P_{(6)}$	-10.554	-1.515	-10.002	-3.552	-14.081	

(2) as above
(4) as above
(5) as above
(6) as above

Table 5.14$_d$: Phosphorus flows (in kg Pha^{-1}) to, within and from the maize plot

	2nd season	between seasons	3rd season	between seasons	4th season	c.v (%)
Inputs:						
Seed input	0.108	0	0.108	0	0.108	1
Wet deposition	0.352	0.064	0.747	0.106	0.451	41
Dry deposition	0	0.017	0	0.006	0	30
Rock weathering	0.038	0.015	0.037	0.005	0.039	n.d
Internal flows:						
Mineralisation	6.001	1.770	4.023	0.570	4.092	82
Root mortality	2.781	0	2.847	0	2.948	29
Root conversion	0	1.980	0.785	1.166	1.654	33
Litter mortality	0	0	0	0	0	
Litter conversion(7)	0.414	0	0	0	1.055	35
Plant uptake (above)	4.372	0	5.292	0	4.539	35
Plant uptake (below)(1)	2.781	0	2.847	0	2.948	29
Net adsorption(2)	0	0	0	0	0	n.d
Outputs:						
Biomass removal(3)	3.958	0	5.292	0	2.554	35
Erosion	8.299	1.502	16.350	2.483	10.670	18
Runoff	0.002	0.001	0.003	0.002	0.002	44
Δinorganic P(4)					8.070	n.d
Δinorganic P(5)	-0.764	1.865	-2.335	0.685	-2.907	
Δorganic P(6)	-13.886	-1.292	-19.588	-1.887	-12.053	

(1) as above
(2) as above
(3) as above
(4) as above
(5) as above
(6) as above
(7) Litter conversion is in this case stover loss due to termites

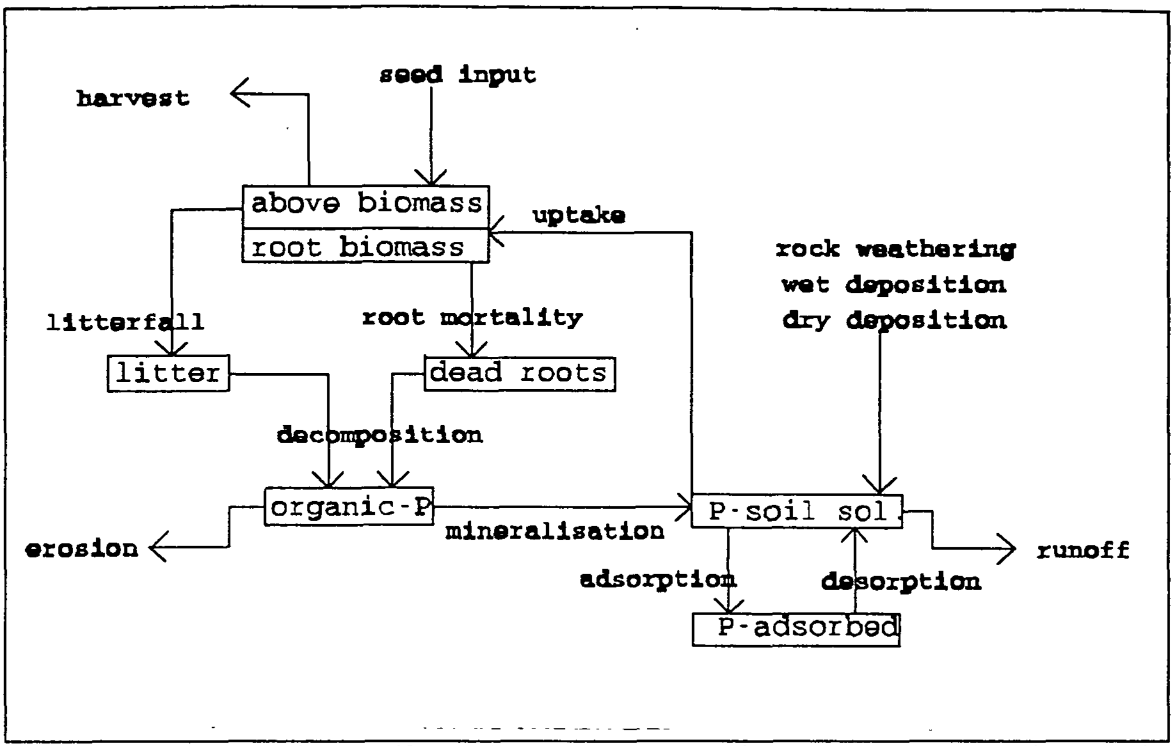


Figure 5.10: Functional flow diagram for organic phosphorus and inorganic phosphorus flows

The net balance

For the total system it is important to know the net balance (=the difference between inputs and outputs) of phosphorus. Both inorganic and organic dynamics play a role in this net balance. The net balance per period in all treatments is presented in Table 5.15. As both inputs and outputs differ per treatment, the relative net balance is also included, see Table 5.16.

Table 5.15: Average net balance for phosphorus (in kg Pha^{-1}) for each treatment per season.

	2nd season	between seasons	3rd season	between seasons	4th season
sesbania fallow	-3.906	-0.341	-9.881	-0.664	-7.837
weed fallow	-0.396	0.014	-0.972	-0.066	-0.540
bare fallow	-12.084	-2.188	-26.224	-3.689	-15.401
maize	-11.761	-1.407	-20.775	-2.369	-12.628

The phosphorus balances are more negative than those reported in literature: For the Kisii area a phosphorus balance of -3 kg $Pha^{-1}yr^{-1}$ was found (Smaling et al., 1993). Shepherd et al. (1993) calculated a balance of -3.8 kg $Pha^{-1}yr^{-1}$ for a crop and -6.2 kg $Pha^{-1}yr^{-1}$ for an improved fallow. Shepherd et al. (in draft) calculated -7.9 kg $Pha^{-1}yr^{-1}$ for a crop and -14.7 kg $Pha^{-1}yr^{-1}$ for improved fallows. The inputs are small; wet deposition is the most important input, but there are also few pathways existing for phosphorus losses from the farm system. The largest losses are from erosion as found by Shepherd et al. (in draft). The main reason of difference between the values reported in literature and those calculated in this study is caused by estimates of erosion losses. The large influence of erosion on the net balance indicates again the influence of soil conservation practices on soil fertility.

Table 5.16: Relative net balance, meaning the amount of outputs divided by the inputs, for phosphorus. All data above 1 indicate a negative balance.

	2nd season	between seasons	3rd season	between seasons	4th season
sesbania fallow	6.43	4.55	13.6	6.68	16.9
weed fallow	2.02	0.85	2.24	1.56	2.10
bare fallow	32.0	23.8	34.4	32.5	32.4
maize	24.6	15.7	24.9	21.2	22.1

It is important to know whether the differences in net balance between treatments are significant. The C.V.'s were used for this analysis similar to the analysis of the net balance for nitrogen. With the use of the calculated minimum and maximum values the range, in which the net balance can occur, was calculated. The results are presented in Table 5.17.

Table 5.17: Range in which the net balance for phosphorus (in kg Pha^{-1}) for each treatment per period can occur. This range is calculated with the use of the C.V. values, as explained in the text.

		2nd season	between seasons	3rd season	between seasons	4th season
sesbania fallow	min	-4.801	-0.443	-11.894	-0.834	-9.425
	max	-3.011	-0.239	-7.868	-0.494	-6.249
weed fallow	min	-0.658	-0.031	-1.542	-0.138	-0.879
	max	-0.134	0.058	-0.402	0.006	-0.201
bare fallow	min	-14.474	-2.635	-31.392	-4.419	-18.447
	max	-9.694	-1.747	-21.055	-2.958	-12.335
maize	min	-14.781	-1.708	-25.856	-2.861	-15.628
	max	-8.736	-1.105	-15.650	-1.875	-9.626

A significant difference (determined as explained in section 5.2.2) between the sesbania fallow and weed fallow is found for all seasons. In the 4th season weed cover under the sesbania trees had become high, decreasing runoff and erosion. Due to this weed cover, the differences were not significant anymore, if wood would not have been removed. Due to the removal of the wood, the differences were significantly different. The differences in net balance between bare fallow and maize were not significant. The differences in net balance in the sesbania fallow and weed fallow on one side and the net balance in the bare fallow and maize on the other side were significant. This means that fallow systems are important for maintenance soil fertility. The absolute values of the net balance were negative, meaning that still soil fertility is lost. The periods between the seasons were very important to maintain the soil fertility status, because during those periods erosion, the most important loss of phosphorus, is small.

The plant model

The phosphorus dynamics can be analysed similarly to the nitrogen dynamics, but will not be treated here. Only a more detailed view on the plant dynamics will be given. The main pathways, as presented in Figure $5.1_{a,b,c}$ with the specific conservions, are presented for the phosphorus dynamics in the 4th season in Figure $5.11_{a,b,c}$. The shortcut from above ground plant biomass to organic matter due to termite activities in the maize plots was not drawn in the functional flow diagram, but is mentioned in Figure 5.11_b.

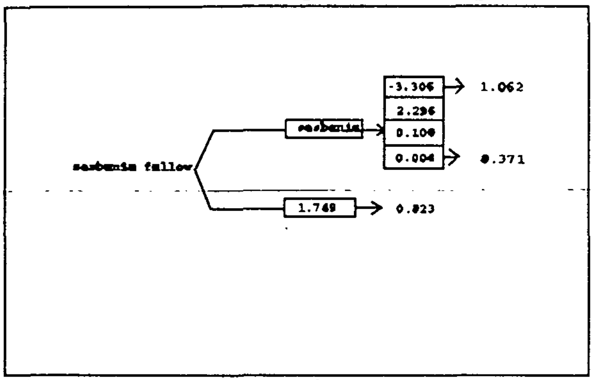


Figure 5.11_a: Main pathways of phosphorus through organic material in the sesbania fallow

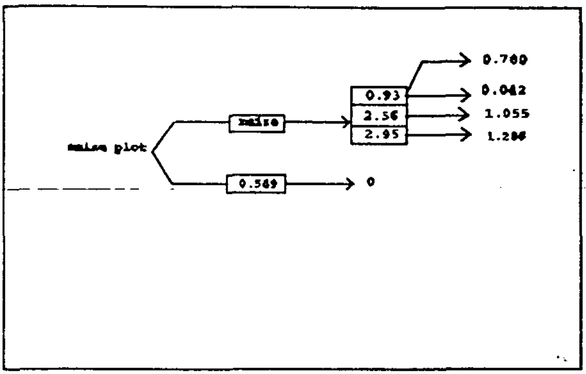


Figure 5.11_b: Main pathways of phosphorus through organic material in the maize plot

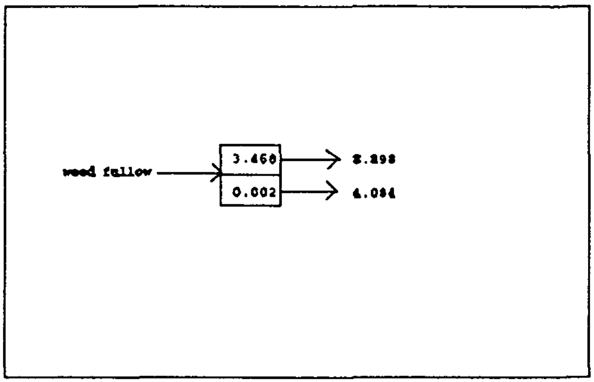


Figure 5.11_c: Main pathways of phosphorus through organic material in the weed fallow

Figure $5.11_{a,c}$ show that biomass had reached maturity in the 4th season, no increase in biomass was found, and that mortality was developed fully. In the maize plots the termite losses contribute for 22% to the biomass losses of maize. Due to this fast turnover of organic nitrogen and due to the rather fast decomposition rates of maize roots (almost all roots are decomposed within one season) changes in organics nitrogen storage were lower than in the bare fallow and similar to the changes in the sesbania fallow. In Tables 5.18 to 5.20 the recycling of nitrogen per treatment is analysed.

Table 5.18: Plant dynamics for maize (all biomass data in kg Pha^{-1}).

		2nd season	between seasons	3rd season	between seasons	4th season
removed from the plots	stover	1.231		1.366		0.683
	grain	1.974		2.435		0.780
	rachis	0.198		0.112		0.042
	weeds	0.335		1.135		0.549
	thinning	0.220		0.244		0.50
	TOTAL	3.958	0	5.292	0	2.554
returned to the plots	roots	2.781		2.847		2.948
	termite losses	0.414		0		1.055
	TOTAL	3.195	0	2.847	0	4.003

Phosphorus in maize grains is 42% of the total removed phosphorus. This percentage can be increased up to 59% if stover would be returned to the soil. Stover would then contribute for (on average) 25% to the total recycled phosphorus, a considerable amount. A lot of biomass is lost due to termite consumption in the ripening phase. This decreased maize yields, but maintained soil fertility. Stover that would be lost otherwise, is returned to the soil, maintaining the soil fertility status.

Table 5.19: Plant dynamics for the weed fallow (all data in kg Pha^{-1}).

		2nd season	between seasons	3rd season	between seasons	4th season
removed	**TOTAL**	0	0	0	0	0
returned to the plots	leaf mortality	0.414	0.650	5.862	1.248	8.898
	root mortality	0.125	0.463	3.463	0.583	4.084
	weed harvest					11.00
	roots					1.527
	TOTAL	0.539	1.113	9.325	5.831	25.509

All biomass from the weed fallow was returned to the soil. Aboveground biomass was a little higher than the belowground biomass.

Table 5.20: The plant model for the sesbania fallow with all biomass data in kg Pha^{-1}

		2nd season	between seasons	3rd seasons	between seasons	4th season
removed	wood					7.06
returned to the plots	leaves					2.41
	weeds					2.23
	weed mortality					0.823
	litter mortality	0.063	0.091	0.593	0.135	1.062
	pods					0.25
	roots					4.941
	root mortality	0.256	0.949	7.099	1.196	8.371
	TOTAL	0.359	1.040	7.692	1.331	20.09

The weed contributed considerably to the phosphorus dynamics of the sesbania fallow. 19% of the stored phosphorus in aboveground biomass was stored in weed biomass. The contribution of weeds to the recycled phosphorus was even larger: 45% of the recycled biomass came from weeds. The weeds within the sesbania fallow were therefore of extreme importance for the phosphorus status within this treatment.

Chapter 6. Discussion

Objectives

The main objectives of this study were to:

i) Synthesize and complete the nitrogen and water seasonal balances in three fallow systems and maize
ii) Develop a preliminary seasonal balance for phosphorus for the three fallow systems and maize
iii) Estimate and measure the different water, nitrogen and phosphorus flows, with as main processes to focus on leaching, evapotranspiration, denitrification, soil mineralisation and litter and root conversion to come to the seasonal balances

These balances were composed to determine whether improved fallows improve the soil fertility status of the soil more than natural fallows can do and to compare this with a continuous maize cultivation.

Sources of error

Before the balances are discussed separately, the sources of error (and the general statistical reliability) will be dealt with. In the study measured and estimated data were analysed. The two types of data analysis require a different approach with different mathematical implications and different sources of errors.

Measuring processes always implies that some variation within the dataset is developed. This variation means that a confidence interval instead of a data point is created. This has several implications:

Treatment differences in processes are harder to prove and require a statistical (ANOVA) analysis. More important however is that variation increases enormously if all processes (each of them with its own variability) are combined to a balance, as happened in this study. Treatment differences for the complete balances are therefore even harder to prove (see Chapter 5).

Non-steady state conditions represent normal conditions for agro-ecosystems due to continued changes. One should therefore not be satisfied with static images of interactions. (van der Bergh, 1991). The integration of the resulting changing continuous flows will propagate variation that was already abundant in the data points.

In addition to this variation, an error is introduced by integrating continuous flows with the use of discrete datapoints. By analysing each process separately, the timestep could be chosen as small as possible for each process, keeping this source of error as small as possible.

Another common source of error and uncertainty is the extrapolation of point measurements to the total system (Paustian et al., 1990). A special case of this source of error is the extrapolation of laboratory data to the field situation. This extrapolation could not be avoided in the measurements of soil mineralisation and denitrification, but was avoided elsewhere.

When processes are not measured, the extrapolation error may be even larger. Data from another system, with its own underlying assumptions, are extrapolated to the system in question. The assumptions of both systems are not necessarily the same. When estimating evapotranspiration, these assumptions were intensively evaluated to avoid such errors. Estimated processes were checked with measured data as much as possible, see for example the leaching calculations. Another source of error with estimated data are the interactions between processes that can be different in other systems. These interactions are more easily taken into account when measuring processes. Processes were therefore measured as much as possible.

All these errors were specified and quantified whenever possible. Such a quantification is very important because the system can not be evaluated with average values alone. Statistical analysis (in the form of regression and ANOVA analysis) was therefore given much attention in this study and is also taken into account in the conclusion.

Water balance

The water balance was analysed, because water is the carrier of nitrogen and phosphorus. Water dynamics therefore influences the soil fertility status indirectly.

Rain water was distributed in the soil-plant system even before the rain actually reached the soil: Interception was highly dependent on the canopy (and therefore dependent on the treatment) ranging from 0% of the rainfall in the bare fallow to an average of 16% in the sesbania fallow. Its influence on the water balance was however rather small. The reason is that variation of interception within and between treatments was much smaller than the variation in other processes.

The indirect influences of the canopy were much larger. Canopy, and especially ground cover, determined to a large extent the runoff. This caused extreme treatment differences with runoff ranging from an average of 7.5% of the throughfall in the weed fallow to 80% in the bare fallow. This had large influences on the total water balance, because it determined the infiltration.

Once in the soil, water was lost by two processes; evapotranspiration and leaching. Both processes had to be estimated. Evapotranspiration calculations had to be adapted to the nutrient deficient situation at Ochinga farm. Without such adaption evapotranspiration would have been largely overestimated. Potential evapotranspiration rates were around 6 mmday^{-1}, which is much higher than the actual rates in the sesbania fallow, which were on average 2.35 mmday^{-1}. Sesbania fallow and weed fallow had highest evapotranspiration rates, because they are perennial canopies with large biomass. Both the weed fallow and the sesbania fallow had deep roots and uptake from depth could occur in both systems. The low moisture contents at depth in the sesbania fallow indicate that uptake from these lower layers indeed occurred. Deep uptake will not have occurred in maize, due to the absence of deep roots and of course not in the bare fallow. Evapotranspiration in maize and the bare fallow was further decreased, because evaporation was very low in the periods without a crop.

Leaching losses in all treatments were however similar, because total moisture in the profile for all treatments was similar. This is accidental: Soil input, being infiltration, was low in the bare fallow and maize due to high runoff, but soil output, being evapotranspiration, was also low. This left the same soil moisture conditions in the profile in all treatments. Only the distribution with depth was different depending on evapotranspiration distribution.

Although total moisture storage was similar in all treatments, distribution of moisture outputs (being completely different per treatment) influenced the soil fertility status. The most extreme example in this aspect is the bare fallow.

The bare fallow had an excessive runoff, which can lead to large nutrient losses due to erosion, and had a very low evapotranspiration. This left still considerable moisture storage leaving enough opportunity for leaching to occur. This could lead to leaching of nutrients. Besides the low agronomical benefits, the bare fallow will never be incorporated in farmers practices due to these large opportunities for losses.

Nitrogen and phosphorus are the two most important elements determining the soil fertility and their balance will be reviewed in more detail below.

Nitrogen balance

Nitrogen inputs into the system were low, with the exception of symbiotic fixation in the sesbania fallow. The magnitude of symbiotic fixation was however highly uncertain. Varying the estimates of symbiotic fixation (presented in Chapter 5) demonstrated however the large influence of symbiotic fixation estimates on the net nitrogen balance. Changing the symbiotic fixation estimate from 0% of the total nitrogen plant uptake to 50%, increased the average net balance for the sesbania fallow from $-1.3*10^2$ kg Nha^{-1} to $-0.7*10^2$ kg Nha^{-1} in the 3rd season.

Nitrogen outputs were generally much larger than nitrogen inputs. Denitrification, nitrogen leaching and soil erosion were the most important processes in this aspect. All of these processes were determined by the water dynamics. Erosion is directly (linearly) related to runoff and was the largest loss of nitrogen in all treatments, except in the weed fallow. The enormous nutrient losses by erosion stress the important influences of soil conservation on soil fertility experiments and agroforestry in particular. This means that the only way for a tree fallow to become useful is by propagating weed ground cover to obtain a positive nitrogen balance by a decrease in soil erosion losses.

Denitrification can only occur at high moisture levels to create anaerobic conditions. Denitrification was highest in the bare fallow. Especially the sesbania fallow and the weed fallow had lower denitrification losses. The main reason for the high denitrification rates in the bare fallow were the higher nitrate contents in the topsoil and not the moisture contents. These high nitrate contents were caused by the combination of soil mineralisation and the absence of nitrogen uptake by plants.

Nitrogen leaching was highest in the bare fallow and maize, for more or less the same reasons. Whereas moisture leaching was not significantly different among treatments, nitrogen leaching was. In the bare fallow and maize, inorganic soil nitrogen was significantly higher than in sesbania fallow and weed fallow. This was again caused by the absence of plant uptake, leaving more nitrogen to be leached.

So there is evidence that uptake from depth occurred. The sesbania fallow and the weed fallow acted similarly in this aspect. Both pumped nitrogen from depth. This is useful because it kept nitrogen in the system. Part of the nitrogen was pumped upwards. Another part however was stored in the root biomass and will have been freed at the same depth by conversion of the roots. In this sense the fallowing partly only retards nitrogen leaching.

This retardation will have been higher in the sesbania fallow than in the weed fallow, because root conversion of sesbania roots was slower. Not only root conversion in the sesbania fallow was slower, but also litter conversion was much slower. This led to a build-up of dead plant material. The last phase in the turnover of organic nitrogen, the soil mineralisation, was however fastest in the sesbania fallow. Soil mineralisation rates in the sesbania fallow were almost twice as high as soil mineralisation rates in the weed fallow. This was caused by direct litter mineralisation in the weed fallow leading to lower inputs of soil organic nitrogen. Average mineralisation rates were lowest in the bare fallow, but the bare fallow also had a very high variation in soil mineralisation rates making a good estimation of soil mineralisation in the bare fallow almost impossible.

The organic nitrogen dynamics in the sesbania fallow were completely different from the dynamics in the weed fallow. The pathway of organic material was looked upon as a boxcar train. Each boxcar in this train has its own retardation time. The weed fallow had a very low retardation due to the high mortality and conversion rates of aboveground and belowground plant material. The high turnover was further increased by direct litter mineralisation. This gave a continuous inflow of inorganic nitrogen in the soil solution, which was directly available for plant uptake. The weed fallow recycled its own nitrogen and will have only short term effects on residual yields.

The sesbania fallow had a completely other dynamics. Most nitrogen was stored in the wood. The nitrogen that was released (by mortality) was retarded in the dead material pool, because conversion was slow. High soil mineralisation rate made large amount of inorganic nitrogen free, decreasing soil organic nitrogen contents in the sesbania fallow. Due to the high retardation the sesbania fallow will mainly have long term effects on residual yields.

The net balance of the weed fallow was similar to the balance of the sesbania fallow if the average symbiotic fixation of 35% is assumed. The losses in the 4th season were however much larger in the sesbania fallow than in the weed fallow. For this reason its net balance was significantly lower than for the weed fallow. This was caused by a removal of wood (containing nitrogen) from the plots. This loss of nitrogen is considerable (151 kg Nha^{-1}) and was much larger than the sum of all other losses during this season and influenced the total net balance enormously.

Maize had a negative nitrogen balance due to the removal of aboveground plant material. Additional measures are therefore needed to maintain soil fertility in amize. Neither the weed fallow nor the sesbania fallow will be successful in this aspect. The weed fallow maintained soil fertility, but it will not be able to increase residual yields as it recycled its own nitrogen. THe sesbani fallow released enough nitrogen for successful residual yields, but depleted the soil due to removal of wood and the decrease in soil organic nitrogen. The sesbania fallow is not suitable as a fallow system, but can be used in a crop rotation system if wood is considered to be a useful product by farmers.

The bare fallow has the most negative net balance of nitrogen. The bare fallow however had a build-up of inorganic nitrogen, because soil mineralisation was higher than leaching. This build-up of inorganic nitrogen especially occurred between two seasons, when rainfall was low. During the rainy seasons this nitrogen is susceptible to leaching. The higher inorganic nitrogen amounts can lead to increased residual yields of maize under the conditions that phosphorus is not limiting. This is not the case at Ochinga farm. In the long run soil depletion will occur when applying this strategy. A similar soil depletion will take place when a continuous maize production is carried out. The net balance for maize was on average -215 kg Nha^{-1} for a rainy season. Farmers will therefore not choose for a bare fallow.

Phosphorus balance

Phosphorus inputs were very small. Wet deposition and seed inputs contributed the most to the total inputs. Including seed inputs was therefore important for a good description of the balances. Phosphorus outputs were generally much larger in quantity than the inputs. The process contributing most to these losses was soil erosion, which was related to runoff losses. The soil erosion losses were quite big. In the bare fallow a soil erosion loss of 27 kg Pha^{-1} was calculated for the 3rd season, while total inputs during that season were smaller than 1 kg Pha^{-1}.

The nutrient uptake from depth in the weed fallow and the sesbania fallow indicate that phosphorus was partly pumped upwards. Not all of this phosphorus uptake could however be used for residual uptake by maize. Part of the phosphorus was stored in the root biomass at that depth. More important, however, was the storage of phosphorus in aboveground biomass in the sesbania fallow. The phosphorus in wood was removed from the plots at harvest. This meant a phosphorus loss of 7 kg Pha^{-1}, but had not the enormous effects it had on the nitrogen balance, because relative minor amounts of phosphorus were stored in wood. So although sesbania pumped phosphorus from depth, losses did not lead to a optimal use of this phosphorus, while all phosphorus pumped by the weed fallow was recycled and available for residual maize. If the sesbania would have been seen as a production system instead of a fallow system, then the storage of phosphorus in wood would have been a right distribution.

The recycling of phosphorus went through mortality, conversion and soil mineralisation, a process that can be analysed by a boxcar train, as described above. Mortality and conversion were much higher in the weed fallow than in the sesbania fallow. This was mainly caused by the higher phosphorus contents in the dead material. Conversion of sesbania litter was much slower although its nitrogen contents were much higher and lignin and polyphenol contents were equal. Sesbania litter had very low phosphorus contents and the phosphorus limitation of the site can have caused these lower conversion rates. This limitation was lower in case of the weed fallow as nitrogen/phosphorus ratios in the weeds were lower.

Indications of phosphorus limitation, besides the lower conversion rates of sesbania litter, are the pronounced effects of phosphorus fertilizer on maize yields (as measured in the test strips), the poorly filled grains of maize, the purple coloured leaves of maize and the uptake of phosphorus out of rain water in the sesbania fallow.

The weeds within the sesbania fallow played a major role, 45%, in the recycling of phosphorus in the fallow, while its biomass was only 9% of the total biomass in the fallow. The weeds within the sesbania therefore not only decreased the losses (by erosion), but it recycled nutrients of the fallow to the soil, decreasing nutrient losses due to biomass removal. This makes its role very important within the fallow. The dominant weed species (in the sesbania fallow similar in species composition in the weed fallow) are also recognized by farmers as soil improvers (contrary to the grasses which occurred at the start of the experiment in the weed fallow). If other weed species would have grown in the fallows, the results could have been different. The high phosphorus mineralisation rates in the sesbania fallow increase the availability of phosphorus for the plants.

The phosphorus net balance for the weed fallow is significantly higher than the net balance of the sesbania fallow. The phosphorus net balance of the sesbania fallow was on its turn significantly less negative than the bare fallow and maize. This difference is caused by differences in erosion losses. The inorganic phosphorus contents measured could only be explained if net adsorption of phosphate was assumed to be higher than zero.

Crop residue management

Nitrogen and phosphorus net balances can be improved by an improvement of soil conservation practices in the three systems (sesbania fallow, weed fallow and maize) having opportunities to be applied in farmers practices. A reduction in runoff can limit the erosion losses of nitrogen and phosphorus. The other way to improve the nitrogen and phosphorus balances is by reducing biomass losses in maize. Returning stover to the soil can increase the recycled nutrients in the biomass with 22% and 28% for nitrogen and phosphorus, respectively.

As long as stover is not returned to the soil, termite consumption will lead to an increase in recyled nutrients. However, in the case of recycling maize stover it is, also from a soil fertility point of view, important to reduce termite losses. This can lead to a higher grain production (due to reallocation of nutrients) leading to a higher harvest efficiency. These higher yields for the farmers are the ultimate goal.

Chapter 7. Conclusions

In this study the dynamics of water, nitrogen and phosphorus processes in four different lands use systems were estimated using a system approach. This means that the systems (in this case a bare fallow, a weed fallow and a sesbania fallow and a maize cultivation system) were analysed first to describe qualitatively the boundaries, major processes and the major pools.

With the use of this system description it was possible to determine the most important processes of the system. These major flows were measured and, if that was impossible, estimated. With this quantitative dataset (presented in Appendix V, VI and VII) it was possible to determine the water, nitrogen and phosphorus dynamics in the land use systems. The dynamics of these components were compared to determine which fallow system improved the soil fertility status of the soil most and to compare this with a continuous maize cultivation.

The most important processes for the water dynamics were evapotranspiration and runoff. These two processes were very important in the distribution of water in the soil-plant system. Accidentally soil moisture storage in the soil profile was similar in all systems. The distribution of water had however large influences on the nitrogen and phosphorus balances.

The potential of trees includes pumping of nutrients and thereby decreasing leaching losses, maintainance of soil organic matter, protection against soil erosion and runoff and addition of nitrogen through biological nitrogen fixation. It followed that the sesbania fallow and the weed fallow are equally good in pumping nutrients, because both fallows have deep rooting patterns. The weed fallow had a much lower soil erosion, yielding a significantly less negative phosphorus budget. The nitrogen budget in the sesbania fallow was only not significantly different from the nitrogen balance in the weed fallow if some symbiotic fixation was assumed. This is a reasonable assumption, because active nodules were found. The nitrogen budget in the sesbania fallow in the 4th season was however lower than the balance in the weed fallow, in spite of the symbiotic fixation, due to the large nitrogen removals with harvested wood. This nutrient removal is very unfavourable for a system that is considered to be a fallow system. The higher budgets for nitrogen and phosphorus in the weed fallow indicate that a natural fallow system could be more suitable than a sesbania fallow for this situation from a soil fertility point of view.

The better nitrogen and phosphorus balance of the weed fallow is caused by the better ground cover (while this only developed during the 4th season in the sesbania fallow), the absence of harvested products and the higher phosphorus amounts in the weeds. The weeds took care of 45% of the recycling of phosphorus in plant biomass in the sesbania fallow, an important issue under these phosphorus limiting circumstances. The weed species in the weed fallow were also considered to be soil improvers by farmers.

The organic matter dynamics is another point of difference between the two fallow systems. Retardation of nutrients captured in organic material takes place at a different position in the chain of organic material turnover. This difference had a large influence on the nutrient dynamics and for this reason on the residual yields. The weed fallow recycled its own nutrients and will have only very short term effects on residual yields whereas the sesbania fallow will have longer term effects on residual yields due to the higher soil mineralisation rates. The sesbania fallow however depleted the soil by removal of wood and a decrease in soil organic nitrogen. So none of the systems is suitable as a fallow system. A sesbania system can however be useful as a rotation system if additional measures are taken to maintain the soil fertility.

The bare fallow is not an option for fallowing. The bare fallow had an excessive runoff leading to enormous erosion losses and still had high nitrogen leaching losses. This nitrogen leaching was caused by the combination of a high nitrogen storage at depth (by the lack of plant uptake) and a considerable amount of moisture at depth (due to very low evapotranspiration).

Continuous maize production had similar high outputs of nitrogen and phosphorus. Erosion losses in maize were lower than those in the bare fallow, but maize had an additional output in the form of biomass removal. This last output can however be reduced by returning stover to the plots. This can lead to increase of recycled nutrients in biomass of 22% (for nitrogen) and 25% (for phosphorus). Another large improvement of the maize balance can be obtained from improvement of soil conservation practices. Establishment of a ground cover early in the season is very important for this aspect.

Chapter 8. Future research

In the system approach used in this study, processes where measured to serve the description of dynamics of water and nutrients. To allow statements based on these balances, it is important decrease the statistical variation as much as possible. In this study sometimes large statistical variation occured in processes essential for understanding the nutrient balances. In future research it should be tried to decrease the variation in especially these processes more. These processes are symbiotic fixation, mineralisation, nitrate leaching and erosion.

At ICRAF an experiment is started to investigate the interaction between soil fertility and soil conservation practices. Such experiments are very important to improve the understanding of the plant-soil system under these nutrient limiting circumstances.

As symbiotic fixation is very variable it is important to monitor symbiotic fixation in the same experiment. This can reduce statistical variation largely. This could be obtained with the use of labeled nitrogen or by estimating nodule activity with a laboratory incubation.

Field core mineralisation experiments turned out to be the most suitable to determine seasonal mineralisation rates, but even in these experiments variability was large, due to the large natural variation in soil nitrate concentrations and microsite variability. Increasing the amount of cores per plot is the only way to decrease this source of variation. Monitoring the inorganic nitrogen dynamics more closely can also be of help.

Estimates for nitrate leaching can be improved when modifying the LEACHN-model by including nitrate adsorption and symbiotic fixation in the computer model. Measurements of leaching under field conditions is very complicated. Porous cups did not function under the field conditions at Ochinga farm as dispersed clay clogged the pores of the ceramic cups. Other field methods disturb the soil to such an extent that results become highly uncertain.

Some conclusions were drawn from the nutrient dynamics. The first was a prediction of residual yields. An increase in maize yields in the former sesbania plots was expected, while in the former weed fallow some increased growth was expected at the beginning of the season. These effects will however decrease later in the season. In the former sesbania increased yields were expected over longer periods. At the moment of writing these residual yields are actually measured. The predictions made should be compared with the measured data. It is possible that, for example, old root channels in the sesbania fallow cause an unexpected effect.

Another conclusion was non-less suitability of the sesbania as a fallow under these phosphorus limiting circumstances. A nitrogen fixing tree fallow is of less importance under these circumstances. Another tree with a larger fractional branching of the root system to allow a more efficient phosphorus uptake and phosphorus use, like *Grevillea Robusta* can be of more importance. Instead of trees, the suitability of an improved weed fallow could also be investigated. A common weed with high phosphorus amounts and a good decomposibility in Western Kenya is *Tithonia spec.*. This weed can be of large practical use for farmers. Some preliminary experiments already started within ICRAF.

The interaction of phosphorus fertilization with improved tree fallows is another point worth investigating. Under non-phosphorus limiting circumstances the results of a similar experiment can be completely different.

The comparison of the suitability of a sesbania fallow and a weed fallow was only based on soil fertility aspects. For the farmers an economical analysis will be at least as important as a soil fertility analysis. If sesbania wood is considered to be useful (in terms of income and product) and if yield is considered to be worth the decrease in total organic nitrogen, then a sesbania fallow can be worthwhile applying. In this case, the sesbania fallow should be considered as a crop rotation system instead of a fallow system. The possible application should however be based on a thorough analysis of advantages and disadvantages, economically and agronomically. Only in that case a useful extrapolation of the knowledge to the practice of the farmer can be made. Farmers should have some influence on the decisions made.

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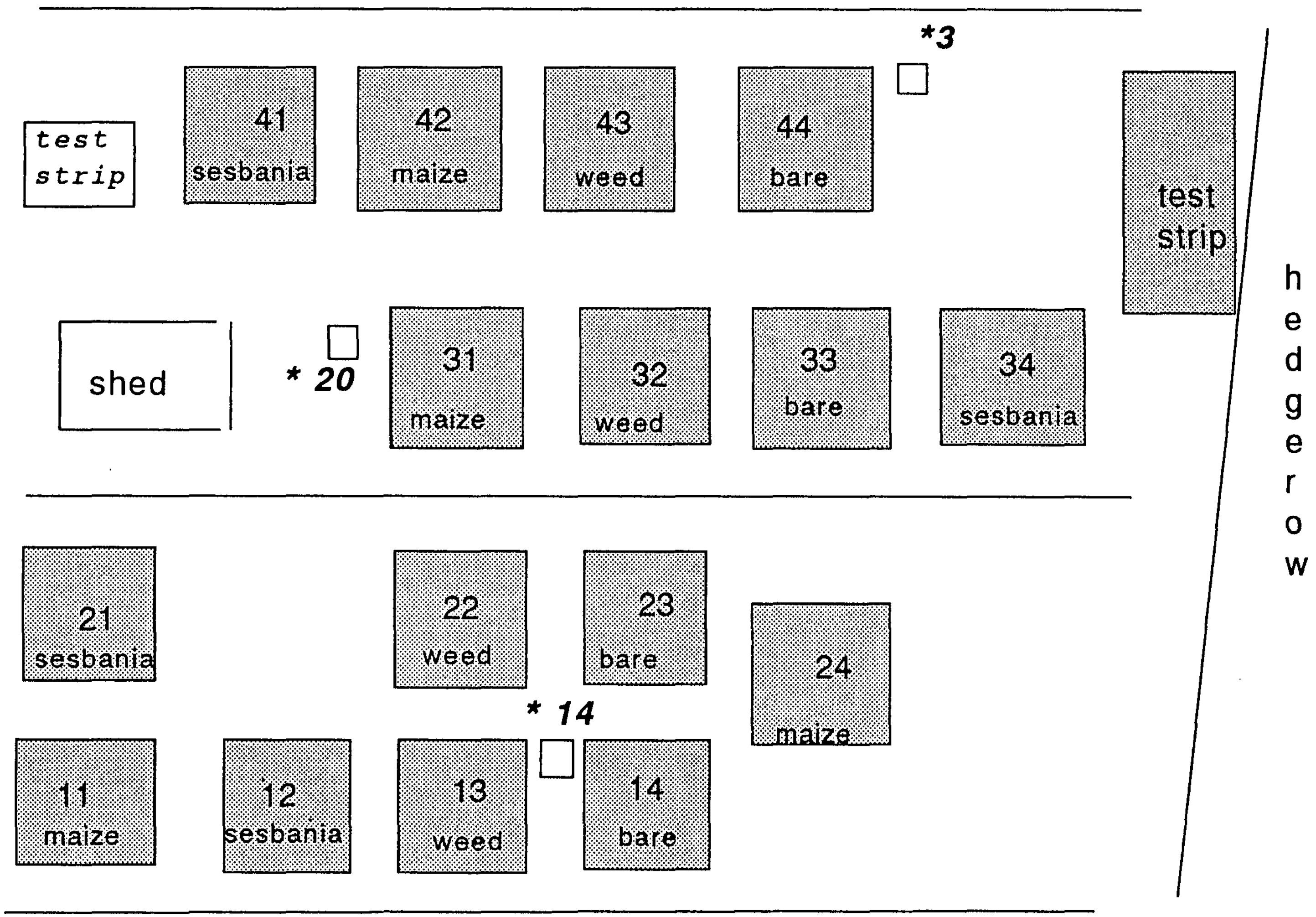
Appendix I: Field map of Ochinga farm, experiment NM1



*Note: *(nr) raingauge*

Appendix II: Determination of bulk density

Introduction

Bulk density is the overall (dry) weight of the soil per unit of volume. Values of 0.9-1.2 gcm^{-3} are normally found inrecently cultivated soil and 1.1-1.4 main range uncultivated, uncompact soil (Landon, 1991). Bulk density data can be used for computing total porosity (assuming a soil particle density of 2.65 gcm^{-3}) and volume percent of available water. Bulk density measurements are therefore generally used as a guide to detect soil compaction, soil porosity, soil aeration and problems of root penetration. Besides these reasons bulk density measurements were required for the calculation of inorganic nitrogen on a kg/ha base.

Several methods of obtaining bulk density data are in use. Most commonly used are core sampling method, replacement methods, excavation method and gamma radiation densitometry techniques. The last two are not used in collecting data for soil classification studies and will not be discussed in further detail.

For the replacement method a volume of soil is removed and weighed after drying. The volume of soil removed is calculated by refilling the hole with small balls. The core sampling method consists of taking a core sample with a coring cylinder of known volume, driven vertically into the soil. The core sample is carefully dug out and weighed after drying. This core-sampling method is used whenever possible (Koorevaar et al., 1983), because it can be used also to obtain undisturbed soil samples. Measurements of bulk densities are affected by its soil structure i.e. its degree of compaction and its swelling and shrinkage characteristics. Different methods are influenced differently by the soil structure.

At Ochinga farm bulk density was evaluated by several persons, using different methods. Buresh and Braun both used an unmodified core sampling method. Braunl made however use of an old soil pit, already dried out. Hartemink (1994) used a core sampling technique horizontally driven into the soil. v.Bodegom used a sampler, developed for this purpose, protecting the core inside the sampler. This method was developed to reduce compaction. Mekonnen used metallic boxes of 1500 cm^3, which were driven vertically into the soil.

Temporal and methodological variation in bulk density measurements will be investigated. The influence of this variation on statistical operations on inorganic nitrogen contents in the soil is also investigated.

Results

Total spatial and method dependent variation in measured bulk densities was considerable: A total variation of 15% was found. Landon (1991) states that variations of 15-20% are to be expected in most soils. Bulk densities were significantly different for different depths.

Besides spatial variation, temporal variation due to variation in moisture contents can occur, particularly for fine textured soils. Influence of this temporal variation was also investigated (See figure II.1 and table II.1).

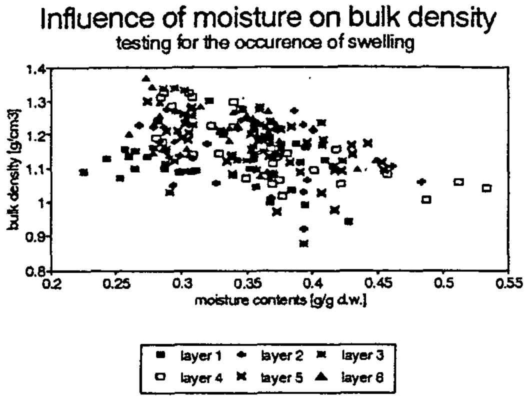


Figure II.1: Influence of soil moisture content on bulk density

Temporal variation due to variation in moisture contents does not have a significant influence on the bulk density values per layer, but it has a significant influence on the total determination for bulk density.

This variation can be caused by swelling and shrinkage effects due to the high clay contents. Swelling and shrinkage is however suppressed, because most clays are kaolinitic, with a low swelling potential. The effects can also be caused by indirect effects. Stickiness increases and workability decreases with increasing soil moisture contents. This can cause soil losses while retrieving the soil cores. To avoid these effects, samples should therefore be taken near or at field capacity (Landon, 1991).

Table II.1: Influence of soil moisture content ,indicated by WFPS (=water filled pore space), on bulk density

P-intercept	P-WFPS	P-model	r^2	layer
0.0659	0.0365	0.0365	0.440	all
0.0001	0.297	0.297	0.135	1
0.0738	0.9338	0.9338	0.001	2
0.7568	0.5707	0.5707	0.042	3
0.0001	0.7134	0.7134	0.018	4
0.0552	0.9226	0.9926	0.001	5
0.0635	0.0315	0.0315	0.459	6

Besides the influence of depth a significant influence of the method used was found at a 99% probability interval. An interaction with depth was not found. The extent of coincidence between methods are indicated in table II.2. The age of the soil pit does not influence the bulk density significantly, neither do persons using the same method (Braunl/2 and Buresh). The data of Mekonnen and v.Bodegom (Both methods have a low potential for compaction.) are significant lower than the data got with the conventional core sampling method: Compaction can still be abundant when using the conventional core sampling method. Another indication of compaction can be obtained from the comparison of soil moisture contents in cm^3/cm^3 at pF=0 and the independently determined pore fraction. In some layers (and especially layer 4) the pore fraction is lower than the soil moisture content at pF=0. This is physically not possible, but is possibly caused by too high bulk density values.

Water filled pore space (WFPS) calculated with the use of bulk densities gives another indication of overestimation occuring. WFPS at field capacity (pF=2) was calculated to be around 75% for the lower layers. This seems very high. Calculated WFPS-values for layer 4 of the experiment was always highest, independent of time. This seems not realistic.

Table II.2: Influence of method of measurement on bulk density. Indicated is the probability that the methods are not significantly different.

	Braun2	v.Bodegom	Buresh	Hartemink	Mekonnen
Braun1	0.7613	0.0012	0.7214	0.0005	0.0134
Braun2		0.0004	0.9588	0.0002	0.0051
v.Bodegom			0.0003	0.3949	0.162
Buresh				0.0002	0.0039
Hartemink					0.0478

The influence of different bulk densities on inorganic soil nitrogen data was also investigated. Three bulk density sets for the second season were compared (See table II.3). Set 1 is the dataset obtained with the conventional core sampling method. Set 2 contains bulk density data from v.Bodegom (to test the influence of lower compaction). Set 3 contains the average of bulk densities falling within the 90%-confidence interval for bulk density.

Table II.3: Datasets used to determine the influence of different bulk densities on statistical operations on inorganic soil nitrogen

set1	set2	set3
1.10	1.14	1.15
1.22	1.17	1.19
1.25	1.20	1.19
1.32	1.21	1.23
1.28	1.16	1.22
1.29	1.21	1.24

Table II.4: Soil inorganic nitrogen in the profile log-transformed for the three sets of bulk densities (in log N/ha*10^2):

	sesb			maize			weed			bare		
	set1	set2	set3	set1	set2	set3	set1	set2	set3	set1	set2	set3
8 Mar	217	215	216	231	228	230	219	216	217	253	251	252
11 Apr	208	206	207	229	227	228	211	208	209	260	258	259
28 Apr	201	199	200	234	231	233	200	198	199	250	248	249
17 May	196	194	195	226	223	225	205	203	204	254	252	253
14 jun	199	196	197	222	219	220	200	198	199	265	263	264
26 jul	191			213	213	215	174			252		
12 aug	200	197	198	227	225	226	199	196	198	259	257	258

The results are shown in table II.4. The log-transformed data are not significantly different. The choice for the bulk density used becomes therefore a principal one. In this study is chosen for set1. This contains data obtained with the international method used for bulk density determinations with the amount of replicates normally used. Using this dataset also facilitates comparison with other sites.

Conclusions

A considerable variation in bulk densities was found. The sources of this variation are spatial variation (termite mounds), temporal variation (due to soil moisture effects on bulk density) and methodological variation. The sources of variation can be reduced by using the data from one method only. This is justified because different bulk densities do not lead to different conclusions of statistical operations on inorganic soil nitrogen and because the results of different methods were significantly different ($P< 0.05$). Data obtained by the conventional core-sampling method were chosen, although these data can lead to an overestimation of soil inorganic nitrogen at a kg/ha base (due to compaction).

No correction could be made for soil moisture effects. Soil moisture had a significant effect ($P<0.05$) on bulk density for all data, but this influence was not significant (at $P<0.05$) for separate layers. It stresses the fact that bulk density measurements should be taken at or near field capacity.

Appendix III: Determination of evapotranspiration

III.1 Introduction

Evapotranspiration is the loss of soil moisture to the atmosphere and can be divided in a part of moisture losses via the plant (transpiration) and a part of moisture losses directly from the soil surface (evaporation). Evapotranspiration (ET) is one of the most important (in quantity) soil moisture losses. The significance of evapotranspiration is however often ignored. The main reason for this ignorance is its extreme difficulty to measure or estimate (Morton, 1983). Evapotranspiration is one of those processes in which one can question whether small-scale processes can be extrapolated to larger scales without taking into account feedback mechanisms. The calculations should only be used for small areas (Morton, 1985) and even then errors of 5-15% can be found if average weather data are used (Nonhebel, 1994). Due to all difficulties it is hardly possible to get an accuracy wit errors less than 20%. For tropical areas there are no suitable models at all (Stewart, 1984).

It has been tried to measure evapotranspiration rates (for example with the use of open water surfaces), but extrapolation of the results of those measurements to the field situation was (and is) very hard to achieve. Too many (doubtful) assumptions are necessary for this extrapolation.

For this reason some indirect methods (making use of the physical background of the evapotranspiration process) were developed, but these measurement were very complex and analysis was even more complex through all kinds of indirect and direct feedbacks inside and outside the plant-soil system. The most common method is therefore still the estimation by calculation.

A number of approaches have been developed for these calculations to tackle the complexity of the process. The approaches can be divided in empirical formulations and physical descriptions. The Food and Agricultural Organization (FAO) has tried to structure the efforts and to make to evapotranspiration calculations more uniform with two publications (Doorenbos and Pruitt, 1975; FAO, 1992). Basis of those publications was the Penman-equation (see below). The Penman-equation was however developed for temperate regions with a good plant production. Especially due to the extremely bad performace of the plants is was not possible to use these publications directly.

In this appendix it is tried to find a suitable way to calculate the evapotranspiration losses under the complex circumstances (bad plant production under tropical conditions) at Ochinga farm. First of all, the approaches mentioned in literature are reviewed, partitioned in empirical and physical formulations. The most useful approaches are reviewed in more detail (in paragraph III.2) to select the most proper approximation. For this purpose the month November 1994 was selected to test all the approaches on. This month knew no problems with the meteorological station and plant characteristics of this month were measured. This led to a complete measurement set to be able to execute the exercise. In paragraph III.3 and III.4 two additional complexities are treated. The appendix will conclude with the chosen approach and a comparison of results obtained with the approaches mentioned (in paragraph III.5). The final results of the whole exercise will however not be presented in this appendix, but are presented in paragraph 4.1.2.1.

Empirical formulations

In the first category an relationship is fitted between the evapotranspiration losses of a vegetation and some easily measurable parameters. Linacre (1977) and Blaney-Criddle (1950), for example, describe a relationship between maximum temperature, minimum temperature, elevation and latitude.

These methods and radiation methods give only accurate results when applied to optimal growing crops with longer time scales than a day. Baldy and stigter (1993) and Monteny (1987) give a formulation for *ET* (in mm) which can be used for this time scale:

$$ET=0.23*LAI*R_g \qquad (1)$$

In which	R_g	Global radiation (in $MJm^{-2}d^{-1}$)
	LAI	Leaf area index (-)

Another way to avoid the complex interactions is to extrapolate data from one system to another system using a correction factor. The complementary method of Morton (1983) is an example of this principle:

$$\boldsymbol{ET} = 2*\ \boldsymbol{ET_{pot,wet}} - \boldsymbol{ET_{pot,dry}}$$

$$=2*ET_{PriestleyTaylor}-\frac{[R_g-(\gamma_p+\frac{4\varepsilon\sigma(T_p+273)^3}{f})*f(T_p-T)]}{\lambda} \qquad (2)$$

In which	$T_{(p)}$	(Potential) temperature (in ^0C)
	γ_p	Latent heat of evaporation under euilibrium conditions (in kPa^0C^{-1})
	σ	Stefan-Boltzmann constant ($=4.90*10^{-9}MJm^{-2}K^{-4}d^{-1}$)
	f	correction factor (-)
	λ	Latent heat of evaporation (in $MJkg^{-1}$)
	ε	net emissivity of the atmosphere (-)

$$\varepsilon=\varepsilon_{atm}-\varepsilon_{veg} \qquad (3)$$

In which	ε_{atm}	Emissivity of the atmosphere (-)
	ε_{veg}	Emissivity of the vegetation (-)

The equilibrium circumstances are indicated with the subscript p. The correction factor f is estimated as 24.2 $MJd^{-1}m^{-2}kPa^{-1}$. These equilibrium data could however not be calculated out of the meteorological data collected by the automatic meteorological station. For this reason (and because it is always needed to calculate the evapotranspiration at another site first) this method will not be considred in the proceedings of this appendix.

The evapotranspiration can also be estimated from the pan evapotranspiration. Problems with the methodology of the pan-ET become more and more clear and it is adviced not to use this methodology anymore (FAO, 1992; Morton, 1982) and will only mentioned for completeness. Evapotranspiration from the pan evaporation is according to Doorenbos and Pruitt (1975):

$$ET_{pot}=f_1*E_{pan} \qquad (4)$$

In which	f_1	Dimensionless crop factor (-)
	E_{pan}	Pan evaporation (-)

The evapotranspiration of a crop is usually estimated from the evapotranspiration from a reference crop, calculated with the Penman-equation (see below). This means that a physical formulation will be needed to be able to calculate the evapotranspiration of the crop (Doorenbos and Pruitt, 1975):

$$ET_{crop}=K_c*ET_{pot_{ref}} \qquad (5)$$

In which	K_c	Crop factor (-)

The reference evapotranspiration is defined as the rate of evapotranspiration from a hypothetic crop with an assumed crop height (12 cm) and a fixed canopy resistance (70) [sm^{-1}], and albedo (0.23) which would closely resemble evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and not short of water (FAO, 1992). Crop factors have been described (Doorenbos and Pruitt, 1975; Jensen et al., 1990), but crop factors correcting for the low growth rates of depleted soils are hard to achieve. This method can therefore only be used with a crop factor adjusted to the local circumstances. Normal crop factors refer to fully grown crops and can't be used.

Physical formulations

The second category uses a physical description of the energy balance. The Bowen-method related most directly to the energy balance could not be used, due to the fact that no measurements at two heights were available. The Bowen-method uses the Bowen ratio (Angus and Watts, 1984; Stewart, 1984 a.o.):

$$\beta=\frac{c_p}{\lambda}*\frac{\Delta T}{\Delta q}=\left(\frac{\Delta T_w}{\frac{\gamma}{\Delta+\gamma}*\Delta T}-1\right)^{-1} \qquad (6)$$

In which	c_p	Specific heat capacity of moist air ($=1.2*10^{-3}$ $MJkg^{-1}$°C^{-1})
	T_w	Difference in temperature of the wet bulb (in °C^{-1}) between two heights
	Δq	Difference in specific humidity between two heights (in g/kg)
	Δ	Slope of the vapour pressure curve (in kPa°C^{-1})

The best known formulation out of this category is the Penman-Monteith formulation for actual evapotranspiration

(Monteith, 1981):

$$\lambda * ET = \frac{\Delta * (R_n - G) - \rho * c_p * \delta e / r_a}{\Delta + \gamma * (1 + r_c / r_a)} \tag{7}$$

In which	r_c	Crop resistance (in dm^{-1})
	r_a	Air resistance (in dm^{-1})
	R_n	Net radiation at the surface ($MJm^{-2}d^{-1}$)
	G	Soil heat flux (in $MJm^{-2}d^{-1}$)
	ρ	Atmospheric density (in kgm^{-3})
	δe	Vapour pressure deficit (in kPa)

The Penman-Monteith formulation was orignially also developed for a fully grown crop (with a LAI > 2.7). Only with the right corrections for aerodynamic resistances and crop resistances the evapotranspiration for a deficient crop can be calculated. Finding these resistances is the largest challenge in applying this equation.

For $r_c/r_a = 0$ the original Penman (1948) formula, see eq. 8, for potential evapotranspiration is found. This condition is true is the surface is wet.

$$ET_{Penman} = \frac{1}{\lambda} * \frac{\Delta * (R_n - G) - \varrho * c_p * \delta e / r_a}{\Delta + \gamma} \tag{8}$$

The crop factor converting the potential ET in the Penman formulation to the actual ET of the Penman-Monteith formula is:

$$K_c = \frac{\Delta + \gamma}{\Delta + \gamma * (1 + r_c / r_a)} \tag{9}$$

The Priestley-Taylor formulation (Priestley and Taylor, 1972) is a simplification of the Penman-equation and does not require measurement or estimation of the resistances, but only applies for a fully grown reference crop (or potential evapotranspiration):

$$\lambda * ET_{PriestleyTaylor} = \alpha_w * \frac{\Delta}{\Delta + \gamma} * (R_n - G) \tag{10}$$

In which	α_w	Crop correction factor according to Priestley and Taylor (1972) (-)

$$\alpha_w = 1 + \frac{\gamma / \Delta * \rho * c_p * \delta e}{(R_n - G) * r_c} \tag{11}$$

Because of its physical background and its good performance (FAO, 1992; Jensen et al., 1990) the Penman-Monteith formulation (eq. 8) will be used as a basis in the following calculations. There are two ways to use this formulation. The first is the one-step approach using the Penman-Monteith equation including estimates of crop resistance and air resistance. The second approach is a two-step approach using the

Penman-equation for a reference crop and correcting this value with a crop factor K_c relatively to the reference crop grass. Both approaches initially assumed a full grown crop completely covering the soil. In the calculation of ET, a correction will be made for nutrient and moisture stress and the consequently low preformanceof the canopies.

Its final performance will be compared with other useful formulations calculating the potential evapotranspiration (eq. 1, 8 and 10).

III.2 Parameter estimations

III.2.1 Crop factor K_c

Procedures for selecting the crop factor, K_c, have to take into account crop characteristics, crop development and general climatic conditions (Doorenbos and Pruitt, 1975). During the early growing period evaporation from the soil surface may be considerable and a great range of K_c values exist for dry and wet soil surface conditions.

The basal crop factors (assuming a normal non-deficient crop), K_c^0, can be reduced due to non-optimal growth circumstances. For this reason two reduction factors were included in the analysis to correct for reductions due to moisture stress and nutrient stress, respectively:

$$K_c = \overset{\circ}{K_c} * K_a * K_n \tag{12}$$

For maize basal K_c values, K_c^0, are considered for four stages: initial stage, development stage, mid-season stage and late-season stage. Using literature found on this subject, this gives the following values for maize (see table III.1) for ET_{penman}. A comparison of those methods is graphically presented in figure III.1. The formulation of Jensen et al. (1990) follows more closely the LAI and will be used in further calculations.

Table III.1: K_c^0 values for maize (Zea Mays). The period is given in daynumbers starting at day 1 at the time of sowing.

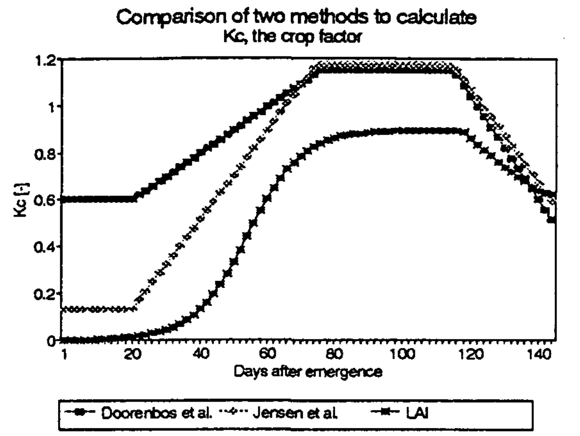
	initial	development	mid-season	late-season
days	0-20	21-75	76-115	116-harvest
$K_c{}^0{}_1$	0.6	$0.0098*day_{nr}$ +0.403	1.15	$-0.022*day_{nr}$ +3.68
$K_c{}^0{}_2$	0.13	$0.019*day_{nr}$ -0.248	1.17	$-0.02*day_{nr}$ +3.47

[1] According to Doorenbos and Pruitt (1975)

[2] According to Jensen et al. (1990)

Perennial crops like sesbania and weeds have a constant basal K_c. For weeds a value equal to the peak value for grass-legume pasture has been assumed. This peak value of 1.1 is reached when the weed fallow reached maturity (see paragraph 4.1.1.6). In the initial period a lower K_c value is assumed.

For the sesbania trees a basal K_c value of 0.8 is assumed during the rainy season and 0.85 during the dry season, values given for deciduous trees with weed ground cover (Doorenbos


Comparison of two methods to calculate

Kc, the crop factor

Figure III.1: Comparison of two methods to calculate basal crop factors as related to LAI

and Pruitt, 1975).

The basal crop factors can be reduced by moisture stress. For the heavy textured soils reduction of K_c values starts to occur if the soil depletion is 40% in the root zone. It reduces to 95% (at a soil depletion of 50%), 90% (at 60%), 80% (at 70%), 55% (at 80%) and 25% (at 90% soil depletion) (Doorenbos and Pruitt, 1975). This reduction especially occurs in the dry spells between the seasons.

Jensen et al. (1990) give a more mathematical description for the reduction of the crop factor (Ka):

$$K_a=\frac{\ln(A_w+1)}{\ln(101)} \qquad (13)$$

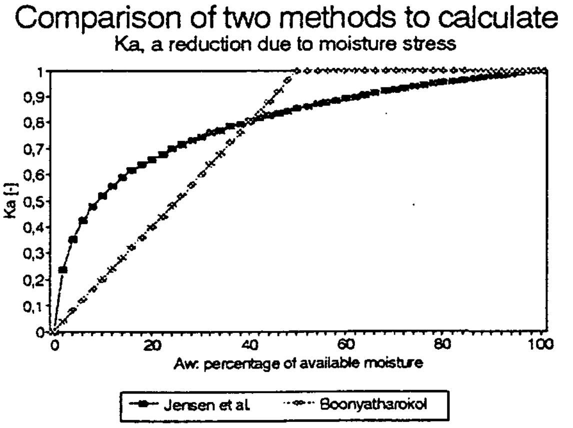
In which A_w Available moisture, defined as the amount of moisture present minus the amount of moisture at permanent wilting point divided by the amount of moisture between field capacity and permanent wilting point (in %)

$K_a = 1$ if $A_w > 50\%$

$K_a = A_w/50$ if $A_w \leq 50\%$

Figure III.2: Reduction of the crop factor due to moisture stress

A third way is mentioned by Boonyatharokol and Walker (1979). They estimated the reduction K_a as presented in figure III.2. A graphical comparison with the approximation given in Jensen et al. (1990) is presented in figure III.3. The approximation of Jensen et al. (1990) follows more close the conductivity of moisture in plants and will be used in further calculations.


Comparison of two methods to calculate

Ka, a reduction due to moisture stress

Figure III.3: Comparison of two mathematical methods to calculate K_a, the reduction of the crop factor due to moisture stress

Sometimes an additional effect on the crop factor through wet soils is mentioned. Wet soils only occur for a very short period (< 1 hr) after a rainfall event and this effect is therefore assumed to be absent.

Nutrient stress affect

seasonal ET_{crop} by their effects on yields. This relationship can be described as (derived from Doorenbos and Pruitt, 1975):

$$K_n=\frac{ET_{actual}}{ET_{crop}}=0.60*\frac{yield}{yield_{max}}+0.40 \qquad (14)$$

The fraction yield/$yield_{max}$ could be calculated out of test strip trials hold at a nearby farm (Paulo Julius farm). At these test strips maize was grown under non-limiting circumstances (applying sufficient amounts of nitrogen, phosphorus and potassium fertilizer). Unfertilized maize was grown as a control. With the use of these yield data (presented by Braun (1995)) the fraction yield/$yield_{max}$ could be calculated. This yielded a K_n of 0.54. Due to this large nutrient deficiency, seasonal evapotranspiration is significantly decreased (Ritchie, 1983).

With the use of the composed crop factor it was possible to make corrections for the low performance of the canopies. The results will be compared with those obtained with the Penman-Monteith equation in paragraph III.5. The other parameters used in the Penman-Monteith equation (eq. 7) will be estimated in the following paragraphs.

III.2.2 Physical constants

psychrometric constant

The psychrometric constant γ is about 0.66 $kPaK^{-1}$ at 20 ^0C. For other temperatures this magnitude can be estimated with (Brunt, 1952):

$$\gamma=0.00163*\frac{P}{\lambda} \qquad (15)$$

In which P Atmospheric pressure (in kPa)

Atmospheric pressure can be approximated with (Burman et al., 1987):

$$P=101.3\left(\frac{293-0.0065*elevation}{293}\right)^{5.26} \qquad (16)$$

The elevation of the site for Ochinga is equal to 1420 m.

Latent heat of evaporation λ depends on the temperature (Harrison, 1963):

$$\lambda=2.501-(2.361*10^{-3})T \qquad (17)$$

This magnitude is equal to 2.45 $MJkg^{-1}$ at 20 ^0C

vapour pressure deficit

The slope of the vapour pressure curve is given by (Murray, 1967):

In which e_s Saturated vapour pressure (in kPa)

$$\Delta=\frac{e_s(T_0)-e_s(T_z)}{T_0-T_z}=\frac{4098*e_a}{(T+237.3)^2} \tag{18}$$

e_a Actual vapour pressure (in kPa)
T Temperature in (°C)

Actual vapour pressure (with $T=T_{act}$) and the saturated vapour pressure (with $T=T_d$) can be approximated with (Dolman, 1987):

$$e_{a,s}=0.61078\exp\frac{17.269T}{(T+237.3)} \tag{19}$$

The atmospheric density ρ (in kgm^{-3}) can be calculated from:

$$\rho=3.486*\frac{P}{T_{kv}} \tag{20}$$

In which T_{kv} Virtual temperature (in K)

$$T_{kv}=(T+273)(1-0.378*\frac{e_d}{P})^{-1} \tag{21}$$

In which e_d Vapour pressure at dew point (in kPa)

The met station had a hygrometer and therefore e_d could be approximated by interpolation as:

$$e_d=\frac{1}{2}*e_{a(Tmin)}*\frac{RH_{max}}{100}+\frac{1}{2}*e_{a(Tmax)}*\frac{RH_{min}}{100} \tag{22}$$

In which RH Relative humidity (-)

Vapour pressure deficit (δe) can be estimated as:

$$\delta e=\frac{(e_{a,Tmax}+e_{a,Tmin})}{2}-e_d \tag{23}$$

The deficit in specific humidity (in g/kg), as used in some descriptions, is directly related to the vapour pressure deficit:

$$\delta q=0.622*\delta e \tag{24}$$

III.2.3 Resistances

Evapotranspiration consists of three processes: interception (with resistance=0), soil evaporation (with resistance r_{soil}) and transpiration (with resistance r_c). In normal use of the Penman-Monteith equation always the r_c is used, neglecting soil evaporation. It is stated that at LAI>1 r_{soil} can be neglected (Jensen et al., 1990). This means that only for the bare fallow the r_{soil} will be used. Calculations of interception can be kept separate from ET-calculations, because a correction is automatically made for the interception because only throughfall enters the soil and is used for the soil moisture balance. It should be noted that interception of rainwater is always a loss: By far most of the intercepted water evaporates directly. Interception is not treated in this appendix, but is presented in paragraph 4.1.1.3.

In temperate regions the vapour transport term has a lot of influence on the Penman-Monteith equation (Beven, 1979), while in tropical circumstances the energy-term is more important. Resistance estimates are however still of importance to convert the potential evapotranspiration to actual evapotranspiration under stressed circumstances. In this paragraph it will be tried to find those adjusted resistances.

soil resistance

Soil resistance, r_{soil}, is directly related to soil hydraulic conductivity, $K(\Theta)$, in md^{-1}:

$$r_{soil}=\frac{1}{K(\theta)} \tag{25}$$

Soil hydraulic conductivity describes the amount of moisture that can be transported through the soil per period of time. Hydraulic conductivity is a function of soil moisture. Soil hydraulic conductivity is largest at saturation. Saturated hydraulic conductivity was measured (see 4.1.2.2), but can also be estimated as a function of the soil texture (Fahmy, 1961):

$$K=\frac{C}{\eta * U^2} * \frac{n^3}{(1-n)^2} \tag{26}$$

In which	C	a constant ($=330\ kgm^{-2}$)
	η	viscosity ($=1.4*10^{-3}\ kgm^{-1}s^{-1}$)
	U	specific surface

Specific surface, U, can be calculated with:

$$U=\frac{1}{\ln(d_2)-\ln(d_1)} * \left(\frac{1}{d_1}-\frac{1}{d_2}\right) \tag{27}$$

In which $d_{1,2}$ diameter boundaries of texture class

Soil hydraulic conductivity decreases very fast with decreasing soil moisture and only some values of unsaturated conductivity are known (0.5-0.8 $mday^{-1}$ at $\Theta=0.30$, (Hartemink, 1994)). Hydraulic conductivities as a function of soil moisture contents can be estimated by approaches described by Campbell (1974) and van Genuchten (1987). Hydraulic conductivity as a function of moisture is estimated with (Campbell, 1974):

$$K(\theta)=K_s\left(\frac{\theta}{\theta_s}\right)^{2b+3} \tag{28}$$

In which	K_s	Saturated hydraulic conductivity (in md^{-1})
	Θ_s	Saturated moisture content (in cm^3cm^{-3})
	b	Empirical parameter (-)

Parameter b can be estimated according to Campbell (1974):

$$h=a\left(\frac{\theta}{\theta_s}\right)^{-b} \qquad (29)$$

In which h Hydraulic potential (in m)
a Empirical parameter (in m)

With the Campbell method it is not possible to estimate saturated hydraulic conductivity independently and use had to be made from measured data. With the use of the iterative RETC-model, a computer program of van Genuchten (1987), it is possible to estimate saturated hydraulic conductivity independently:

$$\theta=\theta_r+\frac{(\theta_s-\theta_r)}{[(1+(\alpha h)^n]^m} \qquad (30)$$

In which $m=1-1/n$

$$\frac{K}{K_s}=\sqrt{\theta}*[1-(1-\theta^{1/m})^{m^2}] \qquad (31)$$

This relationship can be fitted with the use of the pF-curve measured (Hartemink, 1994). K(Θ) can be estimated from particle size distribution too (Fahmy, 1961).

A comparison between measured saturated conductivities and simulated conductivities (using van Genuchten (1987) and Fahmy (1961) is given in paragraph 4.1.2.2.

$1/r_{soil} = K_s$ if $\Theta > \Theta_{critical}$

$r_{soil} = \infty$ if $\Theta < \Theta_{critical}$

Figure III.4: Block function for determining soil conductivity

The last possibility to calculate soil resistance is to use a block function (see figure III.4) (Goudriaan, pers. comm.).

$\Theta_{critical}$ can be determined by plotting $T_{0.05}$ against Θ, assuming that $T_{0.05}$ is equal to the soil surface temperature (see figure III.5). Heat conversions of incoming radiation at soil surface occur due to evaporation and energy absorbance. Evaporation can occur only if the transport of moisture to the surface functions well. This transport depends on the conductivity. The conductivity becomes, at a certain moisture content ($\Theta_{critical}$), too low to transport enough moisture to evaporate. To converse all incoming radiation, energy will be absorbed and soil temperature will make a steep rise. As can be seen in figure III.5, the $\Theta_{critical}$ is about 0.28 cm^3/cm^{-3}.

A comparison of the methods to calculate soil hydraulic conductivity is given in paragraph 4.1.2.2. The van Genuchten parameters to calculate soil hydraulic conductivity were used in further analysis in paragraph 4.1.2.2. These estimates will also be used in this appendix. Parameter estimates and the argumentation to use the van Genuchten parameters are presented in paragraph 4.1.2.2. The estimation presented in figure III.4 gives roughly the same results, but is less flexible.

The large dependance of soil resistance on soil moisture makes evaporation dependent on soil surface cover. Evaporation with decrease very fast with moisture stress. Moisture stress is promoted by a low soil cover.

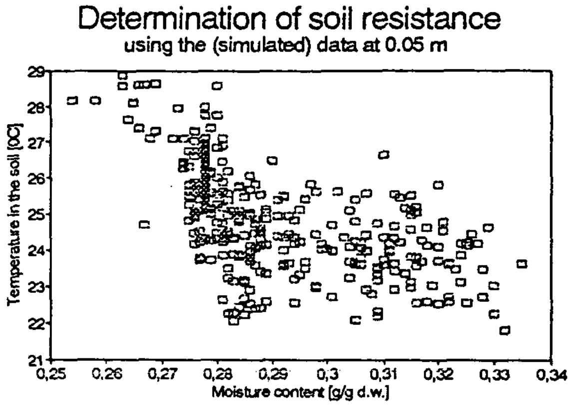


Figure III.5: Determination of the critical moisture content with the use of soil surface temperature data

air resistance

Air resistance can theoretically be approximated with (Goudriaan, 1977):

$$r_a = \frac{0.74}{ku^*} * \ln \frac{(z-0.63*height)}{((1-0.63)*height)} \tag{32}$$

Friction velocity, u*, can be calculated with Eddy correlation techniques if the wind speed is known at two heights. Wind speed was only measured at one height in this study, so the method, mentioned above, could not be used.

Other formulas to calculate the aerodynamic resistance are given in literature. For taller crops the air resistance, r_a, can be estimated from (Thom and Oliver, 1977):

$$r_a = 4.7 \frac{\ln(\frac{z-d}{z_0})^2}{1+0.54*u_z} \tag{33}$$

In which	z	Height of measurement (=2 m)
	z_0	Roughness length (= 0.1 * height of the crop)
	d	zero plane displacement (= 0.67 * crop height)
	u_z	windspeed (in md^{-1})

In this approach (and in the other two approaches using the wind profile) wind speed measured with the automatic meteorological station at 2m height is used. Average wind speed was about $1ms^{-1}$.

Dolman (1987) gives:

$$r_a = \frac{1}{k^2 u_z} * [\ln \frac{(z-d)}{z_0}]^2 \tag{34}$$

In which	*k*	Von Karmann constant (≈ 0,41)

The last approximation using the wind profile found in literature is given by Jensen et al. (1990):

$$r_a=\frac{1}{k^2u_z}\ln\frac{z-d+0.2*z_0}{0.2*z_0}*\ln\frac{z-d+z_0}{z_0} \tag{35}$$

In this formulation vapour roughness is simulated with $0.2*z_0$.

Landsberg and McMurttrie (1984) developed an approximation of r_a (in dm^{-1}) using the plant surface of maize presented by LAI and leaf length (with u_z in ms^{-1}):

$$\frac{1}{r_a}=1.47*10^3*LAI^{-0.56}\sqrt{\frac{u_z}{leaf_{length}}} \tag{36}$$

De Bruin (1983) mentions an average aerodynamic resistance of $8.7*10^{-4}$. Representative values for r_a (in dm^{-1}) as a function of windspeed (in m/s) are given in table III.2.

Table III.2: Aerodynamic resistance of several canopies (in 10^{-4} dm^{-1}) as a function of wind speed (in ms^{-1})

wind speed	0	2	5	10
short grass	16.5	7.87	4.40	2.55
maize	3.94	1.97	1.04	0.58
forest	1.50	0.69	0.41	0.23

The aerodynamic resistance for the bare fallow was calculated using a soil surface roughness of 1 mm. Average aerodynamic resistances were $75*10^{-4}$ (for bare fallow), $6*10^{-4}$ (for maize), $2.3*10^{-4}$ (for weed fallow) and $0.7*10^{-4}$ dm^{-1} (for sesbania fallow). The calculated values shown in figure III.6 for maize are in the same range as those presented in table III.2.

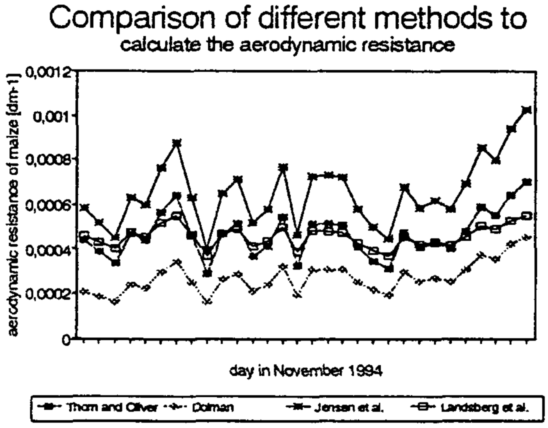


Figure III.6: Comparison of different methods to calculate aerodynamic resistance for maize

The performance of the formulations could not be measured independently. For this reason the performance was measured relative to the other formulations. The formulation that performed, independent of the circumstances, not extremely (compared to the other treatments) was chosen. This same approach was also used to choose between the other formulations following later in this paragraph, when a choice could not be based on physical arguments.

The approximation of Landsberg and McMurttrie (1984) performs well for maize. This approximation however largely underestimated r_a for the sesbania fallow and weed fallow (probably because this formulation was not developed for these canopies). The formulation of Jensen et al. (1990) showed the highest values independent of the crop. The formulation of Thom and Oliver (1977) will be used in further exercisions, because it performed constantly well.

crop resistance

Crop resistances are measured as stomatal or leaf resistances. The measures of stomatal resistance are however based on assumptions that are not always true (Morton, 1983). Measurements of r_{stom} have a very high variability. A lot of measurements are therefore needed (Denmead, 1984). Stomatal resistance is influenced by vapour pressure, global radiation and moisture deficit in the soil (Stewart and de Bruin, 1984), but is independent of wind speed (Monteith, 1981). After the measurement, stomatal resistance values should be extrapolated to field level, to crop resistance, again inducing additional erors.

The most extensive formulation found in literature for the stomatal resistance is given by Dolman (1987) with r_c in sm^{-1} instead of dm^{-1}:

$$\frac{1}{r_{stom}}=2.05*10^{-2}\frac{R_g}{9.02+R_g}(1-0.22*\delta e)(T(40-T))^{1.18}\frac{\theta_{avail}-\delta\theta}{0.4\theta_{avail}}\frac{LAI}{LAI_{max}} \tag{37}$$

In which $\delta\Theta$ Soil moisture deficit (in mm)

Moisture stress influences the stomatal resistance, r_{stom}, as also indicated in eq. 37. It is stated that $r_{stom,stressed} = 4* r_{unstressed}$ for trees reacting on moisture in the upper 80 cm, while for maize reacting on moisture in the upper 30 cm $r_{stom,stressed} = 3* r_{unstressed}$ (Monteith, 1981). Somehow no good results were obtained with the formulation of eq. 37. This can be caused, because empirical factors mentioned in Dolman (1987) were used directly, because no measurements of r_{stom} were available for Ochinga farm.

For taller crops it is possible to increase the r_{stom} without creating a larger vapour pressure gradient. For this reason it is possible for trees to have higher r_{stom}. Average values for r_{stom} vary from 250 sm^{-1} (for maize (Tardieu, 1987; Lorens et al., 1987; Tardieu et al.,1991; Stigter, 1974; Stigter et al., 1974)) and 150 sm^{-1} (for weed fallow (Jones, 1986)) to 450 sm^{-1} (for sesbania fallow (Balashima et al., 1991; Mohd Razi et al., 1992)).

Stomatal resistance is extrapolated to crop resistance using LAI. There are however several formulations given:

$$r_c=\frac{2*r_{stom}}{LAI} \tag{38}$$

(Sceisz and Log, 1969; Jensen et al., 1990; Allen et al., 1989; Monteith, 1981)

$$r_c = \frac{r_{stom}}{LAI} \qquad (39)$$

(Sharma, 1984; Rose, 1984)
This already indicates the large uncertainties with the resistances. In further calculations eq. 38 was used, because this was used slightly more often in literature.

Average crop resistances are $36*10^{-4}$ for maize, $11.5*10^{-4}$ for the weedfallow and $30*10^{-4}$ for the sesbania fallow. This is higher than the r_c of $14*10^{-4}$ dm^{-1} mentioned for a tropical rainforest (Calder, 1986), due to the much lower LAI.

The aerodynamic resistance and crop resistance could be corrected for the bad performance of the canopies by inclusion of plant characteristics (as height of the crop and LAI). The crop resistance was also corrected for moisture stress by using a r_{stom} developed for circumstances of moisture stress. With these corrections it is possible to calculate evapotranspiration under the conditions prevailing at Ochinga farm. The remaining factor to be calculated is the energy balance.

III.2.4 Energy balance

Good radiation data are of crucial importance in view of their predominance in the Penman-Monteith equation and should be estimated well. This is especially true under tropical circumstances. The factor mentioned in McNaugthon and Jarvis (1983) to estimate evapotranspiration is therefore not valid under tropical conditions.

net radiation, R_n

$$R_n = (1-\alpha) R_g - R_{nl} \qquad (40)$$

In which α Albedo (-)
R_{nl} Net longwave radiation (in $MJm^{-2}d^{-1}$)

Clustered leaves (as in bushes and trees) have a lower albedo than non-clustered leaves (like maize) (Goudriaan, 1977; Jacobs and van der Pul, 1990). The albedo value, α, for maize is 0.23 (Ling and Robertson, 1982). For trees an average value of 0.18 was given (Rutter, 1970). This same value was used for tree canopies in western Africa (de Ridder, pers. comm.). A default value of 0.22 was assumed for the bare fallow and weed fallow (similar to the albedo of grass (Hillel, 1971)).

The net outgoing longwave radiation R_{nl} is (FAO, 1992):

$$R_{nl} = (\varepsilon_{atm} - \varepsilon_{veg}) \sigma f_c (T+273)^4 \qquad (41)$$

In which f_c correction factor (-)

The correction factor f_c corrects for cloudiness (Doorenbos and Pruitt, 1975; Jensen et al., 1990):

$$f_c = (0.74 + 0.27 * \frac{n}{N}) \qquad (42)$$

In which n Amount of sunshine hours
N Total amount of daylight hours

Emissivities are usually calculated using corrections for vapour pressure circumstances. Two corrections are mentioned in the literature found:

$$\varepsilon_{atm}-\varepsilon_{veg}=0.34-0.14\sqrt{e_d} \tag{43}$$

(Jensen et al., 1990)

$$\varepsilon_{atm}-\varepsilon_{veg}=0.26\exp(-7.77*10^{-4}T^2)-0.02 \tag{44}$$

(Idso and Jackson, 1969). Results of both approximations are presented in figure III.7. The approximation given by Idso and Jackson (1969) changes little, because average temperature hardly changes. In this case it can't correct for changes in atmospheric cirucmstances, unless it would be used with a smaller time scale than one day. Probably it performs better in temperate regions. The approximation given by Jensen et al. (1990) is more sensitive to changes in atmospheric conditions and will be used in further calculations.

Also two empirical formulas are mentioned to calculate net radiation:

$$R_n=(1-\alpha)R_g\frac{(1-e^{-k_1*LAI})}{LAI} \tag{45}$$

(Goudriaan, 1977)
In which k_1 extinction coefficient (-)

$$R_n=0.675(1-\alpha)R_g-0.59 \tag{46}$$

(Sharma, 1984)

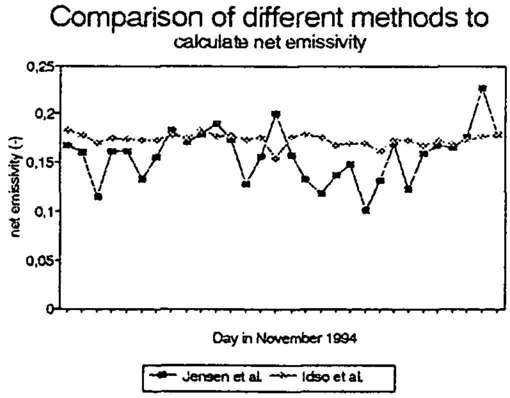


Figure III.7: Comparison of two methods to calculate net emissivity

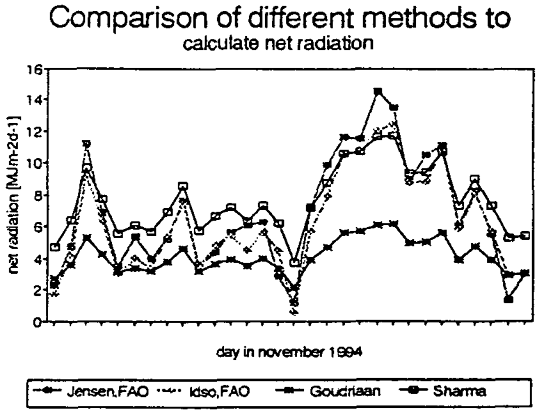


Figure III.8: Comparison of different methods to calculate net radiation

A comparison of different methods to calculate net radiation is presented in figure III.8. Whether net emissivity is approached by the equation given by Jensen et al. (1990) or Idso and Jackson (1969) does not make much difference in net radiation. The approximation given by Goudriaan (1977) is not able to follow the climatic conditions (given by global radiation) closely, whereas the approxiamtion of Sharma is not able to correct for cloudy conditions during the rainy days. For this reason the approximation given by FAO (1992) combined with a net emissivity calculated using Jensen et al. (1990) is used in further calculations.

Soil heat flux, G

Soil heat flux, G, only plays a role when the crop is not fully grown. Unfortunately this is the case in Western-Kenya due to nutrient and moisture stress. G can be approximated in three ways.

The first way is with the use of an (very simplified) empirical formula (Dolman, 1987):

$$G=0.017*R_n \qquad \textbf{(47)}$$

The second way makes use of the differential equation for G (Jensen et al., 1990) with the additional assumption that the soil temperature at 5 cm depth is equal to the soil temperature at the soil surface:

$$G=-\lambda_{soil}\frac{\delta T}{\delta z}=-\lambda_{soil}\frac{T_{0.20}-T_{0.05}}{0.15} \qquad \textbf{(48)}$$

In which	λ_{soil}	Soil thermal conductivity (in $MJd^{-1}m^{-1}K^{-1}$)
	$T_{0.05}$	Soil temperature at 5 cm depth (in 0C)
	$T_{0.20}$	Soil temperature at 20 cm depth (in 0C)

The soil thermal conductivity, λ_{soil} depends highly on the way in which the best conducting mineral particles are connected with the less conducting water particles and the poor conducting air particles. It can be approximated, with λ_{soil} in $Wm^{-1}K^{-1}$, (derived from Koorevaar et al., 1983) by:

$$\lambda_{soil}=8.37*f_{quartz}+2.93*f_{minerals}+0.25*f_{o.m.}+0.59*f_{water} \qquad \textbf{(49)}$$

In which	f_x	Fraction of material x in the soil

For the circumstance at Ochinga farm it can be derived (with λ_{soil} in $MJd^{-1}m^{-2}K^{-1}$) that:

$$\lambda_{soil}=0.138+0.051*\theta \qquad \textbf{(50)}$$

The third way makes use of the partial differential equation for G (FAO, 1992):

$$\frac{\delta G}{\delta z}=C\frac{\delta T}{\delta t}\approx 1.5\,(T_{day_n}-T_{day_{n-1}}) \qquad \textbf{(51)}$$

In which	C	Volumetric heat capacity (in $MJm^{-3}K^{-1}$)

The exact solution of this equation is:

$$G_{0,t}=\frac{\sqrt{2}*A_0*\lambda_{soil}*\sin(2\pi t+1/4\pi)}{\sqrt{\frac{\lambda_{soil}}{\pi C}}} \qquad (52)$$

In which A_0 Amplitude of temperature at the soil surface (in °C)

The volumetric heat capacity can be estimated with (derived from Jenssen et al. (1990) and Koorevaar et al. (1983))

$$C=1.93*fraction_{mineral}+2.5*fraction_{organic\text{-}matter}+4.2*fraction_{water} \qquad (53)$$

This results for the circumstances at Ochinga farm:

$$C=0.56+4.2*\theta \qquad (54)$$

The amplitude, A_0, can be calculated from the dynamics of the temperature at the surface. It was again assumed that the soil surface temperature (and thus the soil surface amplitude) was equal to the soil temperature at 5 cm depth:

$$T_{0.05,t}=\overline{T_{0.05}}+A_{0.05}\sin(2\pi t) \qquad (55)$$

The exact solution yielded soil heat flux values above total net radiation, which does not seem realistic. Other results are presented in figure III.9. A peak value for the soil heat flux of 10% of the total net radiation was found (Goudriaan, 1977). In Western Africa soil heat fluxes of about 15% of the total net radiation were measured (de Ridder, pers. comm.). The soil heat fluxes calculated for Ochinga farm are in this same range if the approach of Jensen et al. (1990) is used. The approach of Dolman gives too low values, especially when the surface is dry, because under those conditions more energy will be converted to soil heat flux. The approach of FAO results in a soil heat flux of about 30% of the net radiation, This seems to be too high, although the conditions are dry (The approximation presented in Jensen et al. (1990) also results in values slgihtly above 15%). The approach of Jensen et al. (1990) will be used in further calculations.

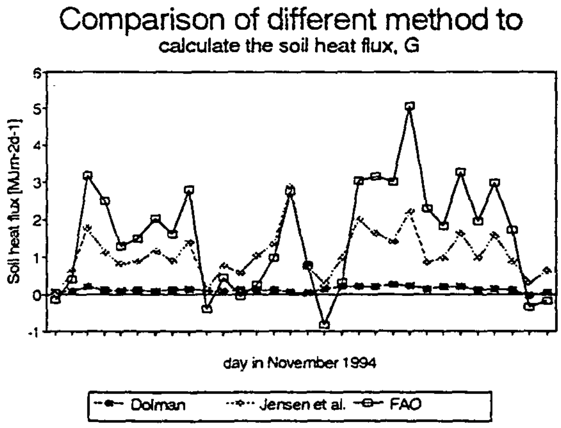


Figure III.9: Comparison of different methods to calculate soil heat flux

III.3 Division of losses between transpiration and evaporation

The evapotranspiration corrected for the bad performance of the canopies at Ochinga farm can now be calculated. For the calculation of the transpiration coefficient, the losses should be distributed among losses due to transpiration and losses due to evaporation. The distribution is dependent on LAI. Since transpiration and evaporation don't vary proportionally with LAI, they should be considered separately (Tanner and Jury, 1976; Jensen et al., 1990).

Transpiration rates are most affected by a low LAI and decrease fastest (Jensen et al., 1990). For a fully grown crop the differences in transpiration rates with LAI become very small, however: Trees are able to compensate a somewhat lower LAI with an increased stomatal resistance. This makes transpiration a conservative process (Dolman, 1987). Ritchie and Burnett (1971) give for the transpiration rate:

$$T_{plant}=(-0.21+0.70\sqrt{LAI})*ET_{Priestley\text{-}Taylor} \qquad (56)$$

This model is a good estimator of transpiration and soil evaporation according to Kanemasu et al. (1976).

Evaporation drops when the soil moisture content of the surface layer drops below a certain minimum, whereas transpiration is limited by plant cover and soil moisture in the total root zone. A generalised formula for this reduction is given by Tanner and Jury (1976):

$$E=\alpha_E*e^{-k_1*LAI}*ET_{Priestley\text{-}Taylor} \qquad (57)$$

In which α_E Corrected value of the Priestley-Taylor constant

α_E is equal to one below a critical value for $e^{-k1*LAI}$ not greatly decreasing the wind and saturation deficit near soil surface. The factor $e^{-k1*LAI}$ describes the fraction of R_n exchanged at the soil surface. This relationship is generalised from Ritchie (1972) and Driessen (1986):

$$E=ET_{Priestley\text{-}Taylor}*e^{-0.4*LAI} \qquad (58)$$

Tanner and Jury (1976) came to the relationship given in figure III.10. This relationship gives a better representation at the low LAI values occuring at Ochinga farm, because LAI is most of the time below 1.3, while normally this does not occur for a long period.

$$E = e^{-0.61*LAI} * ET_{Priestley\text{-}Taylor} \qquad LAI < 1.3$$
$$E = 0.69*e^{-0.32*LAI} * ET_{Priestley\text{-}Taylor} \qquad LAI \geq 1.3$$

Figure III.10: Calculation of evaporation at a LAI lower than the LAI of a fully grown crop

Evaporation can also be calculated in a physical way. During the first stage the rate of evaporation is controlled by heat energy input. During the second stage the surface has begun to dry and evaporation occurs below the soil surface and the rate of evaporation is no longer controlled by meteorological conditions (as indicated by the Penman-Monteith formula) but by soil characteristics (Tanner and Jury, 1976):

$$\int E dt = E_{cum} = C\sqrt{t_e - t_{initial}} \qquad (59)$$

In which E Evaporation rate (in mmd^{-1})
t time (in days)

After each rainfall event the E_{cum} should be reduced with:

$$E_{cum_{new}} = E_{cum_{initial}} - Precipitation \qquad (60)$$

The calculation starts anew after this adjustment. The results using this approach did not give better results than those when applying the approximation presented by Tanner and Jury (1976). The distribution of evapotranspiration losses over evaporation and transpiration as a function of LAI is presented in figure III.11.

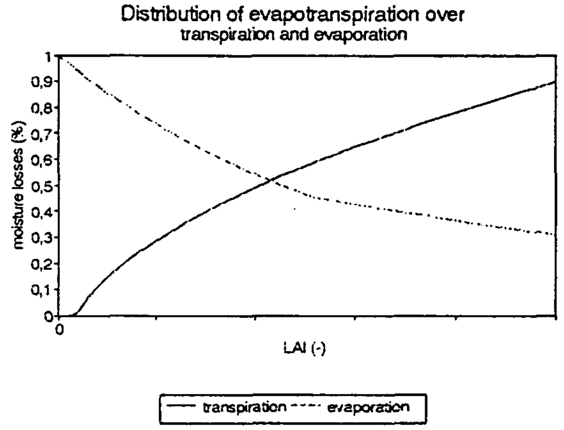


Figure III.11: Distribution of evaporation losses over evaporation and transpiration

Soil surface cover is low due to the low LAI of all canopies. For this reason evaporation will play a role (as long as soil moisture is not deficient), whereas under optimal circumstance only transpiration would play an important role. The influence of evaporation and total evapotranspiration rates makes the evapotranspiration highly dependent on soil surface wetness, as also can be see nin figure III.13. During the periods of highsoil wetness evapotranspiration was highest. This effect is especially large at a LAI smaller than 1. A large part of the variation in evapotranspiration during part of the season is therefore caused by the influence of frequency and duration of soil surface wetness.

III.4 Effects of an isolated canopy

The last corrections to be made concern oasis effects and effects of isolated canopies. Oasis effects only play a role when the conditions are very extreme (FAO, 1992; Morton, 1983) and are assumed to be absent in this case. Isolated canopy effects were estimated by subdiving the canopy in an top layer and a bottom layer (Rose, 1984):

$$ET_{total} = ET_T + ET_{bottom} \qquad (61)$$

In which ET_T evapotranspiration in the top layer (in mmd^{-1})

The evapotranspiration in the top layer is calculated with:

$$ET_T = ET_{Penman\text{-}Monteith} + \frac{height_T * \bar{u}(\delta P_v)_T}{width_{plot}} \qquad (62)$$

In which $(\rho P_v)_T$ Vapour pressure losses in the top layer of the canopy (-)

with

$$(\delta P_v)_T = \frac{(LAI\frac{height_T}{height_{total}}-1)}{(1+LAI\frac{height_T}{height_{total}})} * (\delta P_v)_T \qquad (63)$$

$$ET_{bottom} = \frac{height_{bottom} * \bar{u}(\delta P_v)_b}{width_{plot}} \qquad (64)$$

with

$$(\delta P_v)_b = (\rho_o - \rho_v)(1-\exp(-\frac{1.04*LAI*width_{plot}}{height_{total}} * \bar{u} * (r_a + r_c))) \qquad (65)$$

In which ρ_s Vapour density at the soil surface (in kgm^{-3})
ρ_a Vapour density in the air at 2m (in kgm^{-3})

As can be seen in figure III.12 the effects of isolated canopy are very small (< 4% of the total evapotranspiration). This is within the errors made in the evapotranspiration calculations, which are usually about 20% (see paragraph III.1). For this reason the effects of isolated canopy will be neglected.

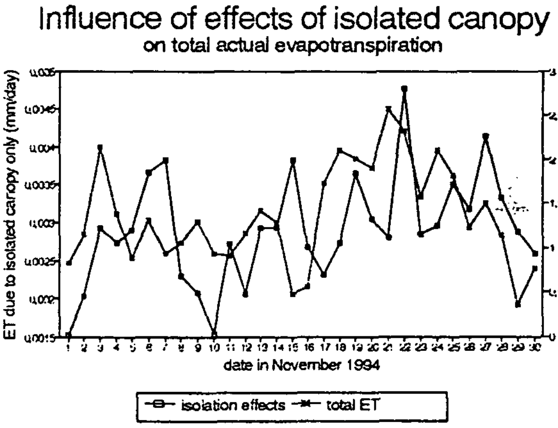


Figure III.12: Contribution of the effects of isolated canopies to the total evapotranspiration
note: Different scales of the y-axes)

III.5 Conclusions

The basis of the all approaches examined (except the approach of Baldy and Stigter (1993)) was the calculation of the energy balance. This was calculated with a soil heat flux based on Jensen et al. (1990) and a net radiation based on FAO (1992) (with a net emissivity calculated based on Jensen et al. (1990)). With this energy balance it was possible to calculate potential evapotranspiration based on the Penman-equation and the Priestley-Taylor equation. Results of these equations for the month November 1994, together with the approach of Baldy and Stigter (1993) are presented in figure III.13. The Approach of

Baldy and Stigter gives surprisingly enough good results.

Out of the potential evapotranspiration the actual evapotranspiration was calculated using adjusted crop factors and adjusted resistances respectively. The argumentation for the selection of these adjustions is presented in paragraph III.2.3. A comparison of both methods is presented in figure III.14.

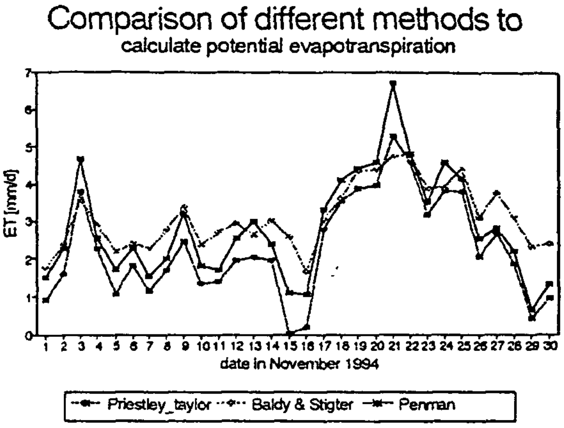


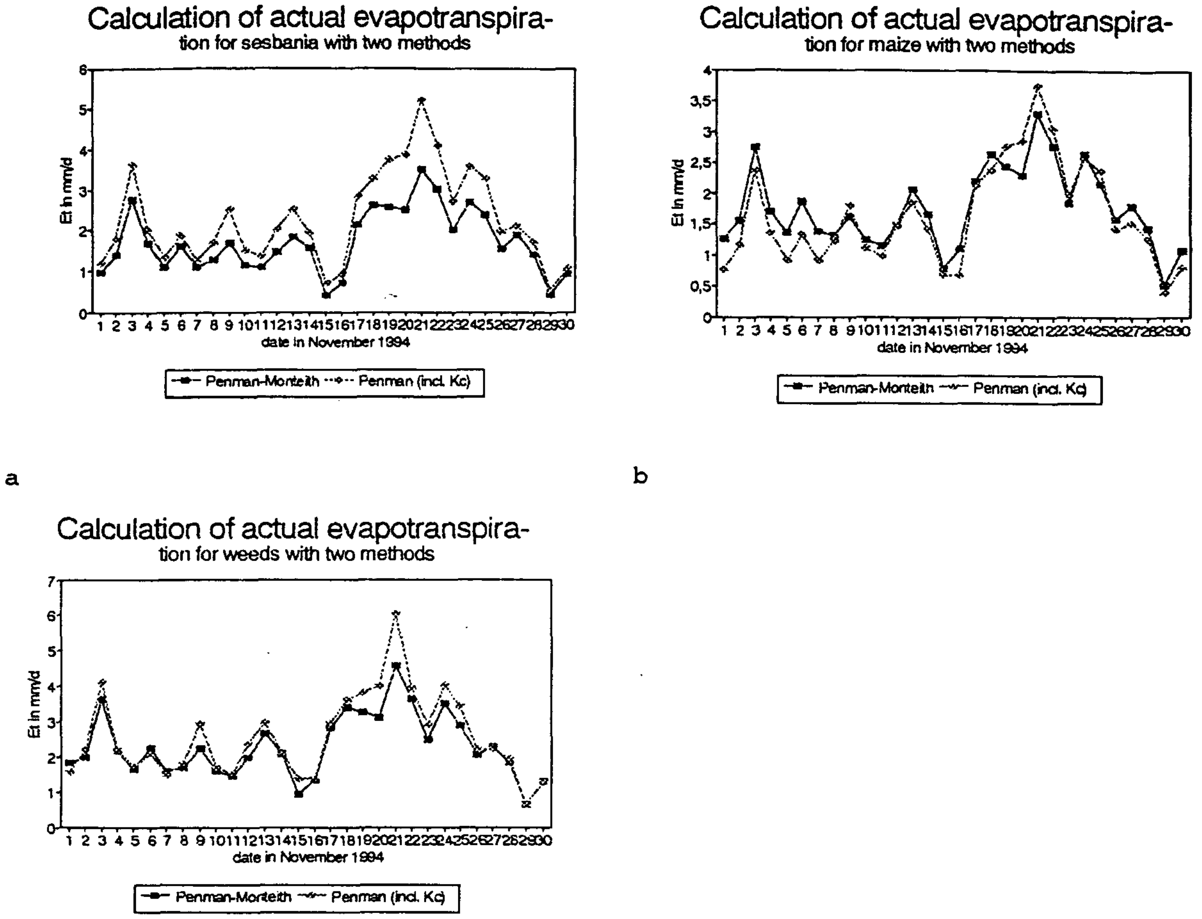
Figure III.13: Comparison of different methods to calculate potential evapotranspiration

The results of using r_{stom} have usually a variability as large as the variability that would have occured if K_c would have been used (Goudriaan, pers. comm.) as was the case this time too. Both approaches function equally well, the Penman method leading to slightly higher results on average. This is all within the variability range of 20% mentioned in the introduction, giving confidence in the calculation method and in the results produced. The average values per day were used to calculated seasonal evapotranspiration losses, presented in 4.1.2.1. The average values are in the range as would be expected for plants with this bad biomass production (Driessen, pers. comm.).

Evapotranspiration is lower in maize than in the fallow systems, especially if compared on a seasonal basis. This has by several causes: Crops are not present continuously and evaporation is smaller than evapotranspiration (especially under conditions of moisture stress). The aerodynamic resistance of a crop is also lower. Evapotranspiration of a crop is therefore lower than the evapotranspiration of a continuous canopy for these reasons.

The weed fallow has higher evapotranspiration rates, than the sesbania fallow, because of its lower crop resistance and (thus) higher crop factor.

The bare fallow, not presented in this appendix, has very low evapotranspiration rates. This is caused, because during large part of the reason soil moisture is rather low. This leads to very low conductivities andthus to high soil resistances. Almost no water is able to evaporate anymore and evapotranspiration decreases to almost zero. Soil surface is almost sealed for water due to this low conductivity. This canhave causedto high runoff found (see 4.1.1.5).



a

b

c

Figure III.14$_{a,b,c}$: Calculation of actual transpiration with two different methods for maize, sesbania and weeds respectively

Appendix IV: List of symbols and abbreviations

abbreviation	units	explanation
α	[-]	Albedo
α_E	[-]	Corrected value of the Priestley-Taylor constant
α_w	[-]	Crop correction factor according to Priestley and Taylor (1972)
β	[-]	Bowen ratio
γ	kPa^{0}C^{-1}	Psychrometric constant
γ_p	kPa^{0}C^{-1}	Psychrometric constant under equilibrium circumstances
Δ	kPa^{0}C^{-1}	Slope of vapour pressure curve
ε	[-]	Net emissivity of the atmosphere
ε_{atm}	[-]	Emissivity of the atmosphere
ε_{veg}	[-]	Emissivity by the vegetation
$\delta\Theta$	mm	Soil moisture deficit
Θ	cm^3/cm^3	Volumetric soil moisture content
Θ_{avail}	mm	Available soil moisture
Θ_s	cm^3/cm^3	Saturated volumetric soil moisture content
λ	MJkg^{-1}	Latent heat of evaporation
λ_{soil}	MJd^{-1}m^{-1}K^{-1}	Soil thermal conductivity
ρ	kgm^{-3}	Atmospheric density
σ	MJm^{-2}K^{-4}d^{-1}	Stefan-Boltzmann constant(=4.90*10^{-9})
τ	[-]	ratio of light penetrating the canopy
ϕ	[-]	Auxiliary variable to calculate the zenith angle
ω	d^{-1}	Angular frequency
a	m	Fitting constant of the Campbell (1974) equation
A_0	^{0}C	Amplitude of soil surface temperature
A_w	%	Remaining available moisture
b	[-]	Fitting constant of the Campbell (1974) equation
c_m	gm^{-2}d^{-1}	Maximum growth rate in the linear phase of the expolinear growth curve
c_p	MJkg^{-1} ^{0}C^{-1}	Specific heat capacity of moist air (=1.013 *10^{-3})
C	MJm^{-3}K^{-1}	Volumetric heat capacity
day_{nr}	[-]	Day number of the growing season
δe	kPa	Vapour pressure deficit
e_a	kPa	Actual vapour pressure
e_d	kPa	Vapour pressure at dew point
e_s	kPa	Saturated vapour pressure
E	mmd^{-1}	Soil evaporation
E_{cum}	mm	Cumulative soil evaporation
E_{pan}	mmd^{-1}	Pan evaporation
ET	mmd^{-1}	Evapotranspiration
ET_{bottom}	mmd^{-1}	Evapotranspiration of the bottom layer of the vegetation
ET_{crop}	mmd^{-1}	Evapotranspiration of a crop
ET_{Penman}	mmd^{-1}	Evapotranspiration according to Penman (1948)
ET_{pot}	mmd^{-1}	Potential evapotranspiration

$ET_{pot,dry}$	mmd^{-1}	Potential evapotranspiration under dry soil circumstances
$ET_{pot,ref}$	mmd^{-1}	Potential evapotranspiration of a reference crop, short cut grass
$ET_{pot,wet}$	mmd^{-1}	Potential evapotranspiration under wet soil circumstances
$ET_{PriestleyTaylor}$	mmd^{-1}	Evapotranspiration according to Priestley and Taylor (1972)
$ET_{reduced}$	mmd^{-1}	Reduced evaporation due to nutrient stress
ET_T	mmd^{-1}	Evapotranspiration of the top layer of the vegetation
f	$MJd^{-1}m^{-2}kPa^{-1}$	Correction factor
f_1	[-]	Crop factor in the pan evaporation
f_c	[-]	Correction factor for cloudiness
f_m	[-]	Reduction factor in the formation of LAI due to nutrient stress in the expolinear growth curve
F	cm	Cumulative infiltration
G	$MJm^{-2}d^{-1}$	Soil heat flux
h	m	Hydraulic pressure head
$height_{bottom}$	m	Height of bottom layer of vegetation
$height_T$	m	Height of top layer of the vegetation
ICRAF		International centre for research in agroforestry
k	[-]	Von Karmann constant (≈ 0.4)
k_1	[-]	Extinction coefficient
k_d	d^{-1}	Decomposition constant
K	md^{-1}	Hydraulic conductivity of the soil
K_a	[-]	Reduction in the crop factor in the Penman evaporatranspiration
K_c	[-]	Crop factor in the Penman evapotranspiration
K_s	md^{-1}	Saturated hydraulic conductivity
LAI	[-]	Leaf area index
LAI_{max}	[-]	maximum leaf area index
LSD		Least significant difference
LUS		Land use system
n	[-]	Amount of sunshine hours
n.d.		not determined
N	[-]	Total amount of daylight hours
NH_{4+}	$kgha^{-1}$	Ammonia concentration
NO_3^-	$kgha^{-1}$	Nitrate concentration
P	kPa	Atmospheric pressure
$(\delta P_v)_{bottom}$	[-]	Vapour pressure losses in the bottom of the canopy
$(\delta P_v)_T$	[-]	Vapour pressure losses in the top of the canopy
q	g H_2O/kg air	Specific humidity
r_a	dm^{-1}	Aerodynamic resistance
r_c	dm^{-1}	Crop canopy resistance
r_m	d^{-1}	Maximum relative growth rate in the exponential phase of the expolinear growth curve
r_{soil}	dm^{-1}	Soil resistance
r_{stom}	dm^{-1}	Stomatal resistance

rgr	d^{-1}	Relative growth rate
R_g	$MJm^{-2}d^{-1}$	Global radiation
R_n	$MJm^{-2}d^{-1}$	Net radiation at surface
R_{nl}	$MJm^{-2}d^{-1}$	Net longwave radiation
RH_{max}	[-]	Maximum relative humidity
RH_{min}	[-]	Minimum relative humidity
SD		Standard deviation
SED		Standard error of difference
t	d	time
t_e	d	time at the end of period considered
t_0	d	time at the beginning of period
T	^0C	Air temperature
T_0	^0C	Temperature at the soil surface
$T_{0.05}$	^0C	Soil temperature at 0.05 m depth
T_{kv}	K	Virtual air temperature
T_p	^0C	Equilibrium air temperature
T_{plant}	mmd^{-1}	Transpiration
T_w	^0C	Temperature of the wet bulb
T_z	^0C	Air temperature at height z
u^*	md^{-1}	Friction velocity of wind speed
u_z	md^{-1}	Wind speed at height z
WFPS	%	Water filled pore space
z	m	Height of measurement. z=2 m in this study
z_0	m	Roughness length of the canopy
z_{canopy}	m	Height of the canopy

Appendix V: Data on the water balance

Appendix V.1: Rainfall data

Table V.1.1: Rainfall (in mm) for September 1994. Raingauges 3, 14 and 20 were installed on the terraces of the experiment. Raingauge 24 was installed next to the automatic logger. The average value presented is the average rainfall from raingauges 3, 14 and 20

	Raingauge					
date	No.24	No.3	No.14	No.20	logger	average
1	0.0	0.0	0.0	0.0	0.0	0.0
2	4.7	4.8	4.8	4.8	5.2	4.8
3	14.1	14.1	14.0	13.2	14.0	13.8
4	1.3	1.3	1.2	1.4	1.4	1.3
5	0.5	0.3	0.3	0.3	0.0	0.3
6	1.2	1.1	1.1	1.2	1.2	1.1
7	1.3	1.2	1.2	1.1	0.8	1.2
8	6.4	6.0	5.6	5.8	6.4	5.8
9	40.5	41.3	40.5	40.9	38.6	40.9
10	0.8	0.6	0.6	0.6	0.6	0.6
11	7.4	6.9	7.0	7.0	6.2	7.0
12	0.0	0.0	0.0	0.0	0.0	0.0
13	0.3	0.5	0.5	0.4	0.0	0.5
14	0.0	0.0	0.0	0.0	0.0	0.0
15	0.8	0.7	0.8	0.8	0.4	0.8
16	0.0	0.0	0.0	0.0	0.0	0.0
17	18.8	18.4	18.6	18.4	14.2	18.5
18	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.2	0.0
20	1.2	1.0	1.0	1.1	1.2	1.0
21	0.0	0.0	0.0	0.0	0.0	0.0
22	1.0	1.1	1.4	1.4	1.0	1.3
23	0.0	0.0	0.0	0.0	0.0	0.0
24	15.6	14.6	15.1	14.6	0.0	14.8
25	0.0	0.0	0.0	0.0	0.0	0.0
26	0.2	0.2	0.3	0.2	0.0	0.2
27	0.0	0.0	0.0	0.0	0.0	0.0
28	0.2	0.2	0.1	0.2	0.0	0.2
29	0.0	0.0	0.0	0.0	0.0	0.0
30	1.0	0.8	1.0	1.0	0.6	0.9
Total	117.3	115.1	115.1	114.4	92.0	114.9

Table V.1.2: Rainfall (in mm) for October 1994. Raingauges 3, 14 and 20 were installed on the terraces of the experiment. Raingauge 24 was installed next to the automatic logger. The average value presented is the average rainfall from raingauges 3, 14 and 20

	Raingauge					
Date	No.24	No.3	No.14	No.20	logger	average
1	0.0	0.0	0.0	0.0	0.0	0.0
2	3.0	3.3	3.3	3.3	0.0	3.3
3	17.4	16.4	17.8	17.6	15.6	17.3
4	0.0	0.0	0.0	0.0	0.0	0.0
5	1.9	1.5	1.7	1.5	0.0	1.6
6	0.0	0.0	0.0	0.0	0.0	0.0
7	29.8	30.5	33.6	33.5	31.2	32.5
8	0.0	0.0	0.0	0.0	0.0	0.0
9	0.4	0.5	0.4	0.4	0.0	0.4
10	0	0	0	0	0.0	0.0
11	24.9	26.5	26.9	26.7	28.4	26.7
12	0.0	0.0	0.0	0.0	0.0	0.0
13	8.8	8.4	8.3	8.5	7.4	8.4
14	0.7	0.7	0.7	0.7	13.6	0.7
15	0.9	0.9	0.9	0.9	0.0	0.9
16	0.4	0.3	0.4	0.3	0.0	0.3
17	0.0	0.0	0.0	0.0	0.0	0.0
18	1.2	1.2	1.1	1.2	0.0	1.2
19	0.0	0.0	0.0	0.0	0.0	0.0
20	0.6	0.6	0.5	0.6	0.0	0.6
21	9.4	9.3	9.6	9.5	0.0	9.5
22	0.3	0.2	0.2	0.3	0.0	0.2
23	0.2	0.2	0.0	0.1	0.0	0.1
24	13.0	13.6	14.1	14.1	0.0	13.9
25	0.0	0.0	0.0	0.0	0.0	0.0
26	4.0	3.6	3.4	3.4	0.0	3.5
27	0.0	0.0	0.0	0.0	0.0	0.0
28	3.0	3.0	2.7	2.9	4.2	2.9
29	8.3	8.8	9.0	8.7	1.2	8.8
30	0.0	0.0	0.0	0.0	0.0	0.0
31	0	0	0	0	0.0	0.0
Total	128.2	129.5	134.6	134.2	101.6	132.8

Table V.1.3: Rainfall (in mm) for November 1994. Raingauges 3, 14 and 20 were installed on the terraces of the experiment. Raingauge 24 was installed next to the automatic logger. The average value presented is the average rainfall from raingauges 3, 14 and 20

	Raingauge					
Date	No.24	No.3	No.14	No.20	logger	average
1	2.8	2.7	2.5	2.6	1.2	2.6
2	1.6	1.5	1.5	1.5	0.0	1.5
3	7.8	7.5	7.9	7.7	4.8	7.7
4	6.3	7.0	6.7	7.1	4.8	6.9
5	8.0	6.7	6.3	6.4	6.0	6.5
6	14.0	13.9	14.1	14.1	12.0	14.0
7	2.4	2.3	2.2	2.3	0.0	2.3
8	13.6	12.6	12.1	12.1	10.8	12.3
9	7.2	7.5	7.3	7.2	4.8	7.3
10	29.3	30.6	28.9	28.2	25.2	29.2
11	1.8	2.0	1.8	1.8	1.2	1.9
12	11.5	11.1	12.0	11.3	9.6	11.5
13	41.5	27.6	39.3	38.8	33.6	35.2
14	41.8	41.6	40.8	40.5	34.8	41.0
15	28.0	28.4	28.2	28.4	0.0	28.3
16	2.2	2.1	2.0	2.1	6.8	2.1
17	24.4	25.0	23.8	25.7	23.2	24.8
18	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0
20	2.5	2.4	2.3	2.4	2.6	2.4
21	1.0	0.9	0.8	0.9	1.2	0.9
22	19.9	18.7	18.5	17.8	20.4	18.3
23	2.8	3.5	3.4	3.5	3.2	3.5
24	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0
26	1.8	2.1	2.2	2.4	2.2	2.2
27	3.2	4.0	4.1	4.1	3.6	4.1
28	11.9	12.4	12.3	12.1	12.2	12.3
29	17.7	17.9	17.9	17.7	17.2	17.8
30	3.3	3.4	3.3	3.3	6.4	3.3
Total	308.3	295.4	302.2	302.0	247.8	299.9

Table V.1.4: Rainfall (in mm) for December 1994. Raingauges 3, 14 and 20 were installed on the terraces of the experiment. Raingauge 24 was installed next to the automatic logger. The average value presented is the average rainfall from raingauges 3, 14 and 20

Date	Raingauge No.24	No.3	No.14	No.20	logger	average
1	2.1	2.0	2.0	2.1	2.2	2.0
2	6.2	6.1	6.1	6.0	6.8	6.1
3	4.3	4.5	4.4	4.3	5.2	4.4
4	18.2	18.6	18.4	18.1	19.0	18.4
5	4.8	4.8	4.9	4.9	5.2	4.9
6	9.3	9.9	10.1	10.0	9.8	10.0
7	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0
14	3.4	3.1	3.2	3.2	3.4	3.2
15	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0
25	6.0	6.0	6.0	5.9	5.6	6.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	1.7	1.7	1.6	1.6	2.0	1.6
28	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0
31	0	0	0	0	0.0	0.0
Total	56.0	56.7	56.7	56.1	59.2	56.5

Table V.1.5: Rainfall (in mm) for January 1995. Raingauges 3, 14 and 20 were installed on the terraces of the experiment. Raingauge 24 was installed next to the automatic logger. The average value presented in the average rainfall from raingauges 3, 14 and 20. Note: The last day of the experiment was on the 16th of this month.

	Raingauge					
Date	No.24	No.3	No.14	No.20	logger	average
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0
6	1.0	1.2	1.1	1.1	1.2	1.1
7	1.9	1.8	1.1	1.8	1.8	1.6
8	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.6	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0
11	0.7	0.4	0.3	0.4	0.6	0.4
12	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0
14	0.4	0.9	0.9	0.9	0.8	0.9
15	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0
Total	4.0	4.3	3.4	4.2	5.0	4.0

Appendix V.2: Soil moisture data

Table V.2.1: Soil moisture, expressed in percentage water filled pore space (WFPS), during the total experiment

	date:	16/09 1993	04/10 1993	19/10 1993	22/11 1993	16/12 1993	10/01 1994	08/03 1994	11/04 1994	28/04 1994	17/05 1994	14/06 1994	26/07 1994	12/08 1994	09/09 1994	11/10 1994	31/10 1994	22/11 1994	13/12 1994	13/ 199
land use system	depth (cm)	........water filled pore space WFPS (%)																		
maize	0-15	54.7	43.9	53.6	37.6	51.3	36.8	47.0	49.2	53.1	58.6	52.8	46.8	48.6	50.3	55.7	42.0	54.1	44.5	33
	15-30	66.1	58.7	64.9	48.0	55.4	46.6	54.6	57.4	67.5	68.5	63.6	60.2	64.5	67.6	60.1	54.8	65.8	62.3	50
	30-50	69.9	70.2	72.1	61.9	61.5	54.1	56.5	59.1	71.6	72.7	66.1	63.0	67.9	70.7	66.2	62.8	71.1	69.5	61
	50-100	78.3	71.1	81.2	75.8	72.3	67.7	66.3	68.3	82.7	81.6	76.7	72.3	75.5	82.5	78.0	73.5	82.7	80.9	75
	100-150	72.2	73.7	74.7	74.0	70.2	68.8	67.1	66.6	78.1	78.9	74.4	68.9	71.3	74.8	73.4	73.6	76.9	75.1	71
	150-200	70.4	70.7	73.8	72.1	71.1	68.6	67.0	66.5	70.3	73.5	73.8	70.4	71.8	75.4	72.6	72.1	73.0	73.5	71
weed	0-15	53.8	45.9	50.2	39.5	50.4	33.3	46.1	45.0	54.0	58.5	55.5	50.3	52.2	52.7	60.8	51.4	58.8	48.1	33
	15-30	66.6	59.6	63.0	51.2	58.9	44.5	53.5	48.3	69.5	70.0	69.8	67.0	62.4	64.2	68.8	59.6	69.3	65.8	44.
	30-50	71.7	70.5	71.5	63.7	62.8	51.0	53.8	53.4	75.6	76.8	75.3	71.3	69.3	69.2	72.3	64.9	75.7	73.0	55.
	50-100	79.3	80.8	81.7	78.0	71.9	66.3	63.0	62.2	84.2	88.2	84.0	78.4	81.7	79.1	75.3	75.2	87.0	82.8	69
	100-150	74.4	72.6	75.7	74.4	71.5	65.5	59.3	60.8	73.2	79.6	78.2	75.9	75.7	74.2	75.9	71.9	80.6	78.5	72.
	150-200	71.4	70.3	70.9	72.3	70.8	67.8	59.9	59.9	63.8	70.8	74.7	72.6	73.9	74.5	72.7	69.0	77.7	75.6	68.
bare	0-15	52.3	48.2	53.0	49.0	53.7	42.8	45.9	51.7	51.2	57.0	50.8	48.0	50.0	50.3	49.4	43.3	54.4	45.1	34.
	15-30	67.0	61.8	65.9	63.1	66.5	54.4	61.8	62.5	69.5	71.9	69.8	65.2	65.7	67.3	61.3	58.3	68.2	60.0	50.
	30-50	71.6	70.2	72.3	71.8	71.1	61.6	64.5	66.5	74.8	75.5	73.6	69.3	71.6	70.7	66.8	65.1	72.4	70.2	63.
	50-100	78.5	77.5	82.0	80.0	77.7	77.4	72.1	76.6	85.4	84.4	82.1	78.9	79.3	80.5	74.3	74.1	78.5	78.2	74.
	100-150	72.1	73.6	74.2	77.7	74.1	73.5	70.6	72.0	76.3	77.8	76.9	74.1	73.7	74.7	73.3	71.7	74.8	75.8	73.
	150-200	70.2	69.9	73.0	74.4	71.2	71.0	68.9	67.5	70.9	71.6	75.1	71.6	73.0	70.7	70.7	70.3	72.5	71.4	73.
sesbania	0-15	51.1	42.9	49.4	37.5	50.1	37.5	40.0	45.1	53.3	54.7	50.8	43.9	47.0	42.4	56.5	44.6	55.8	44.6	33.
	15-30	64.0	57.7	61.5	50.4	58.0	47.7	51.9	50.6	65.4	65.2	62.0	58.9	60.7	58.6	65.4	54.9	67.8	62.6	47.
	30-50	69.6	67.0	66.1	58.2	66.4	56.2	56.3	56.0	67.0	71.2	66.7	65.3	67.0	64.6	68.7	61.5	73.7	70.6	54.
	50-100	77.2	76.9	76.9	70.7	69.2	63.9	65.2	63.3	69.8	77.4	75.7	75.0	75.5	74.5	73.7	70.7	84.0	82.0	69.
	100-150	72.3	71.9	73.1	70.2	67.6	59.3	61.9	59.4	62.2	71.1	71.0	68.2	70.2	71.7	68.6	67.2	78.5	76.3	66.
	150-200	71.4	69.7	71.5	69.0	61.8	59.3	60.0	57.5	60.2	66.5	65.8	65.3	67.7	67.2	65.0	64.9	76.2	74.1	65.

Table V.2.2: Soil moisture data, expressed in volumetric moisture content [cm^3cm^{-3}], short rains 1994

			date:	90994	111094	31194	221194	131294	130195
ot .	land use system	depth (cm)	position (sesbania only)	theta (%)					
	sesbania	0-15	18,75 cm	25.7	35.2	32.7	35.9	27.5	21.8
		15-30	from	33.4	37.6	31.5	40.1	34.6	25.4
		30-50	plant row	37.4	41.3	34.9	42.6	39.1	29.5
		50-100		41.7	42.9	38.0	44.9	42.7	35.9
		100-150		40.2	42.2	34.4	43.2	40.6	34.6
		150-200		36.8	36.1	38.0	40.4	39.6	35.5
	sesbania	0-15	56,25 cm	26.4	33.8	26.8	35.5	27.0	20.2
		15-30	from	33.1	38.1	34.6	39.5	33.5	26.4
		30-50	plant row	36.9	40.5	35.6	40.9	38.3	30.8
		50-100		41.3	42.7	39.9	43.5	41.9	37.9
		100-150		38.8	37.5	36.7	41.9	38.1	34.7
		150-200		37.0	36.0	34.8	39.3	37.4	35.0
	sesbania	0-15	93,75 cm	25.3	34.6	28.4	34.2	27.3	21.4
		15-30	from	34.1	35.3	31.6	36.8	34.7	27.2
		30-50	plant row	37.4	38.2	36.3	40.8	39.4	30.9
		50-100		41.7	40.1	38.2	44.0	43.3	36.7
		100-150		39.6	35.8	34.8	40.8	40.9	35.6
		150-200		37.8	35.8	37.3	40.9	36.3	35.7
	sesbania	0-15	18,75 cm	24.7	33.4	24.7	36.5	25.1	19.5
		15-30	from	31.3	35.2	30.1	37.4	35.3	25.3
		30-50	plant row	34.1	39.4	32.2	40.8	35.7	29.1
		50-100		39.0	40.6	38.2	42.0	39.9	33.8
		100-150		37.0	36.4	34.0	39.3	41.2	34.0
		150-200		35.2	32.5	34.3	37.0	39.2	33.5
	sesbania	0-15	56,25 cm	26.5	34.7	26.0	34.2	25.3	18.8
		15-30	from	31.0	35.5	26.6	36.0	32.8	25.1
		30-50	plant row	33.5	36.6	31.8	37.2	36.2	29.2
		50-100		39.0	36.6	34.9	40.9	39.4	34.7
		100-150		37.1	34.3	36.2	38.7	39.3	35.0
		150-200		37.8	32.8	32.1	36.3	36.6	31.8
	sesbania	0-15	93,75 cm	23.7	33.0	22.7	32.9	24.6	18.5
		15-30	from	31.5	33.8	28.9	35.9	35.5	24.5
		30-50	plant row	32.7	35.2	32.0	38.3	36.8	29.2
		50-100		34.5	34.8	33.8	42.1	39.9	34.2
		100-150		35.4	34.5	33.8	40.0	38.2	36.0
		150-200		32.9	33.9	33.1	39.3	39.4	33.9
	sesbania	0-15	18,75 cm	22.5	31.2	23.4	27.3	26.3	19.1
		15-30	from	30.7	35.1	26.6	36.3	33.0	23.0
		30-50	plant row	33.6	36.7	29.3	35.9	37.1	27.3
		50-100		37.4	33.1	32.7	40.8	41.3	35.2
		100-150		34.7	33.1	33.0	41.8	39.6	34.7
		150-200		33.7	32.2	31.8	42.7	36.6	35.3
	sesbania	0-15	56,25 cm	22.6	30.2	22.5	28.1	25.3	17.0
		15-30	from	28.4	33.6	27.3	34.5	33.2	23.4
		30-50	plant row	32.4	29.9	28.8	36.3	37.6	27.7
		50-100		35.1	32.9	32.8	40.7	40.7	35.7
		100-150		36.3	35.2	34.5	41.9	39.8	36.0
		150-200		30.4	30.6	32.8	38.1	39.1	34.0
	sesbania	0-15	93,75 cm	23.0	30.1	23.0	36.4	24.8	18.0
		15-30	from	29.0	31.3	28.4	35.4	33.3	22.3
		30-50	plant row	31.4	30.4	30.6	40.8	37.1	27.2
		50-100		34.2	33.9	34.0	41.6	40.5	33.4
		100-150		34.9	31.2	35.9	38.7	38.8	35.4
		150-200		31.1	31.1	30.3	36.0	38.2	34.9

Table V.2.2 - continued -

sesbania	0-15	18,75 cm	26.5	33.8	29.2	28.3	25.9	28.3
	15-30	from	35.0	37.6	30.7	35.3	32.3	33.9
	30-50	plant row	33.5	39.0	34.2	37.7	36.5	30.9
	50-100		34.4	39.1	35.3	42.3	39.1	28.5
	100-150		35.8	39.3	35.7	41.3	39.0	24.2
	150-200		34.4	33.1	32.2	40.1	37.8	21.2
sesbania	0-15	56,25 cm	25.0	33.9	26.5	29.0	27.6	16.9
	15-30	from	31.0	36.2	29.3	36.7	33.3	22.6
	30-50	plant row	34.0	36.5	31.8	37.6	37.3	27.5
	50-100		34.5	34.3	34.5	41.6	42.6	33.7
	100-150		37.5	34.3	35.6	40.5	38.2	34.6
	150-200		33.1	33.8	31.7	39.8	38.2	34.7
sesbania	0-15	93,75 cm	25.3	32.4	26.9	33.3	26.6	17.0
	15-30	from	31.3	33.9	29.9	35.0	34.0	25.1
	30-50	plant row	33.0	31.6	32.5	38.6	36.5	28.2
	50-100		36.1	32.7	33.3	41.7	42.2	36.9
	100-150		37.5	31.5	32.5	38.8	40.0	34.8
	150-200		33.7	32.6	31.4	39.2	37.9	34.9
maize	0-15		30.3	32.9	25.0	34.8	26.9	18.6
	15-30		36.6	34.1	30.5	35.5	34.1	26.8
	30-50		38.0	37.5	34.2	39.4	38.0	33.0
	50-100		41.2	40.7	38.0	43.5	40.6	39.0
	100-150		37.9	39.8	37.8	39.4	39.1	38.5
	150-200		39.9	38.1	37.5	37.5	38.8	37.7
maize	0-15		29.3	32.7	24.4	33.3	26.0	20.7
	15-30		37.4	32.8	30.6	36.0	33.1	27.1
	30-50		38.1	34.0	33.1	37.7	35.6	32.6
	50-100		41.7	40.1	37.5	40.3	40.0	38.3
	100-150		36.7	38.4	37.8	40.7	37.9	36.5
	150-200		38.9	38.9	36.8	37.8	38.5	38.2
maize	0-15		28.5	31.8	23.0	29.1	24.1	20.7
	15-30		35.5	30.8	27.9	35.8	33.8	27.2
	30-50		36.2	33.9	31.1	36.5	35.7	33.1
	50-100		41.0	36.7	36.1	41.2	40.4	38.9
	100-150		39.8	36.3	38.1	39.3	37.8	35.0
	150-200		39.0	36.6	36.2	36.2	36.9	36.6
maize	0-15		29.5	32.9	25.9	29.2	27.1	18.5
	15-30		36.4	32.0	29.5	34.7	33.6	26.9
	30-50		37.1	34.5	34.5	36.5	37.6	30.3
	50-100		41.8	39.1	35.9	41.0	41.5	36.2
	100-150		40.3	37.3	38.6	39.7	40.4	37.1
	150-200		37.1	35.5	37.5	38.4	36.7	34.5

Table V.2.2 - continued -

13	weed	0-15	30.8	36.8	33.8	38.2	28.4	20.3
		15-30	33.6	38.1	33.6	36.9	36.1	26.1
		30-50	39.0	40.1	37.2	41.8	40.8	32.3
		50-100	39.4	36.2	37.1	44.2	42.9	33.5
		100-150	37.5	41.2	39.0	42.4	41.7	37.9
		150-200	41.5	41.0	35.6	40.1	37.4	35.6
22	weed	0-15	30.6	35.7	29.6	35.1	27.8	20.1
		15-30	34.2	37.9	32.5	38.6	35.8	23.4
		30-50	35.0	37.5	33.1	40.5	37.0	28.4
		50-100	38.8	40.8	39.2	44.4	42.0	37.7
		100-150	38.8	38.3	37.0	41.7	39.6	37.4
		150-200	36.9	34.6	36.3	38.8	38.5	33.0
32	weed	0-15	30.7	35.0	28.1	31.8	27.6	18.3
		15-30	34.9	37.9	31.4	37.1	35.4	23.2
		30-50	35.5	36.2	32.1	38.1	37.6	28.1
		50-100	39.8	35.4	34.7	42.4	38.3	33.5
		100-150	38.4	36.2	35.5	41.6	40.1	37.0
		150-200	38.6	35.3	34.9	40.1	39.3	36.3
43	weed	0-15	31.2	34.6	28.8	32.4	28.7	19.1
		15-30	35.9	34.6	31.3	37.0	34.7	23.0
		30-50	36.7	39.1	34.9	39.5	39.0	28.1
		50-100	40.9	38.8	40.0	43.7	43.1	34.3
		100-150	38.6	41.4	37.2	41.1	41.0	36.4
		150-200	35.8	38.2	34.9	40.5	39.9	36.5
14	bare	0-15	30.6	31.2	25.7	33.4	26.4	21.5
		15-30	37.5	35.6	33.6	38.3	33.6	28.8
		30-50	38.2	37.4	35.8	38.8	37.5	36.7
		50-100	41.0	36.7	38.3	41.1	39.4	37.1
		100-150	39.7	40.7	36.8	38.9	39.9	39.2
		150-200	36.2	36.3	36.7	39.7	36.8	36.4
23	bare	0-15	27.4	28.5	25.0	30.8	25.8	19.3
		15-30	37.8	32.3	30.8	37.1	32.6	25.5
		30-50	36.9	34.8	34.1	38.5	35.9	32.5
		50-100	42.3	38.4	37.7	39.7	40.1	37.2
		100-150	37.3	36.5	35.9	39.1	37.7	39.1
		150-200	35.1	35.8	35.2	36.4	35.5	35.5
33	bare	0-15	31.4	28.2	25.1	27.2	25.7	20.4
		15-30	34.8	32.1	29.8	33.5	30.5	28.4
		30-50	37.2	33.5	32.9	37.1	36.1	32.5
		50-100	38.2	36.5	35.6	38.1	38.7	37.8
		100-150	38.4	36.1	37.8	37.6	39.6	37.3
		150-200	36.3	35.5	35.9	35.2	37.3	40.4
44	bare	0-15	28.2	27.6	25.5	35.9	27.6	18.8
		15-30	35.3	32.3	31.6	38.3	32.7	27.0
		30-50	37.1	35.5	34.6	38.7	38.7	33.0
		50-100	40.2	37.5	37.1	38.8	38.7	37.0
		100-150	39.1	38.2	37.9	39.1	39.5	35.9
		150-200	37.4	37.4	36.5	37.5	36.9	37.7

Appendix V.3: Throughfall data

Table V.3.1: Thoughfall (in mm and as percentage of rainfall) during September 1994.
Note: S.D. means standard deviation

date	rep. 1 (mm)	(%)	rep. 2 (mm)	(%)	rep. 3 (mm)	(%)	rep. 4 (mm)	(%)	average (mm)	(%)	S.D. (mm)
10994	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
20994	3.45	72	3.31	69	3.37	70	3.48	73	3.40	71	0.07
30994	10.91	79	10.07	73	12.08	88	10.41	76	10.87	79	0.76
40994	0.95	73	0.81	63	0.95	73	1.02	79	0.93	72	0.07
50994	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
60994	0.93	82	0.89	79	0.91	81	0.91	81	0.91	80	0.01
70994	0.79	67	0.66	56	0.81	70	0.88	75	0.78	67	0.08
80994	4.80	83	4.47	77	4.81	83	5.18	89	4.81	83	0.25
90994	32.51	79	31.43	77	33.53	82	33.19	81	32.67	80	0.80
100994	0.49	81	0.44	74	0.47	79	0.53	89	0.49	81	0.03
110994	5.40	78	5.01	72	5.46	78	5.69	82	5.39	77	0.24
120994	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
130994	0.25	53	0.25	54	0.24	52	0.26	56	0.25	54	0.01
140994	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
150994	0.45	59	0.42	55	0.42	55	0.45	58	0.44	57	0.01
160994	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
170994	15.35	83	15.42	84	14.54	79	15.62	85	15.23	82	0.41
180994	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
190994	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
200994	0.72	70	0.66	64	0.69	67	0.77	74	0.71	69	0.04
210994	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
220994	0.74	57	0.66	51	0.76	58	0.82	63	0.74	57	0.06
230994	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
240994	12.04	82	12.55	85	11.69	79	12.59	85	12.22	83	0.38
250994	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
260994	0.22	96	0.20	87	0.23	99	0.21	91	0.22	93	0.01
270994	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
280994	0.26	155	0.21	124	0.25	153	0.28	168	0.25	150	0.03
290994	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
300994	0.58	63	0.45	49	0.67	72	0.53	57	0.56	60	0.08

Table V.3.2: Thoughfall (in mm and as percentage of rainfall) during October 1994.
Note: S.D. means standard deviation

date	rep. 1 (mm)	(%)	rep. 2 (mm)	(%)	rep. 3 (mm)	(%)	rep. 4 (mm)	(%)	average (mm)	(%)	S.D. (mm)
11094	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
21094	2.66	81	2.60	79	2.46	75	2.69	81	2.60	79	0.09
31094	14.26	82	12.31	71	13.07	76	13.04	75	13.17	76	0.70
41094	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
51094	1.18	74	1.22	76	1.24	78	1.22	76	1.22	76	0.02
61094	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
71094	26.94	83	26.03	80	23.51	72	25.92	80	25.60	79	1.27
81094	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
91094	0.28	69	0.25	62	0.23	57	0.26	66	0.25	63	0.02
101094	0	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
111094	21.38	80	21.26	80	20.46	77	21.15	79	21.06	79	0.36
121094	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
131094	6.85	82	6.62	79	6.82	81	6.93	83	6.80	81	0.11
141094	0.26	37	0.31	44	0.34	48	0.33	47	0.31	44	0.03
151094	0.52	58	0.42	47	0.58	65	0.55	61	0.52	58	0.06
161094	0.24	81	0.19	63	0.21	71	0.21	70	0.21	71	0.02
171094	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
181094	0.91	75	0.75	62	0.89	75	0.93	77	0.87	72	0.07
191094	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
201094	0.36	59	0.24	40	0.37	61	0.31	52	0.32	53	0.05
211094	6.34	67	6.54	69	6.79	71	6.68	70	6.59	69	0.17
221094	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
231094	0.28	141	0.21	105	0.32	161	0.39	197	0.30	151	0.07
241094	11.40	82	11.43	82	11.12	80	11.52	83	11.37	82	0.15
251094	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
261094	2.80	80	2.89	82	3.14	90	2.72	78	2.89	82	0.16
271094	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
281094	2.35	81	2.38	82	2.55	88	2.41	83	2.42	83	0.08
291094	7.44	85	7.24	82	7.61	86	8.21	93	7.63	87	0.36
301094	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
311094	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Table V.3.3: Thoughfall (in mm and as percentage of rainfall) during November 1994.
Note: S.D. means standard deviation

	rep. 1		rep. 2		rep. 3		rep. 4		average		S.D.
date	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)
11194	1.73	66	1.75	67	1.95	75	1.98	76	1.85	71	0.11
21194	0.83	55	0.65	43	1.02	68	0.95	63	0.86	57	0.14
31194	6.05	79	5.23	68	6.11	79	6.20	80	5.90	77	0.39
41194	5.60	81	6.03	87	5.63	81	5.80	84	5.76	83	0.17
51194	4.61	71	3.79	59	5.01	77	5.06	78	4.62	71	0.51
61194	11.71	83	11.64	83	11.86	84	11.77	84	11.75	84	0.08
71194	1.81	80	1.64	72	1.95	86	1.90	84	1.82	81	0.12
81194	9.76	80	8.91	73	10.27	84	9.99	81	9.73	79	0.51
91194	5.74	78	5.23	71	6.22	85	5.86	80	5.76	79	0.35
101194	22.97	79	23.00	79	25.61	88	23.85	82	23.86	82	1.07
111194	1.38	74	1.37	73	1.61	86	1.34	72	1.42	76	0.11
121194	9.62	84	10.00	87	9.87	86	9.17	80	9.67	84	0.32
131194	29.31	83	30.25	86	31.38	89	31.97	91	30.73	87	1.03
141194	33.70	82	31.86	78	32.62	80	34.26	84	33.11	81	0.93
151194	19.95	70	23.74	84	21.90	77	22.32	79	21.98	78	1.36
161194	1.38	67	1.35	65	1.49	72	1.65	80	1.47	71	0.12
171194	22.14	89	19.98	80	20.77	84	19.72	79	20.65	83	0.94
181194	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
191194	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
201194	1.75	74	1.60	68	1.67	71	1.73	73	1.69	71	0.06
211194	0.53	61	0.38	43	0.55	63	0.53	62	0.50	57	0.07
221194	11.80	64	12.51	68	14.03	77	15.38	84	13.43	73	1.39
231194	2.72	78	2.49	72	2.55	73	2.72	78	2.62	75	0.10
241194	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
251194	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
261194	1.81	81	1.61	72	1.43	64	1.78	80	1.66	74	0.15
271194	3.25	80	3.23	79	2.49	61	3.42	84	3.10	76	0.36
281194	9.99	81	9.48	77	10.33	84	10.10	82	9.97	81	0.31
291194	12.39	69	11.29	63	11.32	63	12.14	68	11.78	66	0.49
301194	2.46	74	2.49	75	2.55	76	2.72	81	2.55	77	0.10

Table V.3.4: Thoughfall (in mm and as percentage of rainfall) during December 1994.
Note: S.D. means standard deviation

	rep. 1		rep. 2		rep. 3		rep. 4		average		S.D.
date	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)
11294	1.73	85	1.64	81	1.73	85	1.87	92	1.74	86	0.08
21294	4.81	79	4.27	70	4.84	80	4.73	78	4.66	77	0.23
31294	3.00	68	2.91	66	2.14	49	3.28	75	2.84	64	0.42
41294	14.63	80	14.18	77	15.08	82	15.16	83	14.76	80	0.39
51294	4.19	86	3.99	82	3.76	77	3.99	82	3.98	82	0.15
61294	7.95	80	8.18	82	7.75	78	7.13	71	7.75	78	0.39
71294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
81294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
91294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
101294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
111294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
121294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
131294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
141294	3.40	107	3.08	97	2.60	82	2.57	81	2.91	92	0.34
151294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
161294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
171294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
181294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
191294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
201294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
211294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
221294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
231294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
241294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
251294	4.67	78	4.61	77	5.12	86	4.53	76	4.73	79	0.23
261294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
271294	1.24	76	1.23	75	1.32	81	1.25	77	1.26	77	0.03
281294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
291294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
301294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
311294	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Table V.3.5: Thoughfall (in mm and as percentage of rainfall) during January 1995.
Note: 1) S.D. means standard deviation
2) The season stopped at the 16th of this month

	rep. 1		rep. 2		rep. 3		rep. 4		average		S.D.
date	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)
10195	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
20195	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
30195	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
40195	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
50195	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
60195	0.46	40	0.44	39	0.56	49	0.50	44	0.49	43	0.05
70195	0.70	45	0.54	34	0.74	47	0.66	42	0.66	42	0.08
80195	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
90195	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
100195	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
110195	0.22	60	0.11	30	0.14	37	0.18	48	0.16	44	0.04
120195	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
130195	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
140195	0.72	80	0.48	53	0.48	53	0.47	52	0.54	59	0.10
150195	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
160195	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00

Appendix V.4: Infiltration data

Table V.4.1: Infiltration measurements in the bare fallow. Measurements wer taken in February 1995. Before measurements were taken prewettin took place for 3 hrs. at a surface of 2x1 m^2

		rep 1				rep. 2				rep 3				rep 4			
	cum		cum.	cum.			cum.	cum.			cum.	cum.			cum.	cum.	
time	time	intake	intake	intake	inf.rate	intake	intake	intake	inf.rate	intake	intake	intake	inf.rate	intake	intake	intake	inf.rate
(min)	(min)	(ml)	(ml)	(cm)	(cm/hr)	(ml)	(ml)	(cm)	(cm/hr)	(ml)	(ml)	(cm)	(cm/hr)	(ml)	(ml)	(cm)	(cm/hr)
0	0	0	0	0.00		0	0	0.00		0	0	0.00		0	0	0.00	
2	2	900	900	0.36	10.74	300	300	0.21	6.37	1100	1100	0.78	23.34	1500	1500	0.78	23.39
3	5	800	1700	0.68	6.37	400	700	0.50	5.66	600	1700	1.20	8.49	700	2200	1.14	7.28
5	10	1000	2700	1.07	4.77	600	1300	0.92	5.09	1100	2800	1.98	9.34	1000	3200	1.66	6.24
5	15	800	3500	1.39	3.82	300	1600	1.13	2.55	700	3500	2.48	5.94	500	3700	1.92	3.12
5	20	1000	4500	1.79	4.77	900	2500	1.77	7.64	600	4100	2.90	5.09	500	4200	2.18	3.12
10	30	2500	7000	2.79	5.97	1100	3600	2.55	4.67	700	4800	3.40	2.97	900	5100	2.65	2.81
15	45	800	7800	3.10	1.27	1400	5000	3.54	3.96	900	5700	4.03	2.55	700	5800	3.01	1.46
15	60	1700	9500	3.78	2.71	2000	7000	4.95	5.66	1100	6800	4.81	3.11	600	6400	3.33	1.25
30	90	3000	12500	4.97	2.39	3000	10000	7.07	4.24	2700	9500	6.72	3.82	1200	7600	3.95	1.25
30	120	2400	14900	5.93	1.91	2900	12900	9.12	4.10	1600	11100	7.85	2.26	900	8500	4.42	0.94
30	150	1800	16700	6.64	1.43	2500	15400	10.89	3.54	900	12000	8.49	1.27	700	9200	4.78	0.73
30	180	1200	17900	7.12	0.95	1900	17300	12.24	2.69	700	12700	8.98	0.99	900	10100	5.25	0.94

Table V.4.2: Infiltration measurements in the weed fallow. Measurements were taken in February 1995. Before measurements were taken prewetting took place for 3 hrs. at a surface of 2x1 m^2.

		rep. 1				rep. 2			
	cum		cum.	cum.			cum.	cum.	
time	time	intake	intake	intake	inf.rate	intake	intake	intake	inf.rate
(min)	(min)	(ml)	(ml)	(cm)	(cm/hr)	(ml)	(ml)	(cm)	(cm/hr)
0	0	0	0	0.00		0	0	0.00	
2	2	900	900	0.64	19.10	1500	1500	1.06	31.83
3	5	1900	2800	1.98	26.88	900	2400	1.70	12.73
5	10	2600	5400	3.82	22.07	3000	5400	3.82	25.46
5	15	2400	7800	5.52	20.37	1800	7200	5.09	15.28
5	20	2500	10300	7.29	21.22	1700	8900	6.30	14.43
10	30	2000	12300	8.70	8.49	2700	11600	8.21	11.46
15	45	6200	18500	13.09	17.54	3600	15200	10.75	10.19
15	60	5800	24300	17.19	16.41	4000	19200	13.58	11.32
30	90	8100	32400	22.92	11.46	4300	23500	16.62	6.08
30	120	2500	34900	24.69	3.54	3300	26800	18.96	4.67
30	150	5900	40800	28.86	8.35	1400	28200	19.95	1.98
30	180	4300	45100	31.90	6.08	3600	31800	22.49	5.09

Table V.4.3: Infiltration measurements in maize. Measurements were taken in Februar 1995. Before measurements were taken prewetting took place for 3 hrs. at a surface o 2x1 m^2.

		rep. 1				rep. 2				rep. 3			
	cum		cum.	cum.			cum.	cum.			cum.	cum.	
time	time	intake	intake	intake	inf.rate	intake	intake	intake	inf.rate	intake	intake	intake	inf.rat
(min)	(min)	(ml)	(ml)	(cm)	(cm/hr)	(ml)	(ml)	(cm)	(cm/hr)	(ml)	(ml)	(cm)	(cm/hr
0	0	0	0	0.00		0	0	0.00		0	0	0.00	
2	2	400	400	0.21	6.24	400	400	0.16	4.77	2200	2200	0.88	26.2
3	5	300	700	0.36	3.12	100	500	0.20	0.80	2200	4400	1.75	17.5
5	10	500	1200	0.62	3.12	200	700	0.28	0.95	2900	7300	2.90	13.8
5	15	200	1400	0.73	1.25	100	800	0.32	0.48	2900	10200	4.06	13.8
5	20	600	2000	1.04	3.74	200	1000	0.40	0.95	2000	12200	4.85	9.5
10	30	400	2400	1.25	1.25	400	1400	0.56	0.95	2700	14900	5.93	6.4
15	45	700	3100	1.61	1.46	500	1900	0.76	0.80	3000	17900	7.12	4.7
15	60	500	3600	1.87	1.04	800	2700	1.07	1.27	2800	20700	8.24	4.4
30	90	1200	4800	2.49	1.25	1300	4000	1.59	1.03	3700	24400	9.71	2.9
30	120	1000	5800	3.01	1.04	1200	5200	2.07	0.95	3400	27800	11.06	2.7
30	150	900	6700	3.48	0.94	1300	6500	2.59	1.03	3200	31000	12.33	2.5
30	180	1100	7800	4.05	1.14	1200	7700	3.06	0.95	2400	33400	13.29	1.9

pendix V.5: Runoff data

le V.5.1: Runoff (in mm and as a percentage of rainfall) for September 1994

	sesb. 1		weed 1		sesb. 2		weed 2		weed 3		sesb. 3		sesb. 4		weed 4		rain
ate	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.004	0.1	4.8
994	0.089	0.6	0.023	0.2	0.072	0.5	0.019	0.1	0.067	0.5	0.126	0.9	0.067	0.5	0.07	0.5	13.8
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1.3
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.3
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1.1
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1.2
994	0.007	0.1	0	0.0	0.004	0.1	0.006	0.1	0.007	0.1	0.004	0.1	0.003	0.1	0.01	0.2	5.8
994	0.987	2.4	0.458	1.1	0.879	2.1	0.116	0.3	0.113	0.3	26.83	65.6	3.805	9.3	20.75	50.7	40.9
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.6
994	0.008	0.1	0.006	0.1	0	0.0	0.007	0.1	0.014	0.2	0.086	1.2	0.005	0.1	0.014	0.2	7.0
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.5
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.8
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
994	0.243	1.3	0.07	0.4	0.276	1.5	0.053	0.3	0.117	0.6	5.673	30.7	0.119	0.6	0.087	0.5	18.5
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1.0
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1.3
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
994	0.115	0.8	0.056	0.4	0.137	0.9	0.063	0.4	0.111	0.8	1.451	9.8	0.059	0.4	0.074	0.5	14.8
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.2
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.2
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
994	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.9

Table V.5.2: Runoff (in mm and as a percentage of rainfall) for October 1994

	sesb. 1		weed 1		sesb. 2		weed 2		weed 3		sesb. 3		sesb. 4		weed 4		rain
Date	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)
11094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
21094	0	0.0	0	0.0	0	0.0	0.007	0.2	0.01	0.3	0.017	0.5	0.004	0.1	0.005	0.2	3.3
31094	0.249	1.4	0	0.0	0.512	3.0	0.024	0.1	0.092	0.5	2.49	14.4	0.036	0.2	0.044	0.3	17.3
41094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
51094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1.6
61094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
71094	0.04	0.1	0.125	0.4	0.496	1.5	0.013	0.0	0.159	0.5	12.22	37.6	0.355	1.1	0.139	0.4	32.5
81094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
91094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.4
101094	0.008	0.0	0.164	0.6	0.178	0.7	0.105	0.4	0.114	0.4	9.812	36.7	0.201	0.8	0.111	0.4	26.7
111094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
121094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
131094	0.022	0.3	0.013	0.2	0.017	0.2	0.011	0.1	0.041	0.5	0.078	0.9	0.011	0.1	0.016	0.2	8.4
141094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.7
151094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.9
161094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.3
171094	0	0.0	0	0.0	0.276	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
181094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1.2
191094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
201094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.6
211094	0.017	0.2	0.003	0.0	0.004	0.0	0.019	0.2	0	0.0	0.013	0.1	0.007	0.1	0.015	0.2	9.5
221094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.2
231094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.1
241094	0.073	0.5	0.061	0.4	0.058	0.4	0.045	0.3	0.111	0.8	0.136	1.0	0.046	0.3	0.032	0.2	13.9
251094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
261094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	3.5
271094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
281094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	2.9
291094	0.044	0.5	0.004	0.1	0.067	0.8	0.016	0.2	0.063	0.7	0.523	5.9	0.014	0.2	0.024	0.3	8.8
301094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
311094	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0

le V.5.3: Runoff (in mm and as a percentage of rainfall) for November 1994

	sesb. 1		weed 1		sesb. 2		weed 2		weed 3		sesb. 3		sesb. 4		weed 4		rain
ate	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)
194	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	2.6
194	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1.5
194	0	0.0	0	0.0	0	0.0	0.007	0.1	0.013	0.2	0	0.0	0	0.0	0.008	0.1	7.7
194	0.021	0.3	0.008	0.1	0.019	0.3	0.014	0.2	0.033	0.5	0.051	0.7	0.008	0.1	0.013	0.2	6.9
194	0.009	0.1	0.006	0.1	0.006	0.1	0.009	0.1	0.021	0.3	0.024	0.4	0.003	0.0	0.011	0.2	6.5
194	0.066	0.5	0.037	0.3	0.103	0.7	0.043	0.3	0.091	0.6	1.458	10.4	0.043	0.3	0.041	0.3	14.0
194	0	0.0	0	0.0	0	0.0	0	0.0	- 0	0.0	0	0.0	0	0.0	0	0.0	2.3
194	0.023	0.2	0.027	0.2	0.016	0.1	0.023	0.2	0.037	0.3	0.071	0.6	0.026	0.2	0.024	0.2	12.3
194	0.01	0.1	0.004	0.1	0	0.0	0.005	0.1	0.009	0.1	0.009	0.1	0.01	0.1	0.017	0.2	7.3
194	0.146	0.5	0.081	0.3	0.205	0.7	0.063	0.2	0.144	0.5	7.09	24.3	1.366	4.7	0.155	0.5	29.2
194	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1.9
194	0.028	0.2	0.004	0.0	0.041	0.4	0.008	0.1	0.037	0.3	0.392	3.4	0.024	0.2	0.025	0.2	11.5
194	0.13	0.4	0.121	0.3	0.133	0.4	0.113	0.3	0.193	0.5	6.501	18.5	0.148	0.4	0.22	0.6	35.2
.94	0.101	0.2	0.052	0.1	0.103	0.3	0.066	0.2	0.139	0.3	4.358	10.6	0.135	0.3	0.203	0.5	41.0
.94	0.061	0.2	0.053	0.2	0.047	0.2	0.047	0.2	0.097	0.3	1.032	3.6	0.081	0.3	0.085	0.3	28.3
.94	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	2.1
.94	0.113	0.5	0.031	0.1	0.412	1.7	0.113	0.5	0.259	1.0	9.887	39.8	0.213	0.9	0.836	3.4	24.8
.94	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
.94	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
.94	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	2.4
.94	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.9
.94	0.039	0.2	0.02	0.1	0.06	0.3	0.029	0.2	0.087	0.5	0.447	2.4	0.034	0.2	0.036	0.2	18.3
.94	0.003	0.1	0	0.0	0	0.0	0.002	0.1	0.004	0.1	0	0.0	0	0.0	0.001	0.0	3.5
.94	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
.94	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
.94	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	2.2
.94	0	0.0	0	0.0	0	0.0	0	0.0	0.006	0.1	0	0.0	0.006	0.1	0	0.0	4.1
.94	0.029	0.2	0.019	0.2	0.031	0.3	0.026	0.2	0.064	0.5	0.094	0.8	0.017	0.1	0.019	0.2	12.3
94	0.023	0.1	0.01	0.1	0.016	0.1	0.025	0.1	0.048	0.3	0.023	0.1	0.028	0.2	0.033	0.2	17.8
94	0	0.0	0	0.0	0	0.0	0.028	0.8	0.005	0.1	0	0.0	0.005	0.2	0.003	0.1	3.3

Table V.5.4: Runoff (in mm and as a percentage of rainfall) for December 1994

	sesb. 1		weed 1		sesb. 2		weed 2		weed 3		sesb. 3		sesb. 4		weed 4		rain
Date	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)
11294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	2.0
21294	0.004	0.1	0	0.0	0	0.0	0	0.0	0.011	0.2	0	0.0	0.006	0.1	0.006	0.1	6.1
31294	0	0.0	0	0.0	0	0.0	0.006	0.1	0	0.0	0	0.0	0.004	0.1	0	0.0	4.4
41294	0.049	0.3	0.05	0.3	0.07	0.4	0.032	0.2	0.104	0.6	0.748	4.1	0.039	0.2	0.064	0.3	18.4
51294	0.008	0.2	0	0.0	0.006	0.1	0.002	0.0	0.01	0.2	0.024	0.5	0.002	0.0	0.007	0.1	4.9
61294	0.025	0.3	0.033	0.3	0.037	0.4	0.025	0.2	0.057	0.6	0.349	3.5	0.011	0.1	0.035	0.3	10.0
71294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
81294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
91294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
101294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
111294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
121294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
131294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
141294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	3.2
151294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
161294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
171294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
181294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
191294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
201294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
211294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
221294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
231294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
241294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
251294	0.01	0.2	0	0.0	0.006	0.1	0.005	0.1	0.016	0.3	0.002	0.0	0.002	0.0	0.01	0.2	6.0
261294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
271294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1.6
281294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
291294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
301294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
311294	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0

le V.5.5: Runoff (in mm and as a percentage of rainfall) for January 1995

	sesb. 1		weed 1		sesb. 2		weed 2		weed 3		sesb. 3		sesb. 4		weed 4		rain
ate	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)
195	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
195	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
195	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
195	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
195	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
195	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1.1
195	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1.6
195	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
195	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
195	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
195	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.4
195	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
195	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
195	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.9
195	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0
195	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.0

Appendix V.6: Non-destructive plant characteristics

Table V.6.1: Relationship between LAI [m^2m^{-2}] in the sesbania fallow and the distance from the tree row in meters

	Distance from tree row				
date	0.125	0.325	0.55	0.775	1.00
170994	1.706	1.658	1.374	1.411	1.376
051094	1.470	1.341	1.254	1.175	1.142
191094	1.378	1.261	1.319	1.351	1.274
021194	1.857	1.751	1.816	1.584	1.482
161194	1.689	1.595	1.536	1.533	1.533
071294	1.671	1.495	1.352	1.393	1.504
151294	1.806	1.685	1.829	1.773	1.659
090195	1.945	1.762	1.896	1.579	1.509

Table V.6.2: LAI [m^2m^{-2}] as measured during short rains 1994

	Maize				Weed fallow				Sesbania fallow			
date	rep 1	rep 2	rep 3	rep 4	rep 1	rep 2	rep 3	rep 4	rep 1	rep 2	rep 3	rep 4
250894	0.000	0.000	0.000	0.000	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
020994	0.000	0.000	0.000	0.000	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
170994	0.016	0.009	0.019	0.016	1.234	1.249	1.160	1.292	1.436	1.458	1.258	1.467
051094	0.198	0.208	0.240	0.132	1.422	1.491	1.259	1.206	1.412	1.432	1.153	1.408
191094	0.735	0.404	0.306	0.218	1.713	1.563	1.180	1.173	1.428	1.277	1.172	1.490
021194	0.882	0.749	0.772	0.866	1.870	1.684	1.935	1.900	1.632	1.548	1.392	1.620
161194	0.943	0.808	0.921	0.919	1.799	1.755	1.675	1.728	1.567	1.583	1.305	1.749
071294	0.907	0.831	0.819	0.809	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
151294	0.958	0.919	0.980	0.722	2.310	2.142	1.764	1.883	1.874	1.455	1.275	1.626
201294	0.472	0.647	0.788	0.472	2.021	2.033	2.099	1.882	2.028	1.912	1.329	1.702
090195	0.387	0.351	0.400	0.274	1.923	1.970	1.878	1.896	1.876	1.886	1.263	1.728
					New weed growth							
					rep 1	rep 2	rep 3	rep 4				
201294					1.098	1.073	0.569	1.171				
090195					0.889	0.910	0.988	1.054				

Table V.6.3: Summary of some non-destructive plant characteristics in the sesbania fallow during the experiment. Data for the short rains 1993 were collected by Hartemink and Braun measured the characteristics during the long rains 1994.
Note: S.D. means standard deviation

rep. 1

date	Diameter at 0.3 m (mm)	S.D.	Diameter at 1.4 m (mm)	S.D.	Height (m)	S.D.	Width (m)	S.D.
06-09-93	n.d.	n.d.	n.d.	n.d.	0.393	0.136	n.d.	n.d.
08-12-93	2.113	0.117	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
11-03-94	2.617	0.688	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
20-07-94	3.246	1.187	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
15-09-94	n.d.	n.d.	n.d.	n.d.	4.870	0.674	2.180	0.245
02-11-94	n.d.	n.d.	n.d.	n.d.	4.917	0.529	2.345	0.835
15-12-94	n.d.	n.d.	n.d.	n.d.	5.175	0.348	2.060	0.484
20-12-94	4.010	1.282	3.208	1.065	n.d.	n.d.	n.d.	n.d.
12-01-95	4.117	2.115	4.124	1.468	n.d.	n.d.	n.d.	n.d.
16-01-95	n.d.	n.d.	n.d.	n.d.	5.125	49.687	2.156	98.661

rep. 2

date	Diameter at 0.3 m (mm)	S.D.	Diameter at 1.4 m (mm)	S.D.	Height (m)	S.D.	Width (m)	S.D.
06-09-93	n.d.	n.d.	n.d.	n.d.	0.759	0.287	n.d.	n.d.
08-12-93	3.113	0.408	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
11-03-94	3.075	0.700	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
20-07-94	3.846	1.096	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
15-09-94	n.d.	n.d.	n.d.	n.d.	5.470	0.774	2.130	0.270
02-11-94	n.d.	n.d.	n.d.	n.d.	5.317	0.649	2.345	0.846
15-12-94	n.d.	n.d.	n.d.	n.d.	5.575	0.398	2.310	0.574
20-12-94	3.820	1.247	3.263	1.216	n.d.	n.d.	n.d.	n.d.
12-01-95	4.020	1.758	3.417	1.465	n.d.	n.d.	n.d.	n.d.
16-01-95	n.d.	n.d.	n.d.	n.d.	5.988	81.882	2.025	57.825

rep. 3

date	Diameter at 0.3 m (mm)	S.D.	Diameter at 1.4 m (mm)	S.D.	Height (m)	S.D.	Width (m)	S.D.
06-09-93	n.d.	n.d.	n.d.	n.d.	0.476	0.174	n.d.	n.d.
08-12-93	1.838	0.364	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
11-03-94	2.417	0.803	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
20-07-94	2.971	0.902	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
15-09-94	n.d.	n.d.	n.d.	n.d.	4.470	0.574	3.130	0.290
02-11-94	n.d.	n.d.	n.d.	n.d.	4.917	0.429	3.345	1.040
15-12-94	n.d.	n.d.	n.d.	n.d.	4.575	0.298	3.460	0.664
20-12-94	3.384	0.552	2.429	0.413	n.d.	n.d.	n.d.	n.d.
12-01-95	3.395	1.344	2.398	0.955	n.d.	n.d.	n.d.	n.d.
16-01-95	n.d.	n.d.	n.d.	n.d.	4.731	31.118	3.094	94.520

rep. 4

date	Diameter at 0.3 m (mm)	S.D.	Diameter at 1.4 m (mm)	S.D.	Height (m)	S.D.	Width (m)	S.D.
06-09-93	n.d.	n.d.	n.d.	n.d.	0.692	0.366	n.d.	n.d.
08-12-93	2.300	0.328	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
11-03-94	3.408	1.065	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
20-07-94	3.888	1.531	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
15-09-94	n.d.	n.d.	n.d.	n.d.	5.470	0.774	2.130	0.290
02-11-94	n.d.	n.d.	n.d.	n.d.	4.917	0.529	2.345	0.840
15-12-94	n.d.	n.d.	n.d.	n.d.	5.575	0.398	2.460	0.464
20-12-94	3.562	1.099	2.935	0.884	n.d.	n.d.	n.d.	n.d.
12-01-95	3.715	1.435	3.152	1.328	n.d.	n.d.	n.d.	n.d.
16-01-95	n.d.	n.d.	n.d.	n.d.	5.600	43.753	2.227	78.458

Table V.6.4: Summary of maximum height measurements in the weed fallow during short rains 1994.
Note: S.D. means standard deviation

date	Height (m)	S.D.
15-09-94	2.200	0.251
02-11-94	1.971	0.186
15-12-94	2.005	0.243

Table V.6.5: Summary of some non-destructive plant characteristics in maize during short rains 1994.
Note: S.D. means standard deviation

date	No. of (-)	leaves S.D.	Height (m)	S.D.	Width (m)	S.D.
15-09-94	6.400	0.490	0.304	0.041	0.244	0.036
05-10-94	10.000	0.894	0.425	0.063	0.522	0.056
19-10-94	12.500	1.025	0.873	0.093	0.743	0.113
02-11-94	14.800	1.470	1.110	0.203	0.843	0.119
18-11-94	14.200	1.077	1.225	0.159	0.757	0.135
15-12-94	13.700	1.847	1.419	0.254	0.679	0.076
09-01-95	11.500	1.360	1.213	0.238	0.521	0.236

Appendix V.7: Automated logger data from the automatic meteorological station, short rains 1994

Table V.7.1: Meteorological data for September 1994

DATE	Air Temperature max (deg C)	Air Temperature min (deg C)	Air Temperature mean (degC)	ampl (degC)	Solar (kW/m2)	Rainfall radiation (MJ/m2)	Time (10th)	Rain (mm)	Rainfall Intensity No.of 0.5h	Rainfall Intensity Intensity (mm/d)	Rainfall Intensity max (mm/0.5h)	Rel. Hum at Tmax (%)	Mean Rel. Hum (%)	Wind Speed mean (m/s)	Soil Temperature at 5 cm max (deg C)	Soil Temperature at 5 cm min (deg C)	Soil Temperature at 5 cm mean (deg C)	Soil Temperature at 5 cm ampl (deg C)	Soil Temperature at 20 cm max (deg C)	Soil Temperature at 20 cm min (deg C)	Soil Temperature at 20 cm mean (deg C)	Soil Temperature at 20 cm ampl (deg C)	Soil Temperature at 50 cm max (deg C)	Soil Temperature at 50 cm min (deg C)	Soil Temperature at 50 cm mean (deg C)	Soil Temperature at 50 cm ampl (deg C)
010994	27.21	13.84	19.81	13.37	6.042	21.753	0	0	0	0.0	0.0	56.83	79.89	0.937	30.08	19.73	24.19	10.35	24.39	21.72	23.08	2.67	23.81	23.57	23.66	0.24
020994	28.53	13.5	19.29	15.03	5.943	21.394	0.4	5.2	9	27.7	1.2	47.30	86.92	0.952	30.49	19.62	23.95	10.87	24.36	21.78	23.03	2.58	23.88	23.71	23.78	0.17
030994	26.38	15.29	19.08	11.09	5.143	18.513	0.354	14	8	84.0	10.0	62.72	90.47	0.805	29.20	20.76	23.66	8.44	23.95	21.71	22.80	2.24	23.85	23.74	23.80	0.11
040994	25.77	14.32	18.86	11.45	4.579	16.485	0.354	1.4	8	8.4	1.2	62.72	87.16	0.9	26.57	19.94	22.91	6.63	23.40	21.65	22.55	1.75	23.81	23.71	23.74	0.10
050994	26.75	17.53	22.31	9.22	6.027	21.698	0	0	0	0.0	0.0	57.28	73.91	1.194	33.28	21.74	26.90	11.54	24.63	21.54	23.38	3.09	23.74	23.62	23.68	0.12
060994	26.55	15.65	20.21	10.9	4.554	16.394	0.8	1.2	3	17.6	0.6	60.74	84.14	1.03	31.79	19.71	24.77	12.08	24.70	22.32	23.66	2.38	24.06	23.84	23.93	0.22
070994	26.96	14.99	19.50	11.97	4.826	17.375	0.417	0.8	1	38.4	0.8	61.63	87.13	1.171	31.89	18.78	23.79	13.11	24.63	21.85	23.25	2.78	24.12	23.98	24.05	0.14
080994	27.47	17.48	20.28	9.99	4.927	17.737	0.354	6.4	4	76.8	5.4	62.40	88.10	0.875	33.59	20.05	24.35	13.54	24.73	21.73	23.20	3.00	24.12	23.95	24.04	0.17
090994	25.93	13.53	17.95	12.4	4.640	16.704	0.271	38.6	5	370.6	28.8	65.41	95.42	0.835	32.79	16.82	22.07	15.97	24.31	20.77	22.61	3.54	24.08	23.84	23.99	0.24
100994	27.59	14.66	19.98	12.93	6.400	23.041	0.542	0.6	3	9.6	0.2	59.71	87.73	0.89	33.42	17.94	24.18	15.48	24.39	20.66	22.79	3.73	23.95	23.71	23.81	0.24
110994	28.21	13.76	19.52	14.45	5.694	20.498	0.458	6.2	3	99.2	3.4	58.18	87.69	0.986	33.01	17.41	23.51	15.60	24.40	21.35	22.90	3.05	23.96	23.78	23.87	0.18
120994	28.05	16.14	21.53	11.91	5.758	20.729	0	0	0	0	0	52.54	80.16	0.872	33.37	19.71	25.82	13.66	24.80	21.20	23.37	3.60	23.98	23.78	23.86	0.20
130994	22.19	15.93	18.17	6.26	5.742	20.671	0	0	0	0	0	83.84	95.60	0.531	26.17	18.84	21.40	7.33	24.64	21.97	23.42	2.67	24.12	23.91	24.03	0.21
140994	28.99	14.54	20.78	14.45	5.835	21.006	0	0	0	0	0	44.03	80.41	0.871	34.37	18.09	24.44	16.28	25.05	21.84	23.45	3.21	24.22	23.98	24.09	0.24
150994	27.18	15.59	19.65	11.59	5.383	19.38	0.333	0.4	1	19.2	0.4	55.62	89.13	0.984	34.00	18.57	23.95	15.43	24.77	21.80	23.19	2.97	24.22	24.08	24.16	0.14
160994	27.52	14.76	20.31	12.76	5.364	19.31	0.917	0.2	1	9.6	0.2	62.59	86.24	0.902	34.50	18.24	24.51	16.26	24.83	21.72	23.36	3.11	24.22	24.04	24.13	0.18
170994	28.81	14.21	20.08	14.6	6.289	22.64	0.333	14.2	2	340.8	14	57.02	85.82	0.908	37.04	18.41	24.98	18.63	25.51	21.87	23.55	3.64	24.32	24.08	24.21	0.24
180994	27.71	15.65	21.76	12.06	6.032	21.714	0	0	0	0	0	60.48	80.15	0.849	32.26	19.39	25.07	12.87	24.99	21.83	23.59	3.16	24.32	24.11	24.21	0.21
190994	28.91	16.14	21.78	12.77	6.417	23.1	0.667	0.2	1	9.6	0.2	51.84	79.80	0.755	34.29	20.03	25.72	14.26	25.58	22.35	24.05	3.23	24.48	24.21	24.32	0.27
200994	29.07	15.87	21.76	13.2	6.699	24.116	0.417	1.2	2	28.8	0.8	51.26	81.31	0.84	36.05	19.83	26.38	16.22	26.24	22.77	24.58	3.47	24.77	24.46	24.57	0.31
210994	28.99	15.34	22.02	13.65	6.731	24.23	0	0	0	0	0	48.00	78.16	0.789	36.25	19.74	26.83	16.51	26.56	23.09	24.93	3.47	25.01	24.70	24.81	0.31
220994	28.31	14.85	20.38	13.46	5.044	18.158	0.25	1	2	24	0.6	47.30	85.53	0.745	35.11	19.29	24.79	15.82	25.62	22.67	24.30	2.95	25.01	24.90	24.97	0.11
230994	29.33	15.7	21.24	13.63	6.217	22.38	0	0	0	0	0	43.65	84.28	0.764	36.71	20.03	26.46	16.68	26.21	22.56	24.54	3.65	25.02	24.80	24.90	0.22
240994	28.79	14.37	20.89	14.42	6.135	22.085	0	0	0	0	0	48.13	81.60	0.993	36.36	18.62	25.78	17.74	26.32	22.75	24.48	3.57	25.12	24.90	25.00	0.22
250994	30.23	14.05	21.88	16.18	6.316	22.739	0	0	0	0	0	36.29	76.68	0.682	34.06	18.93	25.52	15.13	25.94	22.54	24.34	3.40	25.08	24.90	25.00	0.18
260994	29.01	15.06	21.79	13.95	6.867	24.722	0	0	0	0	0	54.21	80.03	1.046	34.70	19.19	25.86	15.51	25.90	22.65	24.39	3.25	25.10	24.90	25.00	0.20
270994	29.55	14.85	21.31	14.7	6.196	22.305	0	0	0	0	0	47.23	79.05	0.8	36.12	19.79	25.78	16.33	26.02	22.81	24.42	3.21	25.16	24.97	25.06	0.19
280994	29.66	14.72	22.25	14.94	5.797	20.87	0	0	0	0	0	44.16	76.0044	0.814	35.28	19.92	26.12	15.36	26.02	22.93	24.59	3.09	25.22	25.01	25.10	0.21
290994	27.36	14.61	20.68	12.75	5.388	19.395	0.042	0.6	1	28.8	0.6	56.58	81.1592	0.902	34.24	19.37	25.26	14.87	25.86	22.79	24.35	3.07	25.24	25.08	25.16	0.16
300994	28.7	14.5	19.28	14.2	5.041	18.148	0	0	0	0	0	53.44	85.3056	1.002	36.11	18.78	24.36	17.33	25.53	22.20	23.88	3.33	25.20	25.01	25.10	0.19

Table V.7.2: Meteorological data for October 1994

	Air Temperature						Rainfall			Rainfall Intensity				Wind	Soil Temperature at 5 cm				Soil Temperature at 20 cm				Soil Temperature at 50 cm			
DATE	max (deg C)	min (deg C)	mean (deg C)	ampl (deg C)	Solar (kW/m2)	Radiation (MJ/m2)	Time (10th)	Rain (mm)	No.of 0.5h	Intensity (mm/d)	Intensity max (mm/0.5h)	Rel.Hum at Tmax (%)	Mean Rel. Hum (%)	Speed mean (m/s)	max (deg C)	min (deg C)	mean (deg C)	ampl (deg C)	max (deg C)	min (deg C)	mean (deg C)	ampl (deg C)	max (deg C)	min (deg C)	mean (deg C)	ampl (deg C)
011094	29.31	14.13	20.91	15.18	6.047	21.769	0	0	0	0	0	37.31	74.4194	1.163	33.64	18.38	24.45	15.26	25.12	22.10	23.58	3.02	25.08	24.83	24.91	0.25
021094	31.29	15.93	22.58	15.36	6.146	22.124	0	0	0	0	0	35.52	75.4058	1.01	36.68	20.38	26.61	16.30	25.94	22.02	24.28	3.92	25.05	24.77	24.88	0.28
031094	26.52	15.27	19.11	11.25	4.607	16.586	0.25	2.6	2	62.4	2	68.03	92.526	0.871	32.59	19.12	23.43	13.47	24.90	21.78	23.44	3.12	25.05	24.90	24.97	0.15
041094	28.86	14.24	20.76	14.62	6.619	23.829	0	0	0	0	0	42.11	79.1621	0.85	33.99	19.44	25.14	14.55	25.08	21.72	23.55	3.36	24.88	24.65	24.75	0.23
051094	27.6	16.4	21.53	11.2	5.982	21.535	0	0	0	0	0	46.4	84.4585	0.864	33.57	20.12	25.16	13.45	25.01	22.14	23.68	2.87	24.80	24.66	24.74	0.14
061094	27.81	16.91	21.16	10.9	6.119	22.029	0	0	0	0	0	52.42	82.2602	0.847	33.70	20.80	25.55	12.90	25.43	22.44	23.98	2.99	24.90	24.70	24.79	0.20
071094	27.64	14.43	18.68	13.21	4.460	16.057	0.25	5.2	2	124.8	5	50.43	92.0679	0.966	32.75	18.42	22.73	14.33	24.58	21.30	23.00	3.28	24.88	24.68	24.79	0.20
081094	28.29	15.23	20.12	13.06	5.536	19.929	0	0	0	0	0	56.26	88.4417	0.713	33.00	19.83	24.19	13.17	24.26	21.19	22.89	3.07	24.66	24.39	24.48	0.27
091094	28.99	14.69	20.14	14.3	6.135	22.088	0	0	0	0	0	57.66	86.535	0.781	33.79	19.61	24.90	14.18	24.78	21.73	23.35	3.05	24.53	24.33	24.43	0.20
101094	28.58	15.68	21.67	12.9	6.812	24.524	0	0	0	0	0	57.47	83.7913	0.874	33.93	20.13	25.68	13.80	25.20	21.99	23.74	3.21	24.66	24.39	24.51	0.27
111094	25.17	15.48	20.07	9.69	4.655	16.759	0.021	28.4	2	681.6	25.6	68.61	90.1575	0.811	29.69	20.05	24.11	9.64	24.25	22.20	23.25	2.05	24.66	24.53	24.58	0.13
121094	27.28	16.75	21.17	10.53	4.984	17.942	0	0	0	0	0	52.16	79.2066	0.771	31.86	20.72	24.54	11.14	24.59	22.08	23.34	2.51	24.56	24.42	24.51	0.14
131094	28.13	16.02	20.00	12.11	4.660	16.777	0.125	7.4	2	177.6	5	41.54	90.1671	0.837	31.00	20.28	23.84	10.72	24.18	21.94	23.02	2.24	24.56	24.42	24.48	0.14
141094	27.31	13.32	19.32	13.99	5.091	18.331	0.042	13.6	2	326.4	9.6	57.79	85.4869	0.784	31.88	18.90	23.68	12.98	23.95	21.52	22.88	2.43	24.46	24.32	24.37	0.14
151094	26.17	12.79	19.01	13.38	4.481	16.131	0	0	0	0	0	59.79	89.4773	0.701	31.06	18.54	23.17	12.52	23.50	21.29	22.48	2.21	24.38	24.18	24.25	0.20
161094	27.7	16.18	20.56	11.52	6.353	22.87	0	0	0	0	0	44.1	85.2992	0.841	32.77	20.32	24.76	12.45	24.15	21.14	22.83	3.01	24.21	24.03	24.12	0.18
171094	28.38	16.83	21.96	11.55	6.119	22.027	0	0	0	0	0	47.1	79.0875	0.762	33.05	21.16	25.50	11.89	24.63	21.94	23.47	2.69	24.36	24.12	24.21	0.24
181094	29.18	14.28	20.68	14.9	6.202	22.326	0	0	0	0	0	51.26	85.3215	0.795	34.05	20.00	25.15	14.05	25.08	22.37	23.78	2.71	24.57	24.32	24.43	0.25
191094	28.41	14.3	20.71	14.11	5.301	19.084	0	0	0	0	0	49.28	82.1963	0.883	31.17	19.70	24.47	11.47	24.56	22.18	23.45	2.38	24.57	24.46	24.52	0.11
201094	28.19	14.48	20.64	13.71	4.496	16.185	0	0	0	0	0	47.74	85.8373	0.868	30.33	19.56	23.92	10.77	24.06	21.98	23.04	2.08	24.56	24.39	24.46	0.17
211094	28.03	15.71	19.48	12.32	4.812	17.323	0	0	0	0	0	51.26	91.5675	0.85	32.39	20.06	23.87	12.33	23.92	21.82	22.90	2.10	24.44	24.32	24.36	0.12
221094	25.76	15.78	19.31	9.98	3.956	14.241	0	0	0	0	0	66.11	93.1398	0.637	30.13	20.09	23.58	10.04	23.60	21.73	22.67	1.87	24.36	24.18	24.25	0.18
231094	25.67	14.66	19.15	11.01	3.831	13.792	0	0	0	0	0	61.5	92.3669	0.808	28.52	19.46	22.93	9.06	23.17	21.31	22.31	1.86	24.22	24.08	24.12	0.14
241094	27.14	14.49	18.89	12.65	3.944	14.199	0	0	0	0	0	52.54	94.1735	0.734	29.12	19.25	22.45	9.87	22.68	21.03	22.00	1.65	24.08	23.88	23.94	0.20
251094	29.24	14.12	20.58	15.12	6.572	23.66	0	0	0	0	0	46.4	81.7692	0.864	32.49	19.71	24.63	12.78	24.20	20.93	22.79	3.27	23.98	23.71	23.83	0.27
261094	28.5	13.11	19.45	15.39	5.061	18.221	0	0	0	0	0	46.98	87.2865	0.766	31.23	19.09	23.56	12.14	23.81	21.42	22.67	2.39	24.01	23.90	23.96	0.11
271094	28.88	13.9	21.22	14.98	6.065	21.832	0	0	0	0	0	44.54	81.4946	0.877	30.82	19.66	24.48	11.16	24.12	21.27	22.90	2.85	24.05	23.84	23.95	0.21
281094	27.84	14.46	20.81	13.38	4.892	17.611	0.167	4.2	2	100.8	3.8	47.23	83.871	0.947	28.95	20.06	23.85	8.89	23.77	21.75	22.81	2.02	24.05	23.95	24.01	0.10
291094	27.13	14.89	20.51	12.24	5.896	21.225	0.521	1.2	1	57.6	1.2	68.42	89.4221	0.895	31.34	20.27	24.85	11.07	24.25	21.81	23.13	2.44	24.15	23.94	24.04	0.21
301094	28.08	15.67	21.09	12.41	6.752	24.307	0	0	0	0	0	56.19	85.1188	0.777	32.52	21.02	25.60	11.50	24.83	22.02	23.61	2.81	24.36	24.08	24.18	0.28
311094	27.52	16.31	20.03	11.21	4.150	14.94	0	0	0	0	0	57.47	90.8333	0.629	30.54	21.05	24.26	9.49	24.18	22.31	23.31	1.87	24.39	24.29	24.34	0.10

Table V.7.3: Meteorological data for November 1994

	Air Temperature						Rainfall			Rainfall				wind	Soil Temperature at 5 cm				Soil Temperature at 20 cm				Soil Temperature at 50 cm			
DATE	max (deg C)	min (deg C)	mean (deg C)	ampl (deg C)	Solar (kW/m2)	Radiation (MJ/m2)	Time (10th)	Rain (mm)	No.of 0.5h	Intensity (mm/d)	Intensity max (mm/0.5h)	Rel. Hum at Tmax (%)	Mean Rel.Hum (%)	Speed mean (m/s)	max (deg C)	min (deg C)	mean (deg C)	ampl (deg C)	max (deg C)	min (deg C)	mean (deg C)	ampl (deg C)	max (deg C)	min (deg C)	mean (deg C)	ampl (deg C)
011194	25.55	13.28	18.09	12.27	2.822	10.158	0.25	0.2	1	9.6	0.2	68.54	96.5613	0.606	26.69	19.03	22.35	7.66	23.06	21.22	22.44	1.84	24.36	24.15	24.25	0.21
021194	25.12	13.56	18.99	11.56	3.726	13.412	0	0	0	0	0	64.77	94.1263	0.703	27.14	19.11	22.67	8.03	22.87	21.14	22.05	1.73	24.15	23.91	23.96	0.24
031194	27.4	16.05	20.24	11.35	5.492	19.77	0.479	0.8	4	9.6	0.2	51.39	90.5767	0.831	30.12	20.94	24.41	9.18	23.67	21.10	22.66	2.57	23.94	23.76	23.84	0.18
041194	25.81	15.94	19.33	9.87	4.451	16.022	0.479	0.8	2	19.2	0.6	66.56	95.895	0.605	29.89	20.76	23.96	9.13	23.77	21.89	22.85	1.88	24.05	23.88	23.95	0.17
051194	25.56	17.09	19.59	8.47	3.268	11.763	0.146	1	2	24	0.6	66.18	95.6148	0.658	27.07	21.10	23.24	5.97	23.02	21.81	22.46	1.21	24.01	23.92	23.95	0.09
061194	27.44	17.23	19.79	10.21	3.568	12.843	0.25	2	1	96	2	59.07	93.9854	0.522	28.76	21.26	23.31	7.50	23.19	21.75	22.43	1.44	23.95	23.84	23.88	0.11
071194	26.24	17.44	19.81	8.8	3.334	12.003	0	0	0	124.8	0	65.09	95.2354	0.465	28.43	21.41	23.626	7.02	23.23	21.78	22.51	1.45	23.88	23.77	23.823	0.11
081194	25.02	16.08	18.83	8.94	4.024	14.487	0.25	1.8	2	43.2	1.2	72.77	97.6429	0.662	29.28	21	23.356	8.28	23.31	21.78	22.479	1.53	23.88	23.77	23.832	0.11
091194	25.83	15.76	19.36	10.07	4.878	17.56	0.458	0.8	3	12.8	0.4	69.95	94.3775	1.069	29.98	20.96	24.186	9.02	23.74	21.75	22.788	1.99	23.94	23.77	23.836	0.17
101194	24.62	15.54	17.92	9.08	3.388	12.195	0.208	4.2	4	50.4	3.2	70.85	99.0575	0.667	28.08	20.2	22.204	7.88	22.85	21.22	22.095	1.63	23.94	23.75	23.833	0.19
111194	25.42	15.12	19.19	10.3	3.868	13.924	0.25	0.2	1	9.6	0.2	75.78	96.351	0.622	28.97	19.36	22.708	9.61	22.61	21.17	21.941	1.44	23.74	23.58	23.625	0.16
121194	26.23	13.94	18.89	12.29	4.162	14.983	0.333	1.6	3	25.6	0.6	71.87	95.2938	0.87	28.41	18.25	22.397	10.16	22.63	20.88	21.851	1.75	23.6	23.49	23.527	0.11
131194	27.49	16.7	19.62	10.79	3.717	13.383	0.354	5.6	8	33.6	2.2	57.28	94.8088	0.784	29.61	19.47	22.591	10.14	22.51	20.77	21.589	1.74	23.5	23.33	23.389	0.17
141194	25.58	16.67	19.26	8.91	4.215	15.175	0.75	5.8	12	23.2	2.4	64.38	96.1438	0.602	29.74	19.64	23.01	10.1	22.75	20.72	21.683	2.03	23.33	23.19	23.255	0.14
151194	24.35	4.0404	22.83	20.31	3.617	13.022	0	0	0	0	0	77.57	78.5767	1.012	29.68	21.87	27.016	7.81	22	20.84	21.209	1.16	23.26	23.19	23.231	0.07
161194	25.93	16.37	19.06	9.56	2.280	8.207	0.146	6.8	6	47.6	4.2	65.41	96.4188	0.652	31.07	19.31	22.867	11.76	22.85	21.18	22.13	1.67	23.33	23.19	23.257	0.14
171194	27.25	13.33	18.76	13.92	4.169	15.007	0.208	23.2	3	371.2	22.8	58.62	94.4427	0.657	30.09	17.28	21.977	12.81	22.51	20.42	21.704	2.09	23.33	22.37	23.191	0.96
181194	27.9	12.98	19.29	14.92	4.996	17.984	0.229	0.6	3	9.6	0.2	54.34	89.1029	0.675	31.58	17.39	22.624	14.19	22.75	20.3	21.659	2.45	23.26	23.11	23.181	0.15
191194	27.1	15.8	20.76	11.3	5.976	21.513	0	0	0	0	0	60.03	85.8017	0.846	31.75	19.44	24.134	12.31	23.4	20.41	22.178	2.99	23.33	23.1	23.189	0.23
201194	27.33	15.51	20.37	11.82	6.041	21.746	0.396	2.6	5	25.0	1	64.64	87.4892	1.001	32.47	19.24	24.225	13.23	23.93	21.34	22.632	2.59	23.54	23.3	23.393	0.24
211194	28.5	14.48	20.38	14.02	6.530	23.508	0.354	1.2	5	11.5	0.4	48.7	83.941	1.125	33.31	18.48	24.306	14.83	24.42	21.51	22.927	2.91	23.74	23.5	23.591	0.24
221194	27.67	17.48	21.55	10.19	6.554	23.595	0.771	20.4	9	108.8	9.2	59.26	88.009	0.743	32.87	20.67	25.223	12.2	24.49	21.46	23.074	3.03	23.88	23.65	23.745	0.23
231194	27.17	14.47	19.77	12.7	5.286	19.028	0.333	3.2	4	38.4	2.2	72	93.1238	0.874	32.3	18.48	23.86	13.82	24.36	21.54	23.02	2.82	24.01	23.84	23.907	0.17
241194	27.61	14.29	19.87	13.32	5.359	19.292	0.333	0.2	1	9.6	0.2	55.55	90.5723	0.835	31.63	18.55	23.582	13.08	23.91	21.42	22.634	2.49	23.98	23.84	23.911	0.14
251194	27.12	16.58	20.62	10.54	6.016	21.659	0	0	0	0	0	68.29	86.6502	0.894	31.94	20.08	24.44	11.86	24.1	21.36	22.825	2.74	23.95	23.81	23.879	0.14
261194	26.17	16.84	19.80	9.33	4.205	15.137	0.313	2.2	5	21.1	0.8	69.31	93.1498	0.753	31.7	20.13	23.659	11.57	23.84	21.7	22.714	2.14	23.98	23.88	23.929	0.1
271194	26.62	17.09	20.41	9.53	5.107	18.387	0.417	3.6	4	43.2	2.8	69.76	92.4692	0.616	32.26	20.33	24.347	11.93	24.01	21.63	22.802	2.38	23.98	23.84	23.904	0.14
281194	24.79	17.01	19.84	7.78	4.201	15.122	0.333	12.2	7	83.7	10.2	69.95	97.165	0.663	28.51	20.11	23.491	8.4	23.59	21.67	22.606	1.92	23.98	23.91	23.948	0.07
291194	23.09	17.53	19.11	5.56	2.020	7.273	0.313	17.2	12	68.8	4.2	84.23	101.749	0.567	25.76	20.05	22.23	5.71	22.51	21.15	21.93	1.36	23.95	23.74	23.828	0.21
301194	24.66	16.23	18.65	8.43	3.219	11.589	0.396	6.4	7	43.9	2.2	70.91	99.1723	0.523	28.47	19.33	22.325	9.14	22.51	20.94	21.704	1.57	23.74	23.57	23.608	0.17

Table V.7.4: Meteorological data for December 1994

	Air Temperature				Solar Radiation		Rainfall			Rainfall				wind	Soil Temperature at 5 cm				Soil Temperature at 20 cm				Soil Temperature at 50 cm			
DATE	max (deg C)	min (deg C)	mean (deg C)	ampl (deg C)	(kW/m2)	(MJ/m2)	Time (10th)	Rain (mm)	No.of 0.5h	Intensity (mm/d)	Intensity max (mm/0.5h)	Rel. Hum at Tmax (%)	Mean Rel. Hum (%)	Speed mean (m/s)	max (deg C)	min (deg C)	mean (deg C)	ampl (deg C)	max (deg C)	min (deg C)	mean (deg C)	ampl (deg C)	max (deg C)	min (deg C)	mean (deg C)	ampl (deg C)
011294	27.84	15.56	20.35	12.28	5.291	19.049	0.521	2.2	3	35.2	1.2	65.09	91.1052	0.646	31.62	19.1	23.667	12.52	23.36	20.86	22.24	2.5	23.6	23.43	23.519	0.17
021294	27.98	15.41	20.50	12.57	5.887	21.193	0.542	6.8	4	81.6	4.2	54.4	89.5494	0.815	30.34	19.36	23.757	10.98	23.54	21.17	22.392	2.37	23.71	23.54	23.607	0.17
031294	26.85	15.54	19.35	11.31	5.345	19.243	0.229	5.2	7	35.6	2.2	64.13	92.9515	0.782	30.51	19.42	23.335	11.09	23.33	21.23	22.334	2.1	23.74	23.6	23.675	0.14
041294	27.79	14.94	20.34	12.85	5.740	20.664	0.438	19	5	182.4	8.8	56.83	90.7206	0.896	31.35	18.94	23.642	12.41	23.64	21.15	22.391	2.49	23.76	23.6	23.677	0.16
051294	27.8	17.17	20.82	10.63	5.655	20.356	0.438	5.2	4	62.4	3.8	61.5	90.5004	0.7	30.96	20.51	24.264	10.45	23.67	21.11	22.504	2.56	23.77	23.6	23.69	0.17
061294	27.46	15.03	20.1	12.43	5.728	20.621	0.354	9.8	5	94.1	6.2	51.97	91.4944	0.837	30.47	19.34	23.755	11.13	23.64	21.57	22.597	2.07	23.84	23.71	23.765	0.13
071294	27.02	14.49	20.51	12.53	5.839	21.022	0.896	0.2	1	9.6	0.2	65.47	88.5438	0.793	30.32	19.11	24.043	11.21	23.77	21.42	22.673	2.35	23.88	23.74	23.808	0.14
081294	26.92	16.81	20.65	10.11	4.710	16.958	0.417	0.4	2	9.6	0.2	52.54	88.8613	0.674	28.97	20.44	23.722	8.53	23.3	21.51	22.476	1.79	23.88	23.8	23.843	0.08
091294	26.66	12.98	19.82	13.68	4.984	17.943	0.854	0.2	1	9.6	0.2	53.25	86.9471	0.793	28.13	18.15	22.853	9.98	23.26	21.1	22.336	2.16	23.88	23.77	23.82	0.11
101294	27.26	13.64	20.26	13.62	6.467	23.282	0	0	0	50.4	0	49.28	78.3279	1.252	29.5	18.13	22.773	11.37	22.95	20.91	21.94	2.04	23.84	23.67	23.721	0.17
111294	27.64	12.27	20.11	15.37	6.432	23.156	0.75	0.2	1	9.6	0.2	47.3	80.2102	1.057	30.02	17.66	22.858	12.36	23.02	20.78	21.93	2.24	23.71	23.54	23.608	0.17
121294	28.27	14.03	20.42	14.24	6.478	23.322	0.375	0.4	2	9.6	0.2	49.79	82.3175	0.92	30.9	18.55	23.467	12.35	23.3	20.65	22.105	2.65	23.64	23.47	23.547	0.17
131294	27.87	14.37	19.72	13.5	5.147	18.53	0.875	0.2	1	9.6	0.2	42.24	87.4015	0.754	30.23	18.91	23.04	11.32	23.13	21.05	22.058	2.08	23.6	23.5	23.564	0.1
141294	28.05	15.45	21.12	12.6	5.391	19.408	0.479	3.4	1	163.2	3.2	47.68	87.2987	0.811	30.1	19.55	24.016	10.55	23.5	20.99	22.38	2.51	23.67	23.5	23.569	0.17
151294	28.53	15.68	21.49	12.85	5.806	20.9	0	0	0	0	0	42.69	83.2027	1.06	29.98	19.89	23.968	10.09	23.57	21.48	22.57	2.09	23.77	23.61	23.683	0.16
161294	27.92	15.79	20.78	12.13	5.657	20.366	0.896	0.2	1	9.6	0.2	37.18	84.5252	1.012	28.45	19.8	23.192	8.65	23.33	21.4	22.356	1.93	23.79	23.71	23.748	0.08
171294	29.73	13.67	20.71	16.06	6.862	24.704	0.896	0.2	1	9.6	0.2	23.736	80.7885	1.216	31	18.7	23.729	12.3	23.78	21.33	22.538	2.45	23.81	23.66	23.73	0.15
181294	28.79	12.07	19.94	16.72	6.448	23.213	0.833	0.2	1	9.6	0.2	37.63	79.8321	0.876	31.93	17.69	23.625	14.24	23.95	21.16	22.566	2.79	23.81	23.67	23.75	0.14
191294	29.5	12.15	20.34	17.35	6.771	24.376	0.938	0.2	1	9.6	0.2	33.15	75.9073	1.157	30.94	17.61	23.387	13.33	23.74	20.98	22.374	2.76	23.81	23.71	23.757	0.1
201294	28.56	13.16	20.27	15.4	6.725	24.211	0.833	0.2	1	9.6	0.2	45.06	80.5808	0.904	32.05	17.94	23.841	14.11	24.02	20.9	22.53	3.12	23.84	23.66	23.742	0.18
211294	29.35	12.41	20.73	16.94	6.729	24.225	0.875	0.2	1	9.6	0.2	43.58	78.3465	1.001	32.29	18.4	24.124	13.89	24.12	21.08	22.666	3.04	23.88	23.7	23.783	0.18
221294	29.82	13.29	21.27	16.53	6.586	23.709	0	0	0	0	0	40	75.1098	0.971	32.77	18.88	24.685	13.89	24.44	21.31	22.97	3.13	23.98	23.75	23.855	0.23
231294	28.85	14.46	22.09	14.39	5.109	18.391	0	0	0	0	0	42.94	67.9975	1.315	30.55	19.12	23.676	11.43	23.71	21.57	22.64	2.14	23.98	23.88	23.927	0.1
241294	29.46	14.7	21.99	14.76	5.167	18.602	0	0	0	0	0	46.4	79.0283	0.892	31.49	19.42	24.538	12.07	24.08	21.45	22.923	2.63	24.01	23.81	23.906	0.2
251294	29.82	15.47	21.01	14.35	5.026	18.093	0.375	5.6	4	67.2	4.6	37.38	86.5652	0.987	30.94	19.44	24.024	11.5	24.08	21.69	22.867	2.39	24.05	23.91	23.972	0.14
261294	29.2	14.87	21.41	14.33	6.044	21.757	0.771	0.2	1	9.6	0.2	51.71	85.3963	0.847	30.45	19.09	24.18	11.36	24.12	21.57	22.89	2.55	24.08	23.91	23.983	0.17
271294	29.74	14.53	21.32	15.21	6.037	21.733	0.479	2	3	32	1.2	43.71	82.9629	0.964	31.55	19.1	24.139	12.45	24.18	21.57	22.901	2.61	24.12	23.95	24.022	0.17
281294	29.5	14.09	21.31	15.41	6.723	24.204	0.854	0.2	1	9.6	0.2	45.25	80.769	0.855	32.29	18.86	24.514	13.43	24.42	21.54	23.046	2.88	24.15	23.98	24.059	0.17
291294	31.54	12.31	21.06	19.23	6.731	24.23	0.792	0.2	1	9.6	0.2	23.976	78.2115	1.069	33	18.3	24.484	14.7	24.53	21.6	23.078	2.93	24.22	24.01	24.112	0.21
301294	30.87	13.76	21.27	17.11	6.565	23.635	0.875	0.2	1	9.6	0.2	31.24	76.5697	1.204	33.2	19.07	24.544	14.13	24.49	21.51	23.034	2.98	24.22	24.05	24.134	0.17
311294	28.16	14.18	20.88	13.98	5.827	20.978	0	0	0	0	0	49.86	82.6544	0.974	31.59	19.27	24.44	12.32	24.32	21.63	23.03	2.69	24.22	24.05	24.14	0.17

Table V.7.5: Meteorological data for January 1995
Note: Not the complete month is presented, because the experiment expired earlier

	Air Temperature				Solar Radiation		Rainfall			Rainfall Intensity		Rel. Hum	Mean	wind Speed	Soil Temperature at 5 cm				Soil Temperature at 20 cm				Soil Temperature at 50 cm			
DATE	max (deg C)	min (deg C)	mean (deg C)	ampl (deg C)	(kW/m2)	(MJ/m2)	Time (10th)	Rain (mm)	No.of 0.5h	Intensity (mm/d)	max (mm/0.5h)	at Tmax (%)	Rel. Hum (%)	mean (m/s)	max (deg C)	min (deg C)	mean (deg C)	ampl (deg C)	max (deg C)	min (deg C)	mean (deg C)	ampl (deg C)	max (deg C)	min (deg C)	mean (deg C)	ampl (deg C)
010195	27.83	13.48	19.98	14.35	5.887	21.191	0.2	0.2	1	9.6	0.2	44.99	79.1817	1.18	31.78	18.85	24.099	12.93	24.32	21.62	22.935	2.7	24.19	24.05	24.13	0.14
020195	28.68	15.27	21.19	13.41	5.906	21.263	0	0	0	0	0	44.78	81.7771	0.955	32.67	19.98	24.901	12.69	24.47	21.45	23.078	3.02	24.22	24.01	24.113	0.21
030195	30.57	14.63	22.24	15.94	6.115	22.014	0	0	0	0	0	40.58	77.3798	0.9	34.66	20.04	25.806	14.62	25.08	21.91	23.659	3.17	24.42	24.12	24.24	0.3
040195	32.02	15.14	22.64	16.88	6.214	22.372	0	0	0	0	0	29.74	76.1674	0.925	35.56	20.25	26.342	15.31	25.59	22.3	24.106	3.29	24.7	24.36	24.491	0.34
050195	30.98	18.71	23.28	12.27	5.793	20.854	0	0	0	0	0	36.16	79.6283	0.996	34.21	22.02	26.43	12.19	25.52	22.65	24.21	2.87	24.87	24.63	24.721	0.24
060195	28.97	16.27	22.16	12.7	5.103	18.37	0.6	1.2	2	28.8	1	48.58	83.3963	1.019	32.52	20.79	25.922	11.73	25.4	23.12	24.322	2.28	25.03	24.8	24.896	0.23
070195	30.8	15.48	21.90	15.32	5.884	21.184	0.6	1.8	2	43.2	1.6	35.84	82.6044	0.99	34.37	20.21	25.895	14.16	25.69	22.94	24.269	2.75	25.12	24.9	25	0.22
080195	28.45	17.44	22.42	11.01	5.734	20.643	0	0	0	0	0	55.04	84.0535	0.856	34.08	21.68	26.179	12.4	25.59	22.75	24.283	2.84	25.16	24.96	25.054	0.2
090195	28.75	16.08	21.24	12.67	4.897	17.628	0.2	0.6	2	14.4	0.4	54.21	88.2538	0.893	33.61	20.59	25.33	13.02	25.51	22.79	24.231	2.72	25.19	25.03	25.108	0.16
100195	31.5	15.53	22.36	15.97	6.438	23.177	0	0	0	0	0	38.21	81.8575	0.851	35.91	21.04	26.793	14.87	26.21	22.65	24.58	3.56	25.25	24.97	25.093	0.28
110195	30.61	15.34	21.20	15.27	4.912	17.682	0.25	0.6	3	9.6	0.2	34.24	85.1925	1.054	33.8	20.22	25.409	13.58	25.71	22.76	24.328	2.95	25.28	25.12	25.203	0.16
120195	30.04	12.86	21.15	17.18	6.242	22.472	0.75	0.2	1	9.6	0.2	29.31	74.29	0.995	34.88	19.02	25.59	15.86	25.82	22.54	24.204	3.28	25.24	25.03	25.145	0.21
130195	30.65	14.64	22.26	16.01	6.193	22.294	0	0	0	0	0	34.82	72.6953	0.989	34.8	20.43	25.897	14.37	25.59	22.33	24.088	3.26	25.2	24.97	25.085	0.23
140195	31.15	11.65	21.03	19.5	5.927	21.337	0.35	0.8	2	19.2	0.6	31.7	83.0611	1.012	36.04	18.71	25.806	17.33	26.06	22.63	24.341	3.43	25.24	24.97	25.109	0.27
150195	31.6	12.57	21.02	19.03	6.097	21.949	0.8	0.2	1	9.6	0.2	30.9	76.619	1.125	34.75	19.05	25.264	15.7	25.47	22.36	23.935	3.11	25.22	24.98	25.09	0.24
160195	31.21	10.96	21.05	20.25	6.994	25.177	0.8	0.2	1	9.6	0.2	19.24	71.6247	1.319	36.34	18.82	26.163	17.52	26.02	22.25	24.211	3.77	25.2	24.9	25.042	0.3
170195	32.34	10.06	20.71	22.28	7.048	25.373	0.9	0.2	1	9.6	0.2	27.43	65.532	1.229	37.44	18.42	26.212	19.02	26.45	22.34	24.39	4.11	25.28	24.97	25.111	0.31
180195	31.89	10.99	20.82	20.9	7.086	25.511	0	0	0	0	0	23.54	61.4909	1.159	37.77	18.38	26.256	19.39	26.45	22.27	24.386	4.18	25.32	25.01	25.163	0.31

Appendix VI Data on the nitrogen and phosphorus balance

Appendix VI.1: Data on wet deposition and nutrients in throughfall

Table VI.1.1: Nitrogen (measured as ammonia, nitrate and total nitrogen contents in mg/ and phosphorus (measured as total phosphorus in mg/l) in rain water (bei wet deposition) and throughfall. Foliage interception is the difference nutrient amounts between rain water and throughfall.

		Wet deposition				Throughfall				Foliage interception			
date	rep.	ammonia (mg/l)	nitrate (mg/l)	total N (mg/l)	total P (mg/l)	ammonia (mg/l)	nitrate (mg/l)	total N (mg/l)	total P (mg/l)	ammonia (mg/l)	nitrate (mg/l)	total N (mg/l)	tota P (mg/l
230394	1	0.35	0.21	n.d.	n.d.	0.28	0.06	n.d.	n.d.	-0.07	-0.15	n.d.	n.d.
	2	0.44	0.17	n.d.	n.d.	0.07	0.1	n.d.	n.d	-0.37	-0.07	n.d.	n.d.
	3	0.49	0.19	n.d.	n.d.	0.08	0.14	n.d.	n.d.	-0.41	-0.05	n.d.	n.d.
	4	0.39	0.17	n.d.	n.d.	0.24	0.11	n.d.	n.d.	-0.15	-0.06	n.d.	n.d.
190494	1	0.32	0.12	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	2	0.32	0.11	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	3	0.25	0.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	4	0.33	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
030694	1	0.31	0.11	n.d.	n.d.	0.64	0.16	n.d.	n.d.	0.33	0.05	n.d.	n.d.
	2	0.22	0.07	n.d.	n.d.	0.52	0.14	n.d.	n.d.	0.3	0.07	n.d.	n.d.
	3	0.25	0.11	n.d.	n.d.	0.39	0.14	n.d.	n.d.	0.14	0.03	n.d.	n.d.
	4	0.3	0.11	n.d.	n.d.	0.54	0.16	n.d.	n.d.	0.24	0.05	n.d.	n.d.
080694	1	0.09	0.06	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	2	0.07	0.05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	3	0.1	0.05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	4	0.08	0.05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
140794	1	0.89	0.48	n.d.	n.d.	0.64	0.39	n.d.	n.d.	-0.25	-0.09	n.d.	n.d.
	2	0.76	0.41	n.d.	n.d.	0.56	0.4	n.d.	n.d.	-0.2	-0.01	n.d.	n.d.
	3	0.81	0.37	n.d.	n.d.	0.43	0.37	n.d.	n.d.	-0.38	0	n.d.	n.d.
	4	0.74	0.39	n.d.	n.d.	0.56	0.45	n.d.	n.d.	-0.18	0.06	n.d.	n.d.
070994	1	n.d.	n.d.	n.d.	n.d.	2.86	0.27	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	2	n.d.	n.d.	n.d.	n.d.	3.02	0.24	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	3	n.d.	n.d.	n.d.	n.d.	3.19	0.69	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	4	n.d.	n.d.	n.d.	n.d.	2.15	0.71	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
170994	1	0.47	0.14	n.d.	n.d.	1.01	0.13	n.d.	n.d.	0.54	-0.01	n.d.	n.d.
	2	0.4	0.15	n.d.	n.d.	0.96	0.11	n.d.	n.d.	0.56	-0.04	n.d.	n.d.
	3	0.465	0.15	n.d.	n.d.	0.69	0.15	n.d.	n.d.	0.225	0	n.d.	n.d.
	4	0.42	0.15	n.d.	n.d.	0.77	0.17	n.d.	n.d.	0.35	0.02	n.d.	n.d.
031094	1	1.39	0.67	n.d.	n.d.	1.51	0.41	n.d.	n.d.	0.12	-0.26	n.d.	n.d.
	2	1.03	0.66	n.d.	n.d.	2.19	0.76	n.d.	n.d.	1.16	0.1	n.d.	n.d.
	3	0.92	0.67	n.d.	n.d.	1.07	0.65	n.d.	n.d.	0.15	-0.02	n.d.	n.d.
	4	0.63	0.6	n.d.	n.d.	0.68	0.59	n.d.	n.d.	0.05	-0.01	n.d.	n.d.
091094	1	0.315	0.095	0.96	0.012	0.295	0.085	1	0.012	-0.02	-0.01	0.04	0
	2	0.355	0.115	0.44	0.008	0.235	0.085	1.06	0.012	-0.12	-0.03	0.62	0.004
	3	0.275	0.095	1.06	0.012	0.265	0.115	1	0.012	-0.01	0.02	-0.06	0
	4	0.275	0.055	0.8	0.008	0.235	0.055	0.98	0.012	-0.04	0	0.18	0.004
111094	1	0.345	0.12	0.6	0.002	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	2	0.345	0.13	0.76	0.004	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	3	0.345	0.12	0.58	0.004	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	4	0.345	0.13	0.6	0.002	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
131094	1	0.175	0.11	0.33	0.004	0.425	0.06	0.53	0.002	0.25	-0.05	0.2	-0.002
	2	0.235	0.16	0.1	0.002	0.485	0.28	0.47	0.002	0.25	0.12	0.37	0
	3	0.325	0.09	0.11	0.008	0.325	0.68	0.72	0.002	0	0.59	0.61	-0.006
	4	0.325	0.26	0.24	0.016	0.16	0.12	0.02	0.002	-0.165	-0.14	-0.22	-0.014
311094	1	0.15	0.14	n.d.	n.d.	0.46	0.31	1.54	0.006	0.31	0.17	n.d.	n.d.
	2	0.25	0.11	n.d.	n.d.	0.76	0.23	1.94	0.01	0.51	0.12	n.d.	n.d.
	3	0.565	0.13	n.d.	n.d.	0.02	0.1	1.14	0.01	-0.545	-0.03	n.d.	n.d.
	4	n.d.	n.d.	n.d.	n.d.	0.16	0.17	1.09	0.002	n.d.	n.d.	n.d.	n.d.
091194	1	0.06	0.02	0.22	0	0.06	0.04	0.44	0	0	0.02	0.22	0
	2	0.09	0.03	0.21	0	0.03	0.01	0.52	0	-0.06	-0.02	0.31	0
	3	0.19	0.04	0.71	0	0.03	0.01	0.29	0	-0.16	-0.03	-0.42	0
	4	0.08	0.03	0.2	0	0.04	0.01	0.54	0	-0.04	-0.02	0.34	0

ble VI.1.1 **- continued -**

194	1	0.19	0.03	0	0	0.03	0.05	0.39	0	-0.16	0.02	0.39	0
	2	0.11	0.03	0.16	0	0.02	0.02	0.001	0	-0.09	-0.01	-0.159	0
	3	0.04	0.04	0.001	0	0.02	0.02	0.007	0	-0.02	-0.02	0.006	0
	4	0.03	0.03	0.08	0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0
194	1	0.08	0.235	n.d.	n.d.	0.035	0.08	1.19	0	-0.045	-0.16	n.d.	n.d.
	2	0.54	0.345	n.d.	n.d.	1.025	0.095	3.41	0	0.485	-0.25	n.d.	n.d.
	3	0.58	0.185	n.d.	n.d.	0.365	0.045	1.9	0	-0.215	-0.14	n.d.	n.d.
	4	0.46	0.255	n.d.	n.d.	0.08	0.005	2.37	0	-0.38	-0.25	n.d.	n.d.
294	1	0.29	0.06	0.55	0	0.22	0.06	0.39	0	-0.07	0	-0.16	0
	2	0.33	0.05	0.62	0	0.26	0.03	0.46	0	-0.07	-0.02	-0.16	0
	3	0.32	0.06	0.44	0	0.215	0.03	0.44	0	-0.105	-0.03	0	0
	4	0.31	0.03	0.4	0	0.14	0.01	0.36	0	-0.17	-0.02	-0.04	0
294	1	n.d.	n.d.	n.d.	n.d.	1.02	0.05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	2	n.d.	n.d.	n.d.	n.d.	3	0.12	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	3	n.d.	n.d.	n.d.	n.d.	0.87	0.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	4	n.d.	n.d.	n.d.	n.d.	0.76	0.01	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Appendix VI.2: Data on dry deposition

Table VI.2.1: Dry deposition (abbreviated as 'dry depo.') of soil in the month December 1994 after the short rains 1994

rep.	Dry depo. (g)	Dry depo. (kg/ha/d)	Dry depo. N (kg N/ha/d)	Dry depo. P (kg P/ha/d)
1	0.02	0.63	0.96	0.27
2	0.02	0.63	0.96	0.27
3	0.02	0.63	0.96	0.27
4	0.03	0.95	1.44	0.41

Appendix VI.3: Data on biomass assessment at maximum LAI and at harvest

Table VI.3.1: Biomass assessments during the short rains 1994 in sesbania fallow. Litterfall data of the sesbania fallow is presented in appendix VI.5.

Description	rep.	sample	sample d.w. (g)	N (%)	P (%)	yield (kg/ha)	total N (kg/ha)	total P (kg/ha)
weed in sesbania 16/1/95	1	1	377.7	1.09	0.141	3357	36.6	4.734
weed in sesbania 16/1/95	1	2	336.8	1.42	0.093	2994	42.5	2.784
weed in sesbania 16/1/95	1	3	300.2	0.90	0.074	2668	24.0	1.975
weed in sesbania 16/1/95	2	1	409.4	1.03	0.080	6720	69.2	5.376
weed in sesbania 16/1/95	2	2	272.1	1.08	0.084	2419	26.1	2.032
weed in sesbania 16/1/95	2	3	229.6	0.95	0.070	2041	19.4	1.429
weed in sesbania 16/1/95	3	1	209.1	0.82	0.054	1859	15.2	1.004
weed in sesbania 16/1/95	3	2	227.7	1.06	0.071	2024	21.5	1.437
weed in sesbania 16/1/95	3	3	271.6	0.96	0.074	2414	23.2	1.787
weed in sesbania 16/1/95	4	1	299.1	0.89	0.058	2659	23.7	1.542
weed in sesbania 16/1/95	4	2	335.1	0.99	0.066	2979	29.5	1.966
weed in sesbania 16/1/95	4	3	292.1	0.94	0.069	2596	24.4	1.792
Sesbania wood (<2cm) 16/1/95	1	1	1039.5	0.96	0.047	11551	110.9	5.429
Sesbania wood (<2cm) 16/1/95	1	2	900	1.14	0.062	10000	114.0	6.200
Sesbania wood (<2cm) 16/1/95	1	3	648.4	0.98	0.054	7204	70.6	3.890
Sesbania wood (<2cm) 16/1/95	1	4	466.2	0.90	0.053	5180	46.6	2.745
Sesbania wood (<2cm) 16/1/95	1	5	n.d.	0.31	0.019	n.d.	n.d.	n.d.
Sesbania wood (<2cm) 16/1/95	1	6	1383.5	0.98	0.053	15372	150.6	8.147
Sesbania wood (<2cm) 16/1/95	1	7	1508.5	0.80	0.048	16761	134.1	8.045
Sesbania wood (<2cm) 16/1/95	1	8	318.6	0.74	0.035	3540	26.2	1.239
Sesbania wood (<2cm) 16/1/95	2	1	284	0.85	0.037	3156	26.8	1.168
Sesbania wood (<2cm) 16/1/95	2	2	352.4	0.43	0.017	5979	25.7	1.016
Sesbania wood (<2cm) 16/1/95	2	3	1632.6	0.88	0.043	11321	99.6	4.868
Sesbania wood (<2cm) 16/1/95	2	4	797	0.98	0.053	8856	86.8	4.694
Sesbania wood (<2cm) 16/1/95	2	5	1168	0.89	0.039	12978	115.5	5.061
Sesbania wood (<2cm) 16/1/95	2	6	1182.8	0.77	0.045	5830	44.9	2.623
Sesbania wood (<2cm) 16/1/95	2	7	1384.9	0.26	0.014	19114	49.7	2.676
Sesbania wood (<2cm) 16/1/95	2	8	841.7	1.07	0.058	9352	100.1	5.424
Sesbania wood (<2cm) 16/1/95	3	1	702.8	1.00	0.042	7809	78.1	3.280
Sesbania wood (<2cm) 16/1/95	3	2	452.1	0.95	0.045	5023	47.7	2.260
Sesbania wood (<2cm) 16/1/95	3	3	1464.5	0.96	0.043	16272	156.2	6.997
Sesbania wood (<2cm) 16/1/95	3	4	915.9	0.89	0.039	10177	90.6	3.969
Sesbania wood (<2cm) 16/1/95	3	5	1425.8	0.31	0.014	15842	49.1	2.218
Sesbania wood (<2cm) 16/1/95	3	6	1017.4	0.38	0.016	11484	43.6	1.837
Sesbania wood (<2cm) 16/1/95	3	7	775.4	1.05	0.036	8616	90.5	3.102
Sesbania wood (<2cm) 16/1/95	3	8	960.1	0.93	0.046	10668	99.2	4.907
Sesbania wood (<2cm) 16/1/95	4	1	422.7	1.08	0.055	4697	50.7	2.583
Sesbania wood (<2cm) 16/1/95	4	2	1144.7	0.97	0.048	8233	79.9	3.952
Sesbania wood (<2cm) 16/1/95	4	3	391.9	0.76	0.038	6772	51.5	2.573
Sesbania wood (<2cm) 16/1/95	4	4	1051.6	0.80	0.034	11684	93.5	3.973
Sesbania wood (<2cm) 16/1/95	4	5	1227.9	1.19	0.049	13643	162.4	6.685
Sesbania wood (<2cm) 16/1/95	4	6	1187.4	1.02	0.021	13193	134.6	2.771
Sesbania wood (<2cm) 16/1/95	4	7	1217	1.04	0.053	13522	140.6	7.167
Sesbania wood (<2cm) 16/1/95	4	8	775.8	0.26	0.015	16627	43.2	2.494

Table VI.3.1 - continued -

Sesbania	wood (>2cm)	16/1/95	1	1	464.1	0.80	0.039	5156	41.3	2.011
Sesbania	wood (>2cm)	16/1/95	1	2	1305	1.10	0.057	14500	159.5	8.265
Sesbania	wood (>2cm)	16/1/95	1	3	831.4	0.32	0.016	9237	29.6	1.478
Sesbania	wood (>2cm)	16/1/95	1	4	548.3	0.36	0.016	6092	21.9	0.975
Sesbania	wood (>2cm)	16/1/95	1	5	1322	0.31	0.014	14689	45.5	2.056
Sesbania	wood (>2cm)	16/1/95	1	6	1716.9	0.36	0.018	19077	68.7	3.434
Sesbania	wood (>2cm)	16/1/95	1	7	973.1	0.28	0.013	10812	30.3	1.406
Sesbania	wood (>2cm)	16/1/95	1	8	1014.6	0.74	0.036	11274	83.4	4.059
Sesbania	wood (>2cm)	16/1/95	2	1	644.4	0.25	0.014	7160	17.9	1.002
Sesbania	wood (>2cm)	16/1/95	2	2	538.1	0.69	0.029	3916	27.0	1.136
Sesbania	wood (>2cm)	16/1/95	2	3	1018.9	1.10	0.038	18140	199.5	6.893
Sesbania	wood (>2cm)	16/1/95	2	4	1191.9	0.29	0.013	13243	38.4	1.722
Sesbania	wood (>2cm)	16/1/95	2	5	798.7	0.85	0.037	8875	75.4	3.284
Sesbania	wood (>2cm)	16/1/95	2	6	524.7	1.09	0.034	13142	143.2	4.468
Sesbania	wood (>2cm)	16/1/95	2	7	1720.3	1.06	0.054	15377	163.0	8.304
Sesbania	wood (>2cm)	16/1/95	2	8	1554.8	0.28	0.014	17275	48.4	2.419
Sesbania	wood (>2cm)	16/1/95	3	1	478.1	0.89	0.040	5312	47.3	2.125
Sesbania	wood (>2cm)	16/1/95	3	2	800.1	0.98	0.048	8890	87.1	4.267
Sesbania	wood (>2cm)	16/1/95	3	3	1096.8	0.24	0.013	12187	29.2	1.584
Sesbania	wood (>2cm)	16/1/95	3	4	805.5	0.84	0.035	8950	75.2	3.133
Sesbania	wood (>2cm)	16/1/95	3	5	714.9	0.40	0.017	7943	31.8	1.350
Sesbania	wood (>2cm)	16/1/95	3	6	1033.6	1.07	0.044	11304	121.0	4.974
Sesbania	wood (>2cm)	16/1/95	3	7	709	0.24	0.011	7878	18.9	0.867
Sesbania	wood (>2cm)	16/1/95	3	8	594.8	0.77	0.032	6607	50.9	2.114
Sesbania	wood (>2cm)	16/1/95	4	1	1761.7	0.37	0.020	19574	72.4	3.915
Sesbania	wood (>2cm)	16/1/95	4	2	741	0.43	0.024	12719	54.7	3.053
Sesbania	wood (>2cm)	16/1/95	4	3	609.5	0.88	0.047	4354	38.3	2.047
Sesbania	wood (>2cm)	16/1/95	4	4	354	0.94	0.045	3933	37.0	1.770
Sesbania	wood (>2cm)	16/1/95	4	5	612	0.86	0.044	6800	58.5	2.992
Sesbania	wood (>2cm)	16/1/95	4	6	775.7	0.84	0.040	8619	72.4	3.447
Sesbania	wood (>2cm)	16/1/95	4	7	590.9	0.83	0.042	6566	54.5	2.758
Sesbania	wood (>2cm)	16/1/95	4	8	1496.4	1.04	0.055	8620	89.7	4.741
Sesbania	leaf	16/1/95	1	1	988.6	3.29	0.128	989	32.5	1.265
Sesbania	leaf	16/1/95	1	2	2342.9	3.58	0.137	2343	83.9	3.210
Sesbania	leaf	16/1/95	1	3	1038	3.27	0.128	1038	33.9	1.329
Sesbania	leaf	16/1/95	1	4	1833	3.24	0.111	1833	59.4	2.035
Sesbania	leaf	16/1/95	1	5	1922.5	3.28	0.110	1923	63.1	2.115
Sesbania	leaf	16/1/95	1	6	3746.3	3.68	0.159	3746	137.9	5.957
Sesbania	leaf	16/1/95	1	7	2136.3	3.49	0.135	2136	74.6	2.884
Sesbania	leaf	16/1/95	1	8	862.9	3.99	0.163	863	34.4	1.407
Sesbania	leaf	16/1/95	2	1	31.4	3.40	0.128	419	14.2	0.536
Sesbania	leaf	16/1/95	2	2	19.8	3.53	0.128	338	11.9	0.432
Sesbania	leaf	16/1/95	2	3	159.9	3.56	0.143	1776	63.2	2.540
Sesbania	leaf	16/1/95	2	4	103.4	3.75	0.136	1148	43.1	1.562
Sesbania	leaf	16/1/95	2	5	102.4	3.40	0.130	1138	38.7	1.479
Sesbania	leaf	16/1/95	2	6	131.1	3.55	0.143	1457	51.7	2.083
Sesbania	leaf	16/1/95	2	7	189.6	3.36	0.132	2106	70.8	2.781
Sesbania	leaf	16/1/95	2	8	162.8	3.88	0.147	1809	70.2	2.659
Sesbania	leaf	16/1/95	3	1	55.4	3.29	0.110	616	20.3	0.678
Sesbania	leaf	16/1/95	3	2	89.2	3.59	0.137	988	35.5	1.353
Sesbania	leaf	16/1/95	3	3	115.6	3.60	0.147	1299	46.8	1.909
Sesbania	leaf	16/1/95	3	4	135.8	3.38	0.106	1509	51.0	1.600
Sesbania	leaf	16/1/95	3	5	84.9	3.87	0.144	944	36.5	1.359
Sesbania	leaf	16/1/95	3	6	332.6	3.33	0.131	3696	123.1	4.841
Sesbania	leaf	16/1/95	3	7	93.3	3.19	0.118	1036	33.1	1.223
Sesbania	leaf	16/1/95	3	8	351	3.91	0.151	3901	152.5	5.890
Sesbania	leaf	16/1/95	4	1	449.5	3.31	0.106	4994	165.3	5.294
Sesbania	leaf	16/1/95	4	2	168.5	3.68	0.148	1872	68.9	2.771
Sesbania	leaf	16/1/95	4	3	27.9	3.73	0.141	310	11.6	0.437
Sesbania	leaf	16/1/95	4	4	132.4	3.71	0.135	1471	54.6	1.986
Sesbania	leaf	16/1/95	4	5	147.8	3.35	0.127	1643	55.0	2.086
Sesbania	leaf	16/1/95	4	6	371.5	3.84	0.142	4128	158.5	5.861
Sesbania	leaf	16/1/95	4	7	192.5	3.05	0.102	2139	65.2	2.182
Sesbania	leaf	16/1/95	4	8	215.8	3.69	0.137	2397	88.5	3.284

Table VI.3.1 - continued -

Sesbania pod 16/1/95	1	1	0	0	0	0	0	0
Sesbania pod 16/1/95	1	2	0	0	0	0	0	0
Sesbania pod 16/1/95	1	3	0	0	0	0	0	0
Sesbania pod 16/1/95	1	4	0	0	0	0	0	0
Sesbania pod 16/1/95	1	5	0	0	0	0	0	0
Sesbania pod 16/1/95	1	6	8	2.65	0.206	88.89	2.4	0.183
Sesbania pod 16/1/95	1	7	1.6	2.31	0.153	17.78	0.4	0.027
Sesbania pod 16/1/95	1	8	0	0	0	0	0	0
Sesbania pod 16/1/95	2	1	1.2	2.77	0.216	13.33	0.4	0.029
Sesbania pod 16/1/95	2	2	0	0	0	0	0	0
Sesbania pod 16/1/95	2	3	2.3	2.86	0.227	25.56	0.7	0.058
Sesbania pod 16/1/95	2	4	27.8	2.43	0.163	308.89	7.5	0.503
Sesbania pod 16/1/95	2	5	17.4	2.37	0.156	193.33	4.6	0.302
Sesbania pod 16/1/95	2	6	0	0	0	0	0	0
Sesbania pod 16/1/95	2	7	19.6	2.54	0.169	217.78	5.5	0.368
Sesbania pod 16/1/95	2	8	1.5	2.59	0.202	16.67	0.4	0.034
Sesbania pod 16/1/95	3	1	6.3	2.47	0.176	70.00	1.7	0.123
Sesbania pod 16/1/95	3	2	7.5	2.63	0.205	83.33	2.2	0.171
Sesbania pod 16/1/95	3	3	31.6	2.24	0.146	351.11	7.9	0.513
Sesbania pod 16/1/95	3	4	0	0	0	0	0	0
Sesbania pod 16/1/95	3	5	5.2	2.45	0.179	57.78	1.4	0.103
Sesbania pod 16/1/95	3	6	9.5	2.62	0.195	105.56	2.8	0.206
Sesbania pod 16/1/95	3	7	6.1	2.74	0.219	67.78	1.9	0.148
Sesbania pod 16/1/95	3	8	22.3	2.52	0.194	247.78	6.2	0.481
Sesbania pod 16/1/95	4	1	47.1	2.71	0.206	523.33	14.2	1.078
Sesbania pod 16/1/95	4	2	0.9	2.47	0.164	10.00	0.2	0.016
Sesbania pod 16/1/95	4	3	4.3	2.61	0.204	47.78	1.2	0.097
Sesbania pod 16/1/95	4	4	0	0	0	0	0	0
Sesbania pod 16/1/95	4	5	0	0	0	0	0	0
Sesbania pod 16/1/95	4	6	0	0	0	0	0	0
Sesbania pod 16/1/95	4	7	0	0	0	0	0	0
Sesbania pod 16/1/95	4	8	0	0	0	0	0	0

Table VI.3.2: Biomass assessments during the short rains 1994 in weed fallow. Weed mortality data in the weed fallow is presented in appendix VI.5.

Description	rep.	sample	sample d.w. (g)	N (%)	P (%)	yield (kg/ha)	total N (kg/ha)	total P (kg/ha)
Weed harvest regrowth 16/95	1	-	1009.2	0.88	0.099	2018	17.8	1.998
Weed harvest regrowth 16/95	2	-	948.6	0.77	0.122	2710	20.9	3.307
Weed harvest regrowth 16/95	3	-	710.5	1.02	0.125	2034	20.7	2.543
Weed harvest regrowth 16/95	4	-	1004.1	0.92	0.115	2932	27.0	3.372
Weed harvest biomass 16/1/95	1	-	12594	0.83	0.118	7143	59.3	8.428
Weed harvest biomass 16/1/95	2	-	8434.7	1.09	0.140	14072	153.4	19.701
Weed harvest biomass 16/1/95	3	-	14072	0.69	0.088	8435	58.2	7.423
Weed harvest biomass 16/1/95	4	-	7142.6	0.60	0.067	12594	75.6	8.438

Table VI.3.3: Biomass assessments during the short rains 1994 in maize.

Description	rep.	sample	sample d.w. (g)	N (%)	P (%)	yield (kg/ha)	total N (kg/ha)	total P (kg/ha)
Weeding biomass 17/9/94	1	-	41.9	2.42	0.166	4.19	0.1	0.007
Weeding biomass 17/9/94	2	-	53.4	2.53	0.164	5.34	0.1	0.009
Weeding biomass 17/9/94	3	-	36.7	2.79	0.182	3.67	0.1	0.007
Weeding biomass 17/9/94	4	-	36	2.95	0.197	3.6	0.1	0.007
Maize thinning 17/9/94	1	-	348.6	3.02	0.205	34.9	1.1	0.071
Maize thinning 17/9/94	2	-	338.6	2.62	0.166	33.9	0.9	0.056
Maize thinning 17/9/94	3	-	311.9	3.06	0.204	31.2	1.0	0.064
Maize thinning 17/9/94	4	-	36	2.91	0.195	36.0	1.0	0.070
Weeding biomass 14/12/94	1	-	3619.3	1.83	0.140	361.9	6.6	0.507
Weeding biomass 14/12/94	2	-	4415.8	1.72	0.137	441.6	7.6	0.605
Weeding biomass 14/12/94	3	-	2713	1.73	0.122	271.3	4.7	0.331
Weeding biomass 14/12/94	4	-	2479.9	1.98	0.145	248.0	4.9	0.360
Biomass cob 16/12/94	1	-	478.1	1.85	0.290	773.0	14.3	2.242
Biomass cob 16/12/94	2	-	181.9	1.87	0.287	293.9	5.5	0.844
Biomass cob 16/12/94	3	-	75.9	1.87	0.287	122.7	2.3	0.352
Biomass cob 16/12/94	4	-	69.4	1.84	0.285	112.1	2.1	0.319
Biomass stover 16/12/94	1	-	1989	1.36	0.104	3214.6	43.7	3.343
Biomass stover 16/12/94	2	-	1577.8	1.51	0.110	2549.9	38.5	2.805
Biomass stover 16/12/94	3	-	1398.4	1.41	0.104	2260.1	31.9	2.350
Biomass stover 16/12/94	4	-	1177.7	1.36	0.093	1903.3	25.9	1.770
Weeding biomass 9/1/95	1	-	43.8	2.29	0.186	16.34	0.4	0.030
Weeding biomass 9/1/95	2	-	60	2.03	0.170	22.38	0.5	0.038
Weeding biomass 9/1/95	3	-	12.7	2.02	0.179	4.74	0.1	0.008
Weeding biomass 9/1/95	4	-	29.8	2.14	0.189	11.11	0.2	0.021
Harvest grain 9/1/95	1	-	460.1	1.44	0.197	924.0	13.3	1.820
Harvest grain 9/1/95	2	-	230.1	1.43	0.182	191.9	2.7	0.349
Harvest grain 9/1/95	3	-	306.4	1.43	0.180	224.1	3.2	0.402
Harvest grain 9/1/95	4	-	292.9	1.47	0.187	291.5	4.3	0.545
Harvest stover 9/1/95	1	-	5019.7	0.8	0.055	1872.1	15.0	1.030
Harvest stover 9/1/95	2	-	1758.9	0.8	0.055	656	5.2	0.361
Harvest stover 9/1/95	3	-	3348.1	0.8	0.055	1248.7	10.0	0.687
Harvest stover 9/1/95	4	-	3183.6	0.8	0.055	1187.4	9.5	0.653
Harvest rachis 9/1/95	1	-	98.2	0.51	0.04	197.2	1.0	0.079
Harvest rachis 9/1/95	2	-	78.1	0.51	0.04	65.7	0.3	0.026
Harvest rachis 9/1/95	3	-	106	0.51	0.04	77.5	0.4	0.031
Harvest rachis 9/1/95	4	-	84.1	0.51	0.04	83.7	0.4	0.033

Appendix VI.4: Root production data

Table VI.4.1: Root biomass before the start of the incubation of root ingrowth cores to measure root production

	root d.w. (g)	N (%)	P (%)
maize	0.178	0.75	0.080
sesbania	5.593	0.68	0.059
weed	3.346	0.82	0.051

Table VI.4.2: Root biomass and root production (abbreviated with prod.) at the er of the incubation of root ingrowth cores per treatment

Trt	rep	distance from row (m)	soil f.w. (g)	root d.w. (g)	d.w.$_{root}$/ d.w.$_{soil}$ (g/kg)	d.w.$_{root}$/ volume (g/cm3)	root prod. (kg/ha/d)	rel. root prod (1/day)
maize	1	0.125	1127.9	0.405	0.359	0.000	68.885	0.034
		0.25	1253.2	0.523	0.417	0.001	96.302	0.07
		0.375	1309.7	0.502	0.383	0.001	82.176	0.081
	2	0.125	1143.2	0.51	0.446	0.001	86.744	0.043
		0.25	1151.3	0.492	0.427	0.001	90.594	0.075
		0.375	1197.9	0.507	0.423	0.001	82.994	0.082
	3	0.125	1113.5	0.547	0.491	0.001	93.037	0.047
		0.25	1283.1	0.536	0.418	0.001	98.696	0.081
		0.375	1194.9	0.315	0.264	0.000	51.564	0.051
sesb.	1	0.25	810.2	0.316	0.390	0.000	81.195	0.004
		0.5	895.3	0.664	0.742	0.001	240.057	0.019
		0.75	1060.3	1.04	0.981	0.001	232.238	0.022
		1	998.2	1.126	1.128	0.001	221.362	0.042
	2	0.25	1088	0.948	0.871	0.001	202.989	0.010
		0.5	834.1	0.7	0.839	0.001	253.072	0.020
		0.75	966.2	0.997	1.032	0.001	222.636	0.021
		1	1064	0.787	0.740	0.001	154.717	0.030
	3	0.25	992	1.194	1.204	0.001	255.663	0.013
		0.5	987	0.967	0.980	0.001	314.641	0.025
		0.75	948.1	0.916	0.966	0.001	204.548	0.019
		1	1057	0.49	0.464	0.001	96.330	0.018
weed	1	-	1106.1	1.058	0.957	0.001	176.128	0.019
	2	-	950.4	0.377	0.397	0.001	72.416	0.008
	3	-	1165.7	0.533	0.457	0.001	88.730	0.010
	4	-	1109.5	0.604	0.544	0.001	100.550	0.011
	5	-	1150	0.822	0.715	0.001	136.841	0.015
	6	-	922.5	0.656	0.711	0.001	121.340	0.013
	7	-	962.6	0.768	0.798	0.001	127.851	0.014
	8	-	1050.7	0.63	0.600	0.001	104.878	0.012

Table VI.4.3: Total root biomass at the end of the incubation

	Root d.w. (g)	N (%)	P (%)
maize	0.482	1.31	0.093
sesbania	0.845	1.44	0.092
weed	0.681	1.43	0.075

Appendix VI.5: Data on sesbania leaf and weed mortality

Table VI.5.1: Leaf mortality data in the sesbania fallow during the short rains 1994

		sesb. 1			sesb. 2			sesb. 3			sesb. 4		
	date	rep.1	rep.2	rep.3	rep.1	rep.2	rep.3	rep.1	rep.2	rep.3	rep.1	rep.2	rep.3
d.w.	190894	192.9	208.9	189.3	207.7	270.2	288.1	119.6	149.4	112.5	219.6	179.8	161.9
(kg/ha)	070994	313.7	249.4	201.8	311.9	335.1	412.5	190.5	238.1	242.9	370.2	276.8	366.1
	280994	237.5	488.1	397.6	387.5	435.1	550.0	275.6	367.9	347.6	422.0	469.6	492.3
	191094	278.6	248.8	176.8	182.1	246.4	258.3	141.7	156.0	156.0	261.3	271.4	285.1
	091194	162.5	154.2	153.6	205.4	159.5	148.2	88.1	111.9	104.2	228.0	288.7	158.3
	071294	383.9	329.2	238.7	374.4	392.9	510.1	220.8	227.4	229.8	367.9	362.5	467.3
	211294	206.5	197.6	148.8	182.7	245.2	321.4	108.3	129.2	129.8	190.5	278.0	289.3
	110195	271.4	208.9	200.0	241.7	150.6	181.0	136.3	130.4	207.7	180.4	203.0	330.4
N	190894	2.72	2.61	2.58	2.59	2.77	2.29	2.45	2.44	2.89	2.62	2.66	2.79
(%)	070994	2.18	2.35	2.50	2.34	2.31	2.29	2.26	2.17	2.26	2.28	2.15	2.17
	280994	2.36	2.14	2.19	2.39	2.07	2.28	2.38	2.03	2.37	2.22	2.24	2.23
	191094	2.14	2.10	2.16	2.17	2.27	2.19	1.94	2.12	2.03	2.42	2.08	2.44
	091194	2.05	1.98	1.97	2.16	2.08	2.12	2.08	1.88	2.05	2.19	2.16	2.24
	071294	2.07	2.25	2.06	2.05	2.66	2.70	2.33	2.39	2.14	2.31	2.71	2.67
	211294	2.26	2.17	2.17	2.23	2.14	2.14	2.19	2.18	2.21	2.17	2.22	2.13
	110195	1.88	2.29	1.95	2.01	2.27	1.94	1.78	1.90	1.78	1.84	1.93	1.91
P	190894	0.053	0.067	0.047	0.045	0.064	0.070	0.064	0.068	0.080	0.079	0.079	0.092
(%)	070994	0.064	0.048	0.064	0.066	0.067	0.067	0.061	0.061	0.067	0.047	0.061	0.061
	280994	0.059	0.052	0.060	0.064	0.055	0.049	0.061	0.059	0.062	0.053	0.058	0.050
	191094	0.045	0.045	0.045	0.057	0.054	0.057	0.048	0.057	0.051	0.069	0.056	0.063
	091194	0.048	0.044	0.040	0.054	0.051	0.053	0.061	0.053	0.063	0.069	0.067	0.076
	071294	0.053	0.074	0.046	0.047	0.084	0.088	0.066	0.070	0.053	0.070	0.086	0.087
	211294	0.075	0.075	0.074	0.072	0.072	0.073	0.074	0.074	0.078	0.079	0.080	0.074
	110195	0.052	0.075	0.060	0.061	0.077	0.061	0.054	0.064	0.056	0.055	0.060	0.063

Table VI.5.2: Weed mortality, measured by amount of dead plant material per 0.25 m^2 in the weed fallow during the short rains 1994

		weed 1				weed 2				weed 3				weed 4			
		rep.1	rep.2	rep.3	rep.4	rep.1	rep.2	rep.3	rep.4	rep.1	rep.2	rep.3	rep.4	rep.1	rep.2	rep.3	rep.4
d.w.	280994	103.3	89.3	99.5	76.6	62.1	79.7	73.6	127.5	57.8	94.1	109.7	101.2	64	141.6	165.9	156
(kg/ha)	191094	54.7	35.7	22.5	22.3	27.3	33	63	31.5	14.3	27.4	34.6	51.2	17.8	27.8	37.8	58.5
	091194	36.5	23.1	19.9	23.4	18.7	25.6	23.8	30.4	13	22.2	21.6	19.4	18.5	16.8	18.9	27.8
	051294	41.6	43.1	23.4	22.7	21	19.5	27.4	31.2	38.7	29.7	33.3	38	21.7	25.8	19.2	30.6
	211294	16	26.3	24	13.4	17.8	20.6	24.3	28.1	11.7	15.6	22	17.9	10.8	18.1	25.9	32.7
	110195	16.8	26.3	20.4	9.6	34.5	25	27.2	43.3	29.7	20	20.2	23.9	14.4	20.1	27.3	41.4
N	280994	0.92	1.09	0.83	1.47	0.94	0.83	1.05	0.91	1.05	0.76	1.03	1.06	1.06	0.72	1.24	0.96
(%)	191094	1.36	0.85	0.89	1.16	0.81	0.96	1.24	1.00	0.82	1.29	1.27	1.04	1.38	0.91	1.12	1.34
	091194	0.75	0.10	0.99	1.12	0.81	1.11	0.97	1.05	1.02	0.79	1.15	0.98	1.17	0.76	1.18	1.03
	051294	0.62	1.02	1.09	0.97	0.97	0.85	0.98	0.93	1.06	0.83	1.12	1.12	0.64	1.01	0.56	0.90
	211294	0.84	1.16	1.06	0.88	1.01	1.22	0.99	1.14	0.99	0.91	1.15	1.14	1.20	0.80	1.17	0.81
	110195	1.00	0.87	1.02	1.27	0.88	0.81	0.73	1.03	1.24	0.74	0.99	0.94	1.25	1.05	1.38	1.06
P	280994	0.074	0.073	0.068	0.110	0.094	0.072	0.108	0.081	0.078	0.064	0.079	0.097	0.082	0.069	0.122	0.091
(%)	191094	0.149	0.070	0.086	0.099	0.085	0.091	0.109	0.104	0.078	0.107	0.117	0.101	0.110	0.085	0.073	0.145
	091194	0.057	0.008	0.083	0.104	0.088	0.119	0.091	0.101	0.079	0.074	0.105	0.094	0.086	0.078	0.111	0.102
	051294	0.050	0.073	0.097	0.087	0.085	0.092	0.085	0.087	0.103	0.081	0.105	0.099	0.050	0.091	0.042	0.092
	211294	0.088	0.163	0.110	0.093	0.126	0.163	0.123	0.136	0.096	0.106	0.128	0.137	0.140	0.081	0.126	0.087
	110195	0.115	0.095	0.091	0.169	0.102	0.088	0.072	0.117	0.109	0.068	0.105	0.114	0.112	0.111	0.166	0.109

Appendix VI.6: Root conversion data

Table VI.6.1: Sesbania root conversion data as measured with a mesh bag incubation study in the 10-20 cm soil layer during the short rains of 1994.
Note retr. = retrieval

Retr. time (day)	weight t=0 (g d.w.)	weight t=retr. (g d.w.)	N content (%)	P content (%)	ash content (%)	fraction d.w. (-)	fraction N (-)	fraction P (-)
0	3.627	3.522	1.30	0.085	47.2	1.000	1.000	1.000
0	2.044	2.007	1.77	0.083	23.7	1.000	1.000	1.000
0	2.500	2.929	1.52	0.079	29.7	1.000	1.000	1.000
0	2.650	2.244	1.66	0.086	34.4	1.000	1.000	1.000
0	1.077	1.108	1.46	0.065	17.6	1.000	1.000	1.000
9	3.490	3.342	1.19	0.058	24.8	0.906	0.868	0.861
9	3.177	2.779	1.36	0.063	21.0	0.869	0.952	0.898
9	1.779	1.19	1.18	0.054	30.4	0.586	0.556	0.518
9	2.932	2.248	1.25	0.062	16.0	0.810	0.815	0.823
9	2.994	2.355	1.24	0.061	15.0	0.841	0.840	0.841
10	2.402	2.273	1.42	0.057	28.1	0.979	0.902	0.701
10	1.964	2.005	1.38	0.062	36.5	0.933	0.835	0.727
10	1.386	1.228	1.46	0.064	27.9	0.919	0.871	0.739
10	1.673	1.786	1.37	0.080	34.5	1.006	0.894	1.011
10	2.515	3.304	0.69	0.045	38.9	1.155	0.517	0.653
17	2.154	1.7	1.00	0.047	19.4	0.916	0.594	0.541
17	3.728	3.547	1.27	0.125	53.2	0.641	0.528	1.006
17	3.213	3.511	1.43	0.056	36.5	0.999	0.926	0.703
17	3.552	4.56	1.63	0.093	46.1	0.996	1.053	1.164
17	1.127	0.754	1.31	0.064	30.6	0.668	0.568	0.537
36	2.909	2.195	1.45	0.074	35	0.617	0.720	0.748
36	2.809	1.762	1.18	0.059	30.6	0.548	0.520	0.530
36	2.857	1.802	1.13	0.055	30.6	0.551	0.501	0.496
36	2.715	1.66	1.09	0.048	24.8	0.578	0.508	0.455
36	1.801	1.607	1.17	0.060	42.1	0.650	0.612	0.639
39	2.516	2.253	1.60	0.081	36.1	0.824	0.855	0.838
39	3.090	2.402	0.69	0.050	65.6	0.385	0.172	0.242
39	2.780	2.593	1.49	0.057	27.4	0.975	0.942	0.698
39	2.689	2.963	1.31	0.077	51.9	0.763	0.648	0.738
39	2.708	2.021	1.64	0.081	37.1	0.676	0.719	0.688
51	4.539	3.27	1.74	0.073	27.3	0.659	0.923	0.788
51	2.733	2.158	1.00	0.041	13.0	0.864	0.696	0.581
51	1.793	1.186	0.93	0.050	32.6	0.561	0.420	0.460
51	3.969	2.891	1.44	0.074	37.9	0.569	0.660	0.690
51	2.669	1.932	1.42	0.064	24.6	0.687	0.785	0.720
57	2.583	0.681	0.98	0.046	30.5	0.230	0.182	0.174
57	2.546	1.644	1.54	0.067	23.6	0.621	0.769	0.682
57	1.692	1.835	1.37	0.064	48.0	0.709	0.782	0.744
57	2.381	1.397	0.98	0.049	39.3	0.448	0.353	0.360
57	2.994	2.73	0.49	0.031	30.4	0.798	0.315	0.406
62	3.396	1.31	0.61	0.053	50.5	0.240	0.118	0.209
62	3.615	1.081	1.14	0.049	20.9	0.298	0.273	0.239
62	2.925	1.699	0.95	0.052	39.9	0.439	0.336	0.374
62	5.190	1.642	1.00	0.057	48.3	0.206	0.166	0.192
62	4.339	1.569	1.06	0.047	39.9	0.273	0.233	0.211

Table VI.6.1 - continued -

72	3.847	5.986	0.45	0.052	77.1	0.513	0.150	0.335
72	3.261	3.259	1.30	0.077	54.0	0.662	0.558	0.640
72	2.218	0.744	0.95	0.042	24.7	0.364	0.224	0.192
72	2.624	1.943	1.36	0.063	30.8	0.737	0.650	0.584
81	1.724	0.483	1.36	0.054	15.6	0.340	0.300	0.231
81	2.976	2.162	1.44	0.067	27.5	0.758	0.708	0.638
81	3.478	2.311	1.52	0.080	39.4	0.580	0.571	0.582

Table VI.6.2: Maize root conversion data as measured with a mesh bag incubation study in the 10-20 cm soil layer during the short rains of 1994.
Note retr. = retrieval

Retr. time (day)	weight t=0 (g d.w.)	weight t=retr. (g d.w.)	N content (%)	P content (%)	ash content (%)	fraction d.w. (-)	fraction N (-)	fraction P (-)
0	3.097	2.937	0.79	0.054	51.8	1.000	1.000	1.000
0	5.694	3.303	1.24	0.069	26.5	1.000	1.000	1.000
0	2.559	2.716	0.84	0.048	40.7	1.000	1.000	1.000
0	2.467	1.876	0.93	0.062	47.9	1.000	1.000	1.000
0	2.491	4.032	0.70	0.048	40.1	1.000	1.000	1.000
9	1.033	0.727	1.09	0.047	30.3	0.716	0.805	0.601
9	0.861	0.701	1.41	0.068	28.8	0.846	1.020	1.028
9	0.910	0.76	0.91	0.042	33.2	0.814	0.764	0.611
9	0.988	0.495	0.97	0.042	33.3	0.488	0.488	0.366
9	1.615	0.276	0.80	0.071	52.8	0.118	0.097	0.149
10	5.335	6.389	0.64	0.058	58.5	0.848	0.603	0.875
10	2.388	2.931	0.85	0.062	53.6	0.972	0.918	1.072
10	2.594	3.076	0.84	0.048	48.5	1.042	0.973	0.890
10	3.403	5.967	0.52	0.052	75.5	0.733	0.424	0.678
10	1.835	2.717	0.77	0.042	54.6	1.147	0.981	0.857
17	3.733	3.074	0.63	0.063	65.6	0.483	0.338	0.542
17	4.330	3.284	0.75	0.054	59.8	0.520	0.434	0.500
17	2.990	3.558	0.68	0.052	57.6	0.861	0.651	0.797
17	2.104	3.003	0.73	0.049	58.8	1.004	0.814	0.875
17	5.280	2.184	0.61	0.053	48.1	0.366	0.248	0.345
36	3.482	1.215	0.94	0.041	34.1	0.336	0.325	0.246
36	2.579	0.203	1.23	0.060	37.8	0.071	0.091	0.077
36	2.583	0.17	0.92	0.040	29.5	0.068	0.064	0.048
36	1.502	0.581	0.89	0.039	34.9	0.368	0.337	0.256
36	1.057	0.3	0.79	0.053	34.1	0.273	0.222	0.258
39	2.665	3.501	0.92	0.054	54.3	1.024	1.047	0.984
39	5.114	2.673	1.28	0.060	40.0	0.535	0.761	0.571
39	3.901	3.259	0.75	0.053	59.6	0.576	0.480	0.543
39	3.467	2.366	0.74	0.053	65.0	0.408	0.335	0.384
39	2.094	2.667	0.98	0.063	54.8	0.982	1.070	1.101
39	3.986	3.811	0.88	0.054	44.1	0.912	0.892	0.876
51	1.558	0.083	0.92	0.052	32.3	0.053	0.050	0.049
51	1.811	0.717	1.03	0.040	28.4	0.414	0.439	0.296
51	2.129	0.093	1.27	0.057	29.0	0.045	0.059	0.046
51	1.678	0.295	0.50	0.043	49.2	0.130	0.067	0.100
51	1.750	0.34	0.91	0.037	34.7	0.185	0.174	0.122

Table VI.6.2 - continued -

57	1.770	0.248	0.93	0.039	38.9	0.125	0.120	0.087
57	1.627	0.631	1.26	0.060	38.8	0.346	0.450	0.371
57	2.455	0.695	0.61	0.049	68.6	0.130	0.082	0.114
57	1.021	0.265	0.95	0.051	26.9	0.277	0.271	0.252
57	1.060	0.478	1.22	0.049	35.2	0.427	0.537	0.373
62	1.025	0.064	1.25	0.051	17.9	0.075	0.096	0.068
62	1.070	0.252	1.01	0.047	24.8	0.259	0.269	0.217
62	2.712	0.651	1.71	0.077	26.9	0.256	0.452	0.352
62	1.620	0.25	1.2	0.053	24.8	0.169	0.210	0.160
62	1.793	0.581	0.84	0.038	29.5	0.333	0.289	0.226
72	4.000	3.46	1.51	0.085	45.6	0.803	1.347	1.214
72	4.652	3.419	0.68	0.040	42.2	0.725	0.548	0.516
72	3.786	1.655	0.50	0.054	72.1	0.208	0.116	0.200
72	6.603	4.995	0.63	0.047	68.2	0.411	0.287	0.343
72	6.394	3.659	0.88	0.055	55.0	0.439	0.430	0.430
81	3.002	0.351	0.86	0.043	36.4	0.127	0.121	0.097
81	4.576	0.49	0.88	0.041	36.4	0.116	0.114	0.085
81	2.235	0.121	0.83	0.044	36.4	0.059	0.054	0.046

Table VI.6.3: Weed root conversion data as measured with a mesh bag incubation study in the 10-20 cm soil layer during the short rains of 1994.
Note retr. = retrieval

Retr. time (day)	weight t=0 (g d.w.)	weight t=retr. (g d.w.)	N content (%)	P content (%)	ash content (%)	fraction d.w. (-)	fraction N (-)	fraction P (-)
0	1.689	2.52	0.98	0.060	15.6	1.000	1.000	1.000
0	2.587	3.098	1.38	0.062	12.0	1.000	1.000	1.000
0	1.977	1.876	1.67	0.065	10.9	1.000	1.000	1.000
0	2.201	2.162	1.51	0.058	13.2	1.000	1.000	1.000
0	1.204	1.235	1.67	0.083	12.1	1.000	1.000	1.000
9	2.731	0.314	0.64	0.059	21.4	0.271	0.167	0.288
9	2.030	0.131	0.38	0.022	21.4	0.190	0.090	0.105
9	3.082	0.249	0.44	0.029	21.4	0.179	0.076	0.093
9	2.790	0.131	1.00	0.052	27.8	0.102	0.113	0.106
9	2.055	0.305	1.26	0.061	14.9	0.464	0.563	0.510
10	2.053	2.857	1.09	0.058	34.8	1.040	0.786	0.920
10	3.206	4.458	0.76	0.044	31.2	1.097	0.578	0.735
10	2.562	4.083	1.00	0.056	39.3	1.109	0.769	0.947
10	2.764	3.363	1.26	0.063	26.2	1.029	0.899	0.989
10	2.413	1.628	0.96	0.059	36.4	0.492	0.327	0.442
17	2.295	3.812	1.16	0.059	48.3	0.984	0.792	0.885
17	2.550	1.497	1.47	0.057	18.2	0.550	0.561	0.478
17	2.862	3.972	0.95	0.056	34.7	1.039	0.684	0.887
17	2.491	2.46	0.69	0.041	21.0	0.894	0.428	0.559
17	3.149	3.895	0.68	0.038	28.6	1.012	0.477	0.586
36	3.158	0.054	0.72	0.064	13.0	0.041	0.028	0.047
36	1.686	0.864	0.72	0.064	33.0	1.638	1.134	1.886
36	3.204	0.086	0.72	0.064	13.0	0.064	0.044	0.074
36	2.358	0	0.72	0.064	13.0	0.000	0.000	0.000

Table VI.6.3 - continued -

39	2.811	2.547	0.90	0.049	51.0	0.509	0.318	0.380
39	3.143	3.748	0.94	0.058	43.2	0.776	0.506	0.686
39	3.168	3.781	0.91	0.057	42.4	0.788	0.497	0.685
51	1.320	0.122	0.38	0.024	25.6	0.544	0.199	0.235
51	2.123	0.182	0.93	0.067	25.6	0.231	0.207	0.278
51	1.842	0.195	1.04	0.048	25.6	0.330	0.330	0.285
51	3.516	0.072	0.79	0.048	25.6	0.041	0.031	0.035
51	3.176	0.096	0.61	0.049	25.6	0.063	0.037	0.055
57	2.564	0.081	0.60	0.039	26.4	0.073	0.042	0.051
57	2.923	0.272	0.56	0.029	21.4	0.212	0.114	0.110
57	1.548	0.071	0.64	0.029	26.4	0.183	0.113	0.095
57	2.312	0.313	1.44	0.078	42.0	0.274	0.379	0.384
57	2.056	0.079	0.81	0.044	15.9	0.119	0.093	0.094
62	3.632	0.63	1.01	0.047	25.0	0.344	0.334	0.291
62	2.212	0.044	0.90	0.055	50.6	0.036	0.032	0.036
62	2.795	0.035	1.17	0.047	23.7	0.028	0.032	0.024
62	3.051	0.402	1.09	0.047	24.4	0.283	0.297	0.240
62	2.152	0.017	1.09	0.047	24.4	0.021	0.022	0.018
72	2.565	1.159	0.78	0.054	59.8	0.208	0.113	0.171
72	3.095	1.755	0.87	0.052	52.2	0.311	0.187	0.246
72	2.173	0.71	0.84	0.053	45.2	0.205	0.120	0.166
81	3.887	2.312	0.71	0.041	53.7	0.316	0.155	0.197

Appendix VI.7: Litter conversion data

Table VI.7.1: Weed litter conversion as measured with a mesh bag incubation stu
on top of the soil during the short rains of 1994.
Note:1) retr. = retrieval
2) termite activity; 1 (= yes), 0 (= no)

retr. time (day)	termite activity (-)	weight t=0 (g d.w.)	weight t=retr. (g d.w.)	N content (%)	P content (%)	ash content (%)	fraction N (-)	fraction P (-)	fraction d.w. (-)
3	1	6.941	1.884	0.83	0.059	31.3	0.128	0.106	0.186
3	1	8.101	5.551	0.76	0.060	42.3	0.248	0.228	0.395
3	1	5.485	0.688	1.21	0.124	22.0	0.098	0.117	0.098
3	1	4.530	0.061	0.48	0.035	18.9	0.004	0.004	0.011
3	0	4.615	4.303	0.62	0.048	17.5	0.394	0.355	0.769
3	0	5.489	5.628	1.12	0.088	18.3	0.775	0.709	0.838
3	0	5.119	5.042	1.25	0.087	15.3	0.862	0.698	0.834
3	0	5.282	5.206	1.00	0.095	16.2	0.683	0.754	0.826
8	1	6.688	0.473	0.67	0.058	53.5	0.018	0.018	0.033
8	1	6.972	0.132	0.75	0.054	21.8	0.009	0.008	0.015
8	1	5.205	0.935	1.21	0.092	29.7	0.126	0.112	0.126
8	1	6.524	0.58	0.78	0.065	29.4	0.040	0.039	0.063
8	1	6.448	0.407	1.25	0.080	16.0	0.055	0.041	0.053
11	1	3.863	2.533	0.83	0.074	39.0	0.274	0.284	0.400
11	1	4.853	0.979	1.04	0.087	29.9	0.121	0.118	0.141
11	1	5.526	2.61	0.81	0.072	28.1	0.227	0.235	0.340
11	0	4.701	5.348	1.10	0.086	15.6	0.872	0.793	0.960
11	0	5.475	6.561	0.86	0.080	16.9	0.707	0.765	0.996
11	0	3.842	4.807	0.96	0.066	18.1	0.812	0.650	1.025
11	0	3.540	3.728	1.17	0.106	14.1	0.874	0.921	0.905
11	0	5.560	6.477	1.07	0.095	15.4	0.871	0.899	0.986
12	1	5.879	0.97	0.60	0.041	18.2	0.067	0.053	0.135
12	1	5.028	0.321	0.86	0.063	26.3	0.033	0.029	0.047
12	1	4.166	0.708	0.60	0.050	21.6	0.066	0.064	0.133
14	1	3.839	0.182	1.72	0.047	18.9	0.055	0.017	0.038
14	1	5.464	0.465	0.92	0.038	30.6	0.045	0.022	0.059
14	1	5.426	1.349	0.86	0.057	22.6	0.137	0.105	0.192
14	1	3.817	5.439	1.22	0.074	30.7	0.995	0.702	0.988
14	0	6.234	6.394	0.75	0.062	30.0	0.445	0.428	0.718
14	0	3.843	3.993	1.46	0.072	33.7	0.830	0.476	0.689
14	0	9.226	8.823	1.31	0.144	12.0	0.910	1.164	0.842
14	0	3.623	4.355	1.16	0.102	14.9	0.980	1.002	1.023
18	1	5.594	2.415	1.20	0.076	14.3	0.367	0.270	0.370
18	1	5.283	0.089	1.54	0.109	20.6	0.017	0.014	0.013
18	1	6.523	4.079	1.47	0.061	18.7	0.618	0.298	0.508
18	1	5.229	0.835	1.20	0.095	17.0	0.131	0.121	0.133
18	0	5.397	4.594	1.08	0.080	13.6	0.656	0.566	0.735
18	0	4.219	3.346	1.22	0.089	16.9	0.664	0.564	0.659
18	0	5.404	5.921	0.89	0.076	45.7	0.438	0.435	0.595
18	0	5.829	5.25	1.29	0.095	18.5	0.783	0.671	0.734
19	1	3.664	1.854	1.00	0.055	16.2	0.350	0.224	0.424
19	1	3.709	0.702	1.46	0.040	21.0	0.180	0.057	0.150
19	1	4.178	0.025	1.16	0.061	35.0	0.004	0.002	0.004
19	0	4.072	6.449	0.69	0.051	56.4	0.393	0.338	0.691
19	0	4.545	4.673	1.11	0.087	20.7	0.747	0.681	0.815
19	0	5.093	5.208	1.22	0.083	19.1	0.833	0.659	0.827
19	0	3.590	4.976	0.87	0.066	27.8	0.719	0.634	1.001
19	0	3.146	4.001	0.87	0.086	20.5	0.726	0.835	1.011
25	1	3.624	0.292	1.04	0.071	32.6	0.047	0.037	0.054
25	1	5.119	0.941	0.69	0.076	22.4	0.081	0.104	0.143
25	1	4.052	1.238	0.97	0.067	17.5	0.202	0.162	0.252
25	1	6.172	1.379	0.99	0.117	29.7	0.128	0.176	0.157
25	0	5.698	4.26	0.62	0.039	20.1	0.306	0.224	0.597
25	0	3.519	3.199	1.06	0.075	14.4	0.681	0.560	0.778
25	0	4.742	4.47	0.82	0.059	11.6	0.564	0.472	0.833

Table VI.7.1 - continued -

26	1	5.876	0.73	0.69	0.048	44.1	0.040	0.032	0.069
26	1	3.867	1.262	0.98	0.071	9.4	0.239	0.202	0.296
26	0	5.313	4.644	1.40	0.088	13.0	0.880	0.643	0.760
26	0	6.373	5.691	1.40	0.092	19.2	0.835	0.638	0.722
26	0	7.935	6.811	1.15	0.078	10.5	0.730	0.576	0.768
26	0	3.682	3.068	0.63	0.126	37.7	0.270	0.629	0.519
26	0	5.175	4.483	1.34	0.101	17.0	0.796	0.698	0.719
26	0	6.522	5.889	1.01	0.073	12.0	0.663	0.558	0.795
35	1	5.649	1.225	0.68	0.058	48.5	0.063	0.062	0.112
35	1	3.347	0.466	0.85	0.036	30.2	0.068	0.034	0.097
35	1	3.462	1.219	0.74	0.045	35.1	0.140	0.099	0.229
35	1	4.645	0.791	1.46	0.071	22.9	0.158	0.090	0.131
35	0	5.318	3.413	0.70	0.052	38.8	0.227	0.196	0.393
35	0	3.260	3.916	1.06	0.087	22.5	0.815	0.778	0.931
35	0	4.634	4.494	1.28	0.098	22.2	0.797	0.710	0.754
35	0	4.312	2.688	0.41	0.049	47.9	0.110	0.153	0.325
35	0	4.565	5.109	1.10	0.074	18.3	0.830	0.650	0.914
46	1	4.621	0.926	1.31	0.044	41.5	0.127	0.050	0.117
46	1	3.209	0.365	1.04	0.057	11.9	0.086	0.055	0.100
46	1	5.633	1.042	0.97	0.070	32.6	0.100	0.084	0.125
46	1	6.334	1.075	0.98	0.068	32.4	0.093	0.075	0.115
46	1	3.867	0.68	1.34	0.081	18.0	0.160	0.112	0.144
46	1	6.192	0.577	0.68	0.049	42.0	0.030	0.025	0.054
46	1	4.914	0.175	1.01	0.070	25.4	0.022	0.018	0.027
46	1	4.400	0.244	1.60	0.108	15.0	0.062	0.049	0.047
46	1	6.192	2.028	0.55	0.045	31.4	0.102	0.097	0.225
46	1	5.321	1.057	0.82	0.062	44.0	0.075	0.066	0.111
46	0	2.379	2.922	1.01	0.085	43.8	0.576	0.564	0.690
46	0	6.134	4.639	1.08	0.078	32.7	0.454	0.382	0.509
46	0	3.394	2.576	1.14	0.079	10.1	0.643	0.518	0.682
46	0	6.556	4.652	0.62	0.057	35.4	0.235	0.251	0.458
46	0	4.597	3.862	1.44	0.081	19.5	0.805	0.527	0.676
46	0	5.620	4.415	1.54	0.110	14.9	0.851	0.707	0.669
57	1	4.322	0.066	0.77	0.056	24.1	0.007	0.006	0.012
57	1	5.070	0.293	0.99	0.071	24.1	0.036	0.030	0.044
57	1	3.806	0.086	0.69	0.042	24.1	0.010	0.007	0.017
57	0	5.505	4.479	1.41	0.085	15.3	0.803	0.563	0.689
57	0	7.505	5.936	1.30	0.091	14.8	0.724	0.590	0.674
57	0	3.341	2.41	0.78	0.053	23.5	0.356	0.281	0.552
57	0	8.191	7.809	0.42	0.033	13.7	0.286	0.261	0.823
57	0	6.703	4.134	0.65	0.055	27.0	0.242	0.238	0.450

Table VI.7.2: Sesbania litter conversion as measured with a mesh bag incubation study on top of the soil during the short rains of 1994.
Note:1) retr. = retrieval
2) No distinction between different amounts of termite activity was made

retr. time (day)	weight t=0 (g d.w.)	weight t=retr. (g d.w.)	N content (%)	P content (%)	ash content (%)	fraction N (-)	fraction P (-)	fraction d.w. (-)
11	5.486	4.841	1.84	0.044	17.1	0.880	0.762	0.892
11	5.209	4.506	1.38	0.041	14.1	0.671	0.721	0.906
11	5.123	4.147	1.61	0.047	20.4	0.678	0.717	0.786
11	5.687	5.618	1.56	0.041	18.8	0.818	0.779	0.978
11	4.629	3.461	1.42	0.050	18.4	0.566	0.722	0.744
11	4.838	3.947	1.72	0.046	19.2	0.741	0.718	0.804
11	5.378	5.072	1.92	0.046	21.5	0.929	0.806	0.903
11	5.352	4.731	1.53	0.039	13.9	0.761	0.703	0.928

Table VI.7.2 - continued -

19	5.104	3.836	1.82	0.045	20.3	0.713	0.638	0.730
19	5.551	5.272	1.60	0.041	19.7	0.798	0.740	0.930
19	5.672	5.421	1.51	0.042	19.3	0.762	0.767	0.941
19	5.704	5.268	1.75	0.047	23.2	0.812	0.789	0.865
19	5.214	4.327	1.58	0.040	19.9	0.687	0.630	0.811
19	5.438	4.667	1.83	0.047	23.1	0.790	0.735	0.805
19	5.711	5.149	1.59	0.042	21.6	0.735	0.703	0.862
19	5.155	4.488	1.77	0.045	21.2	0.794	0.731	0.837
35	5.519	8.342	1.15	0.049	45.1	0.624	0.963	1.012
35	5.417	6.804	1.52	0.046	41.9	0.725	0.795	0.890
35	5.484	5.275	1.66	0.048	34.1	0.688	0.720	0.773
35	5.369	4.697	1.71	0.061	26.6	0.718	0.927	0.783
35	5.429	5.160	1.67	0.047	33.0	0.695	0.709	0.777
35	5.091	3.908	1.69	0.048	31.2	0.584	0.600	0.644
35	6.173	6.273	1.84	0.049	29.5	0.862	0.831	0.874
35	4.905	3.344	1.90	0.051	28.2	0.608	0.591	0.597
46	5.385	6.047	1.29	0.044	45.8	0.513	0.634	0.742
46	4.903	5.200	1.25	0.044	42.4	0.499	0.637	0.745
46	5.405	4.865	1.46	0.049	36.7	0.544	0.661	0.695
46	5.461	5.402	1.56	0.057	39.7	0.608	0.805	0.727
46	5.118	5.253	0.45	0.053	72.7	0.082	0.352	0.342
46	5.112	5.992	1.34	0.044	39.1	0.625	0.744	0.871
46	6.209	6.490	1.72	0.054	36.6	0.745	0.847	0.808
46	4.984	4.329	1.52	0.046	36.0	0.552	0.605	0.678
63	5.083	5.494	1.41	0.047	45.5	0.543	0.656	0.718
63	5.417	7.768	1.24	0.046	47.3	0.613	0.823	0.922
63	5.068	4.100	1.31	0.050	46.6	0.370	0.511	0.527
63	6.270	6.744	1.67	0.051	41.0	0.693	0.766	0.774
63	5.062	5.681	1.09	0.047	61.6	0.307	0.480	0.526
63	5.935	5.165	1.74	0.054	38.8	0.606	0.681	0.649
63	4.952	4.724	1.39	0.043	38.8	0.531	0.594	0.712
63	5.111	4.778	1.28	0.048	52.9	0.369	0.500	0.537
94	5.191	1.541	1.25	0.034	35.7	0.156	0.154	0.233
94	5.459	2.680	0.46	0.046	61.1	0.057	0.208	0.233
94	5.235	4.462	1.21	0.053	50.0	0.337	0.535	0.520
94	5.013	3.796	1.51	0.047	34.0	0.493	0.556	0.609
94	4.794	4.038	1.28	0.041	36.1	0.451	0.523	0.656
94	6.384	4.911	1.60	0.054	34.5	0.527	0.644	0.614
94	5.137	3.366	1.42	0.044	38.0	0.377	0.423	0.495

Appendix VI.8: Soil mineralisation data

Table VI.8.1: Soil mineralisation rates as a function of depth, measured as the rate of ammonia formation in an anaerobic incubation

depth (m)	rep.	moisture contents (g/g dw)	ammonia t=0 (mg/kg)	ammonia t=7 (mg/kg)	min.rate (mg/kg/d)	relative min. rate (1/day)
0-15	maize 1	0.295	6.29	41.64	5.050	0.115
	sesb. 1	0.427	16.09	59.65	6.222	0.055
	sesb. 1	0.325	15.05	73.81	8.394	0.080
	sesb. 1	0.283	4.42	47.07	6.093	0.197
	weed 1	0.326	5.84	45.63	5.686	0.139
	bare 1	0.289	2.91	16.11	1.886	0.093
	sesb. 2	0.310	5.84	64.12	8.325	0.204
	sesb. 2	0.306	6.66	47.36	5.813	0.125
	sesb. 2	0.346	5.85	56.91	7.295	0.178
	weed 2	0.299	8.96	38.85	4.270	0.068
	bare 2	0.216	5.40	3.46	-0.278	-0.007
	maize 2	0.303	2.82	39.86	5.291	0.268
	maize 3	0.243	3.76	15.81	1.722	0.065
	weed 3	0.304	3.84	40.54	5.243	0.195
	bare 3	0.234	3.51	19.27	2.250	0.091
	sesb. 3	0.235	3.43	43.09	5.667	0.236
	sesb. 3	0.239	3.82	43.72	5.700	0.213
	sesb. 3	0.304	3.74	41.55	5.402	0.207
	sesb. 4	0.277	13.15	50.09	5.277	0.057
	sesb. 4	0.251	3.30	42.44	5.591	0.242
	sesb. 4	0.251	5.93	19.18	1.893	0.046
	maize 4	0.227	3.68	19.27	2.228	0.086
	weed 4	0.270	3.37	44.95	5.940	0.252
	bare 4	0.320	2.61	12.25	1.378	0.076
15-30	maize 1	0.283	12.38	40.34	3.994	0.046
	sesb. 1	0.303	8.66	36.41	3.964	0.065
	weed 1	0.302	4.66	26.54	3.127	0.096
	bare 1	0.296	4.26	22.05	2.541	0.085
	sesb. 2	0.275	6.82	45.71	5.556	0.116
	weed 2	0.302	4.47	21.75	2.469	0.079
	bare 2	0.278	5.09	18.55	1.923	0.054
	maize 2	0.288	3.97	25.25	3.040	0.109
	maize 3	0.239	9.77	21.60	1.690	0.025
	weed 3	0.291	2.83	19.74	2.416	0.122
	bare 3	0.284	5.04	15.32	1.469	0.042
	sesb. 3	0.280	5.80	23.95	2.594	0.064
	sesb. 4	0.278	6.85	27.71	2.981	0.062
	maize 4	0.248	3.49	19.41	2.274	0.093
	weed 4	0.279	3.79	18.75	2.137	0.081
	bare 4	0.285	13.02	26.33	1.901	0.021

Table VI.8.1 - continued -

30-50	maize 1	0.282	10.23	25.00	2.110	0.029
	sesb. 1	0.315	6.36	17.99	1.662	0.037
	weed 1	0.318	9.49	19.55	1.438	0.022
	maize 1	0.293	5.41	14.16	1.250	0.033
	sesb. 2	0.289	8.62	19.30	1.526	0.025
	weed 2	0.307	9.46	18.18	1.246	0.019
	bare 2	0.302	5.51	14.44	1.275	0.033
	maize 2	0.294	6.15	17.06	1.558	0.036
	maize 3	0.277	8.90	17.51	1.230	0.020
	weed 3	0.292	3.66	15.28	1.659	0.065
	bare 3	0.275	4.74	10.97	0.891	0.027
	sesb. 3	0.275	4.49	18.21	1.960	0.062
	sesb. 4	0.304	5.33	13.61	1.183	0.032
	maize 4	0.286	5.89	13.18	1.042	0.025
	weed 4	0.318	3.67	13.69	1.433	0.056
	bare 4	0.304	6.06	12.99	0.989	0.023
50-100	rep. 1	0.317	8.60	8.89	0.041	0.001
	rep. 2	0.298	4.36	9.15	0.685	0.022
	rep. 3	0.303	5.38	8.22	0.406	0.011
	rep. 4	0.356	4.12	6.77	0.378	0.013
100-150	rep. 1	0.309	5.18	4.64	-0.078	-0.002
	rep. 2	0.300	5.23	5.08	-0.021	-0.001
	rep. 3	0.332	5.52	5.15	-0.053	-0.001
	rep. 4	0.299	5.93	4.40	-0.219	-0.005
150-200	rep. 1	0.092	3.13	3.16	0.004	0.000
	rep. 2	0.281	3.08	3.28	0.029	0.001
	rep. 3	0.281	8.22	3.32	-0.700	-0.012
	rep. 4	0.289	3.82	3.40	-0.060	-0.002
200-250	rep. 1	0.261	3.42	3.54	0.017	0.001
	rep. 2	0.262	2.95	3.32	0.054	0.003
	rep. 3	0.254	4.08	6.57	0.356	0.012
	rep. 4	0.253	3.40	4.46	0.151	0.006
250-300	rep. 1	0.244	4.13	2.96	-0.167	-0.006
	rep. 2	0.239	3.38	2.86	-0.074	-0.003
	rep. 3	0.250	2.57	2.40	-0.024	-0.001
	rep. 4	0.237	3.27	2.66	-0.088	-0.004
300-350	rep. 1	0.216	4.78	3.40	-0.198	-0.006
	rep. 2	0.207	3.69	1.98	-0.244	-0.009
	rep. 3	0.233	4.04	2.42	-0.232	-0.008
	rep. 4	0.227	8.87	3.63	-0.749	-0.012
350-400	rep. 1	0.198	2.65	3.07	0.061	0.003
	rep. 2	0.202	2.31	1.87	-0.063	-0.004
	rep. 3	0.209	3.29	3.02	-0.038	-0.002
	rep. 4	0.216	4.56	2.76	-0.258	-0.008

Table VI.8.2: Mineralisation rates per treatment in the top soil (0-15 cm) using a field incubation study

		t=0						t=1						
trt.	rep.	moisture lab. (g/g dw)	moisture field (g/g dw)	ammonia 1st (mg/kg)	nitrate 1st (mg/kg)	ammonia 2nd (mg/kg)	nitrate 2nd (mg/kg)	moisture lab. (g/g dw)	moisture field (g/g dw)	ammonia 1st (mg/kg)	nitrate 1st (mg/kg)	ammonia 2nd (mg/kg)	nitrate 2nd (mg/kg)	min. rate (mg/kg/d)
maize1	1	0.247	0.258	1.46	25.43	1.12	25.64	0.290	0.296	0.72	27.96	0.96	29.49	0.130
	2	0.263	0.266	1.33	13.04	1.16	13.15	0.296	0.301	1.08	20.99	1.38	19.91	0.350
	3	0.259	0.269	1.47	13.59	1.24	13.76	0.295	0.295	1.13	16.46	1.17	16.51	0.124
sesb.1	1	0.269	0.270	1.88	3.16	1.69	3.81	0.293	0.295	1.66	19.74	2.55	20.40	0.805
	2	0.277	0.276	2.48	3.28	1.73	3.25	0.278	0.280	2.04	7.87	2.46	8.09	0.232
	3	0.263	0.276	5.39	1.80	5.19	2.28	0.339	0.339	5.77	19.03	5.59	20.18	0.855
weed 1	1	0.319	0.326	2.09	0.28	1.78	0.35	0.364	0.373	3.20	2.12	3.56	2.50	0.164
	2	0.337	0.325	2.83	0.50	2.64	0.49	0.330	0.343	1.97	2.44	2.48	2.80	0.077
	3	0.327	0.335	2.39	0.36	2.38	0.28	0.396	0.387	5.87	0.18	5.86	0.62	0.170
bare 1	1	0.231	0.227	1.69	45.63	1.43	39.29	0.300	0.299	1.28	11.57	1.30	11.30	-1.490
	2	0.231	0.243	1.80	42.51	1.44	39.53	0.288	0.296	1.26	61.34	1.37	61.23	0.950
	3	0.251	0.238	2.00	44.80	1.44	41.75	0.296	0.298	1.28	53.66	1.45	56.91	0.555
sesb.2	1	0.199	0.196	2.67	1.28	2.34	1.06	0.277	0.285	1.19	12.89	1.57	15.22	0.560
	2	0.205	0.199	3.36	1.56	3.89	1.43	0.313	0.309	2.56	9.15	2.30	9.71	0.321
	3	0.187	0.201	3.74	0.62	3.86	0.62	0.330	0.332	5.59	32.60	5.62	28.43	1.510
weed 2	1	0.236	0.241	2.02	0.59	1.52	0.45	0.285	0.291	2.20	1.34	2.81	1.51	0.078
	2	0.244	0.230	1.29	0.52	0.95	0.46	0.273	0.281	1.84	1.71	2.17	2.00	0.107
	3	0.213	0.246	1.36	0.45	1.25	0.32	0.298	0.293	1.46	1.87	1.55	1.92	0.081
bare 2	1	0.193	0.201	4.53	44.56	4.10	54.19	0.264	0.269	2.85	80.86	3.30	79.71	1.413
	2	0.210	0.206	4.69	84.42	4.04	83.25	0.250	0.275	1.80	33.10	2.01	33.66	-2.520
	3	0.197	0.194	4.76	89.69	5.18	89.64	0.241	0.233	3.65	83.26	3.64	87.66	-0.263
maize2	1	0.223	0.219	2.14	17.33	1.92	19.18	0.282	0.264	1.11	23.55	1.07	25.43	0.252
	2	0.214	0.240	1.36	6.72	1.58	6.23	0.279	0.286	0.84	21.84	1.75	21.65	0.719
	3	0.224	0.226	2.16	20.93	1.78	21.79	0.279	0.286	1.06	24.78	1.16	24.05	0.104
maize3	1	0.193	0.197	1.45	21.10	0.95	20.47	0.255	0.259	1.17	27.83	1.13	31.86	0.429
	2	0.196	0.190	2.15	23.27	1.84	23.45	0.263	0.256	0.44	21.55	1.26	22.92	-0.108
	3	0.206	0.198	2.99	7.96	2.50	8.32	0.265	0.269	0.98	26.45	0.93	27.96	0.823
weed 3	1	0.241	0.245	1.71	0.39	1.25	0.33	0.260	0.261	1.73	1.93	1.34	1.75	0.074
	2	0.226	0.228	1.47	0.26	1.10	0.26	0.288	0.293	1.77	1.02	1.35	2.28	0.079
	3	0.232	0.236	1.02	0.07	1.10	0.32	0.270	0.279	1.75	0.27	1.23	1.04	0.042
bare 3	1	0.185	0.214	3.42	62.35	3.22	58.97	0.269	0.276	3.26	66.60	2.43	62.30	0.158
	2	0.188	0.209	3.24	57.42	2.96	57.64	0.279	0.279	5.00	62.45	5.03	63.55	0.352
	3	0.195	0.196	4.60	69.28	4.20	69.12	0.260	0.262	1.61	52.95	1.36	55.32	-0.856
sesb.3	1	0.177	0.189	1.43	3.31	1.11	3.07	0.239	0.237	1.76	1.63	1.37	1.71	-0.058
	2	0.196	0.194	2.71	2.74	2.26	3.01	0.244	0.239	4.55	11.01	4.17	9.36	0.437
	3	0.182	0.187	5.02	1.35	4.66	1.17	0.246	0.248	1.82	4.39	1.32	4.52	-0.004
sesb.4	1	0.224	0.229	3.72	0.89	3.68	0.90	0.291	0.291	2.70	12.01	2.76	10.71	0.452
	2	0.268	0.265	4.13	1.33	3.59	1.26	0.316	0.315	2.17	6.02	1.84	5.21	0.117
	3	0.252	0.256	4.71	0.13	3.86	0.20	0.293	0.301	2.60	6.29	2.87	6.20	0.216
maize4	1	0.180	0.188	1.21	23.06	0.87	26.02	0.262	0.266	1.54	24.71	0.94	24.19	0.005
	2	0.193	0.204	1.24	19.28	1.19	18.81	0.284	0.286	1.35	17.40	1.05	16.83	-0.093
	3	0.198	0.236	1.43	19.38	1.15	20.43	0.291	0.287	1.31	12.48	0.90	12.21	-0.369
weed 4	1	0.276	0.267	2.57	0.60	2.71	0.68	0.301	0.306	1.24	1.20	1.13	1.63	-0.032
	2	0.242	0.267	1.98	0.26	1.50	0.26	0.293	0.298	1.65	1.93	1.25	1.19	0.048
	3	0.266	0.253	1.83	0.90	1.30	0.89	0.290	0.296	1.68	1.34	1.47	1.14	0.017
bare 4	1	0.192	0.207	2.29	52.21	2.25	49.75	0.268	0.273	2.92	6 1.36	2.13	67.86	0.661
	2	0.196	0.198	1.15	40.95	1.30	43.02	0.257	0.255	1.47	5 9.94	1.43	56.95	0.794
	3	0.202	0.195	2.54	59.28	2.08	57.06	0.265	0.268	1.70	6 6.99	0.96	63.69	0.295

Table VI.8.3: Measurement of mineralisation rates as a function of depth under field conditions using a tent mineralisation study

t=0 27-10-94

rep.	depth (cm)	moisture lab (g/g dw)	moisture field (g/g dw)	ammonia 1st (mg/kg)	nitrate 1st (mg/kg)	ammonia 2nd (mg/kg)	nitrate 2nd (mg/kg)
1	0-15	0.268	0.280	4.16	11.74	4.58	11.78
	15-30	0.275	0.282	4.56	8.14	4.83	8.64
	30-50	0.283	0.290	3.63	10.99	3.62	12.77
	50-100	0.292	0.303	2.34	17.88	2.35	17.83
	100-150	0.299	0.310	2.02	6.54	2.15	6.09
	150-200	0.299	0.298	1.88	2.60	2.02	2.50
2	0-15	0.306	0.286	4.51	11.94	4.60	11.25
	15-30	0.281	0.285	3.08	9.47	3.34	9.41
	30-50	0.283	0.286	2.58	9.46	2.87	9.10
	50-100	0.308	0.300	2.09	18.55	1.81	19.18
	100-150	0.298	0.305	2.15	8.14	1.18	8.95
	150-200	0.296	0.295	2.08	3.63	2.15	4.71
3	0-15	0.273	0.283	2.85	8.18	3.89	7.91
	15-30	0.282	0.283	3.48	7.94	3.82	7.16
	30-50	0.283	0.287	2.06	11.96	2.33	11.45
	50-100	0.294	0.287	1.62	15.62	1.89	15.84
	100-150	0.301	0.297	1.60	7.60	1.39	7.56
	150-200	0.293	0.286	1.79	2.99	1.72	3.03
4	0-15	0.274	0.280	1.90	14.45	3.40	14.81
	15-30	0.283	0.286	3.62	10.83	4.09	10.60
	30-50	0.284	0.272	2.37	12.59	3.69	13.02
	50-100	0.299	0.284	1.58	18.06	1.92	17.74
	100-150	0.296	0.310	1.18	10.28	1.45	11.10
	150-200	0.286	0.299	1.77	3.16	2.04	3.27
5	0-15	0.286	0.282	2.53	15.01	2.39	14.73
	15-30	0.278	0.284	2.40	14.93	2.39	14.38
	30-50	0.291	0.293	1.95	17.40	1.82	16.66
	50-100	0.293	0.291	1.44	22.75	1.71	24.92
	100-150	0.296	0.303	2.78	9.03	2.05	11.27
	150-200	0.284	0.280	2.21	2.88	2.56	3.97
6	0-15	0.277	0.276	3.71	10.65	3.31	14.19
	15-30	0.281	0.291	1.30	11.56	1.37	12.03
	30-50	0.299	0.295	2.38	17.89	2.27	17.30
	50-100	0.303	0.304	2.08	17.02	2.01	16.81
	100-150	0.298	0.305	3.02	5.29	2.34	5.50
	150-200	0.291	0.292	3.75	3.28	2.98	3.46

Table VI.8.3 - continued -

t=1 8-12-1994

rep.	depth (cm)	moisture lab (g/g dw)	moisture field (g/g dw)	ammonia 1st (mg/kg)	nitrate 1st (mg/kg)	ammonia 2nd (mg/kg)	nitrate 2nd (mg/kg)
1	0-15	0.191	0.201	1.19	13.29	2.22	12.90
	15-30	0.228	0.236	2.16	13.18	2.30	11.07
	30-50	0.269	0.263	1.78	22.77	2.03	24.45
	50-100	0.301	0.300	2.56	15.08	2.45	16.25
	100-150	0.298	0.292	2.61	5.46	2.46	5.94
	150-200	0.298	0.302	2.12	2.32	2.41	2.90
2	0-15	0.203	0.195	1.33	13.39	1.61	12.77
	15-30	0.233	0.230	1.94	12.91	2.31	11.44
	30-50	0.260	0.260	1.70	15.75	2.12	15.52
	50-100	0.302	0.302	3.40	17.61	2.40	16.72
	100-150	0.307	0.306	3.27	9.75	4.59	8.27
	150-200	0.296	0.302	2.20	3.58	2.35	3.25
3	0-15	0.211	0.211	4.02	10.40	3.93	10.11
	15-30	0.234	0.232	3.52	10.75	3.52	10.57
	30-50	0.283	0.274	2.67	10.66	3.15	9.71
	50-100	0.303	0.296	2.62	14.33	2.23	13.54
	100-150	0.308	0.311	2.00	5.40	2.82	5.65
	150-200	0.297	0.302	2.38	2.78	2.74	3.01
4	0-15	0.220	0.209	1.13	19.00	1.44	18.26
	15-30	0.244	0.266	1.89	16.40	2.22	16.99
	30-50	0.272	0.260	2.41	17.99	2.74	16.35
	50-100	0.296	0.280	2.32	23.93	2.61	22.79
	100-150	0.297	0.296	2.22	14.12	2.76	13.58
	150-200	0.295	0.300	2.25	3.82	2.82	3.44
5	0-15	0.202	0.202	1.46	17.92	1.69	16.19
	15-30	0.241	0.261	1.98	18.61	2.88	17.90
	30-50	0.269	0.268	1.84	21.10	2.77	19.20
	50-100	0.285	0.278	2.62	25.58	2.53	26.67
	100-150	0.292	0.302	2.89	11.25	2.58	11.02
	150-200	0.279	0.291	2.61	4.25	2.52	3.65
6	0-15	0.200	0.202	2.68	16.25	2.23	17.76
	15-30	0.215	0.227	3.06	17.65	2.95	17.24
	30-50	0.270	0.260	2.89	13.68	2.89	13.21
	50-100	0.298	0.292	2.27	19.30	2.55	18.01
	100-150	0.305	0.298	2.85	6.49	2.64	6.09
	150-200	0.289	0.286	1.96	2.87	2.38	2.79

Table VI.8.3 **- continued -**

t=2 19-1-1995

rep.	depth (cm)	moisture lab (g/g dw)	moisture field (g/g dw)	ammonia 1st (mg/kg)	nitrate 1st (mg/kg)	ammonia 2nd (mg/kg)	nitrate 2nd (mg/kg)
1	0-15	0.158	0.171	3.27	16.18	3.30	14.61
	15-30	0.193	0.186	3.56	16.11	3.56	17.28
	30-50	0.250	0.251	2.19	17.35	2.10	17.12
	50-100	0.278	0.286	2.21	19.87	2.25	19.75
	100-150	0.294	0.297	1.68	4.86	2.29	7.28
	150-200	0.290	0.291	2.73	3.30	2.43	3.31
2	0-15	0.166	0.170	2.60	14.61	2.86	14.26
	15-30	0.178	0.180	2.77	14.17	2.95	20.02
	30-50	0.214	0.223	2.63	15.37	2.61	15.58
	50-100	0.270	0.266	3.17	18.74	2.98	18.34
	100-150	0.294	0.294	2.48	7.34	1.96	7.97
	150-200	0.287	0.290	2.64	3.29	4.05	3.78
3	0-15	0.170	0.169	2.95	13.32	3.66	13.65
	15-30	0.179	0.179	3.85	12.61	3.48	15.14
	30-50	0.218	0.241	2.39	16.49	3.25	15.91
	50-100	0.273	0.297	1.59	12.72	2.26	16.61
	100-150	0.294	0.289	2.61	4.40	2.25	6.62
	150-200	0.287	0.291	2.19	3.57	2.11	3.88
4	0-15	0.169	0.186	2.36	18.39	2.38	19.91
	15-30	0.196	0.221	3.74	17.35	3.76	16.84
	30-50	0.272	0.283	2.14	18.72	1.66	19.12
	50-100	0.245	0.250	2.57	16.36	2.71	17.17
	100-150	0.286	0.288	2.82	7.76	1.98	7.58
	150-200	0.286	0.269	2.45	2.95	1.84	4.03
5	0-15	0.158	0.164	2.29	24.29	2.49	24.73
	15-30	0.177	0.188	2.96	15.13	2.09	26.15
	30-50	0.209	0.238	3.11	22.85	2.82	21.82
	50-100	0.274	0.265	2.74	26.61	2.22	25.91
	100-150	0.275	0.286	2.00	11.35	1.69	11.44
	150-200	0.278	0.279	2.06	4.60	1.96	4.53
6	0-15	0.168	0.180	3.52	19.72	3.50	17.61
	15-30	0.164	0.172	4.18	26.33	3.98	23.33
	30-50	0.185	0.191	3.09	15.50	2.79	17.50
	50-100	0.233	0.247	3.14	20.28	3.34	22.68
	100-150	0.268	0.273	3.04	10.24	2.64	11.44
	150-200	0.289	0.291	1.38	3.27	1.78	3.67

Table VI.8.4: Mineralisation rates analysed as a function of depth and moisture content (expressed as water filled pore space (=WFPS)) in a laboratory incubation study

depth (cm)	WFPS t=0 (%)	WFPS t=10 (%)	ammonia t=0 (mg/kg)	ammonia t=10 (mg/kg)	min. rate (mg/kg/d)
0-15	81.93	78.65	10.70	15.93	0.523
	81.91	73.26	17.81	38.12	2.031
	80.73	76.80	10.70	20.02	0.932
	78.73	69.30	16.04	24.98	0.894
	72.98	63.79	14.60	42.05	2.745
	71.82	65.04	18.00	45.70	2.770
	69.35	66.72	2.56	7.59	0.503
	67.69	59.54	19.59	41.32	2.173
	65.18	62.44	1.60	5.35	0.375
	64.89	60.53	13.32	19.06	0.573
	63.46	65.07	4.58	16.10	1.153
	61.77	58.77	2.52	15.15	1.262
	61.64	56.78	3.62	15.49	1.188
	59.01	57.72	4.24	7.78	0.355
15-30	89.19	91.83	13.51	21.37	0.786
	87.21	91.86	12.83	12.57	-0.026
	87.19	85.27	13.51	18.96	0.544
	80.65	73.37	12.21	23.44	1.123
	78.43	77.40	11.32	12.50	0.118
	74.75	70.13	10.75	22.60	1.185
	73.06	69.49	9.74	17.06	0.732
	72.70	71.83	9.25	9.71	0.046
	71.54	66.90	10.84	10.43	-0.041
	70.93	62.45	7.26	12.03	0.477
	68.64	69.41	10.33	18.84	0.852
	68.41	75.01	10.93	20.62	0.970
	67.00	67.24	13.43	27.84	1.441
	66.30	60.34	10.22	14.59	0.437
30-50	87.57	91.27	17.35	16.32	0.896
	84.98	79.27	6.59	12.65	0.606
	84.86	84.85	10.61	19.22	0.861
	82.28	89.36	7.91	14.73	0.683
	81.75	81.59	9.44	14.00	0.456
	81.72	83.11	7.32	15.32	0.800
	79.78	84.85	10.03	15.53	0.550
	79.67	73.59	7.02	11.58	0.456
	79.02	74.26	7.24	35.87	2.863
	76.58	78.65	8.61	14.50	0.589
	74.63	66.08	13.82	33.61	1.978
	73.61	68.13	10.05	16.06	0.602
	61.14	58.25	16.59	40.55	2.396

Table VI.8.4 - continued -

50-100	90.11	86.97	8.42	9.04	0.062
	85.50	88.17	10.12	10.59	0.047
	82.18	77.87	10.16	14.04	0.388
	82.08	77.67	7.24	18.26	1.102
	80.11	84.61	8.42	9.28	0.087
	78.15	75.40	12.95	18.84	0.589
	76.47	74.29	8.71	10.23	0.152
	74.91	76.51	17.24	24.60	0.737
	73.70	72.50	6.08	13.64	0.756
	73.49	71.84	9.92	14.93	0.501
	72.11	68.62	5.21	10.56	0.535
	70.90	73.53	8.82	19.97	1.115
	68.27	73.21	12.57	20.98	0.840
	62.46	66.10	13.80	27.15	1.336
100-150	89.50	91.04	4.73	7.33	0.260
	88.50	83.86	4.73	7.14	0.241
	87.43	88.35	3.88	8.41	0.453
	83.79	87.01	6.38	9.60	0.322
	81.17	77.42	5.82	9.09	0.327
	78.06	71.37	4.50	7.29	0.279
	77.71	65.69	5.26	8.82	0.355
	74.00	77.55	5.41	6.89	0.148
	72.31	67.28	8.47	12.06	0.358
	71.99	71.02	4.42	9.89	0.547
	70.43	67.72	4.29	8.31	0.403
	67.87	66.83	6.16	8.61	0.444
	66.53	67.06	4.93	13.22	0.829
	64.60	70.50	5.00	9.07	0.408
150-200	88.83	79.87	3.13	5.20	0.207
	86.83	80.37	3.13	6.63	0.350
	83.86	88.27	3.55	2.91	-0.064
	83.73	80.70	3.80	9.07	0.527
	78.25	72.97	4.27	7.45	0.318
	77.85	81.07	3.61	7.56	0.395
	77.42	76.48	3.02	6.57	0.355
	76.02	82.60	3.86	6.50	0.264
	72.97	71.47	3.72	5.44	0.171
	72.62	66.33	3.82	6.09	0.227
	70.85	70.12	3.25	7.75	0.450
	68.41	70.01	4.93	7.80	0.287
	67.42	61.24	3.71	7.13	0.342
	65.11	71.57	4.45	7.30	0.285

Appendix VI.9: Inorganic soil nitrogen data

Table VI.9.1: Soil ammonium data, expressed in kg Nha^{-1}, during the short rains 1994

lot o.	land use system	depth (cm)	position (sesbania only)	date: 090994	111094	031194	221194	131294	130195
				.... NH4	(kg N/ha)	....			
2	sesbania	0-15	18.75 cm	6.5	3.9	6.5	2.3	3.1	8.3
		15-30	from	6.1	6.6	7.8	3.9	6.5	7.4
		30-50	plant row	11.4	8.0	6.6	6.4	8.9	7.0
		50-100		32.3	27.0	29.8	13.8	28.2	18.7
		100-150		25.1	30.1	22.0	13.1	40.9	12.6
		150-200		26.1	26.7	27.8	13.5	40.8	10.2
2	sesbania	0-15	56.25 cm	4.9	6.0	4.0	3.2	5.4	5.1
		15-30	from	6.6	5.5	5.2	3.4	5.6	6.6
		30-50	plant row	9.8	8.6	10.8	4.6	9.1	6.2
		50-100		30.2	24.8	19.2	15.5	22.8	18.6
		100-150		32.2	25.9	19.0	14.0	26.8	12.2
		150-200		27.7	26.9	22.4	14.2	27.6	12.1
2	sesbania	0-15	93.75 cm	4.8	7.1	4.8	4.6	2.7	4.6
		15-30	from	6.0	8.2	6.4	6.1	5.7	5.3
		30-50	plant row	9.1	8.9	7.7	6.5	10.9	6.8
		50-100		23.5	23.3	23.7	16.6	23.0	15.7
		100-150		26.2	33.2	32.1	13.9	29.2	17.2
		150-200		8.8	26.4	24.2	15.6	30.1	14.8
1	sesbania	0-15	18.75 cm	7.1	4.6	2.0	2.1	5.0	5.7
		15-30	from	4.9	5.9	10.0	3.2	8.4	6.9
		30-50	plant row	4.9	5.2	7.0	2.7	9.7	7.8
		50-100		18.2	20.2	13.4	13.9	18.7	14.1
		100-150		16.8	18.5	19.4	15.0	21.9	20.6
		150-200		12.2	13.6	15.1	13.6	21.6	19.3
1	sesbania	0-15	56.25 cm	6.3	4.3	4.6	1.9	5.5	4.8
		15-30	from	5.1	6.3	6.6	6.5	6.5	5.6
		30-50	plant row	5.1	6.0	5.7	4.8	7.4	6.7
		50-100		15.3	18.4	12.4	12.0	15.5	14.0
		100-150		16.7	15.6	17.7	12.6	28.9	17.8
		150-200		14.6	14.9	19.9	11.2	23.5	19.2
1	sesbania	0-15	93.75 cm	4.4	3.9	4.4	3.5	3.4	4.9
		15-30	from	5.7	6.2	12.2	7.2	7.0	5.5
		30-50	plant row	5.0	6.3	7.9	8.8	7.3	6.1
		50-100		9.7	19.3	14.9	16.9	16.4	17.7
		100-150		16.4	25.3	21.0	26.9	18.2	20.2
		150-200		15.1	20.9	16.1	14.5	16.4	17.7
1	sesbania	0-15	18.75 cm	5.5	2.2	11.4	4.7	4.6	3.1
		15-30	from	5.5	4.9	5.6	3.8	5.5	5.2
		30-50	plant row	6.9	6.6	6.2	5.1	5.4	8.1
		50-100		16.5	17.5	15.1	14.7	26.2	13.7
		100-150		13.5	19.8	12.7	18.8	26.9	12.9
		150-200		16.5	20.7	12.4	18.0	18.2	11.7
	sesbania	0-15	56.25 cm	5.2	5.3	2.1	1.9	3.2	3.5
		15-30	from	5.8	6.0	2.5	3.6	3.1	7.3
		30-50	plant row	5.9	7.2	6.0	3.3	4.6	9.8
		50-100		13.5	20.6	13.8	15.0	22.8	9.3
		100-150		12.8	22.1	14.4	19.6	10.9	11.3
		150-200		11.2	22.8	11.2	15.2	10.6	11.2

Table VI.9.1 - continued -

34	sesbania	0-15	93.75 cm	4.5	4.9	2.0	4.2	1.9	2.6
		15-30	from	5.9	5.9	4.2	5.3	3.7	5.3
		30-50	plant row	6.7	8.1	6.3	6.6	5.3	7.0
		50-100		12.5	25.1	13.0	13.1	11.1	11.0
		100-150		13.1	22.6	13.8	14.7	13.3	10.9
		150-200		13.9	26.3	14.3	14.8	16.2	13.0
41	sesbania	0-15	18.75 cm	5.8	3.9	2.4	3.2	2.5	5.5
		15-30	from	6.3	5.6	2.8	4.2	4.5	4.4
		30-50	plant row	6.1	6.5	3.3	4.7	4.8	7.8
		50-100		18.7	12.9	13.4	10.2	7.5	10.4
		100-150		15.3	13.4	13.9	14.2	4.7	8.5
		150-200		18.3	10.4	15.4	12.0	4.2	8.0
41	sesbania	0-15	56.25 cm	6.5	3.1	2.9	3.1	3.1	3.3
		15-30	from	5.9	4.5	3.1	3.8	3.0	5.5
		30-50	plant row	6.9	5.2	5.0	3.0	3.1	6.6
		50-100		18.0	13.8	14.4	7.6	10.5	8.6
		100-150		20.0	17.7	14.1	16.3	5.5	10.1
		150-200		17.6	12.5	12.9	15.9	4.1	9.4
41	sesbania	0-15	93.75 cm	5.0	3.9	2.7	4.0	3.3	2.3
		15-30	from	6.1	4.4	3.3	3.8	5.7	3.9
		30-50	plant row	5.3	4.8	7.5	4.7	4.7	6.1
		50-100		14.6	10.6	15.2	5.3	11.9	10.9
		100-150		15.8	20.5	12.7	15.6	13.1	12.3
		150-200		15.5	27.5	11.7	16.0	9.0	9.7
11	maize	0-15		4.3	6.0	2.2	4.1	3.4	4.1
		15-30		8.2	8.8	10.6	7.0	5.7	8.5
		30-50		9.7	10.2	9.6	7.4	8.2	9.7
		50-100		26.3	25.6	16.6	16.9	18.6	17.1
		100-150		23.4	27.0	26.2	18.4	23.7	18.4
		150-200		22.4	26.3	27.3	15.5	17.5	15.8
24	maize	0-15		3.7	3.5	2.0	2.4	1.7	1.7
		15-30		6.9	6.2	3.4	3.9	3.9	5.1
		30-50		5.9	9.0	5.5	4.0	6.4	7.1
		50-100		12.2	18.8	14.6	18.1	22.4	14.3
		100-150		10.3	15.5	16.6	23.8	19.2	12.3
		150-200		11.0	17.9	16.9	21.2	16.7	17.5
31	maize	0-15		4.2	3.3	1.4	2.5	3.1	3.7
		15-30		5.3	5.6	2.7	9.0	5.0	4.6
		30-50		7.0	6.9	6.2	6.9	5.2	6.5
		50-100		15.5	18.3	13.1	19.8	14.2	12.5
		100-150		15.2	13.6	15.5	17.2	10.6	9.3
		150-200		10.5	16.5	20.8	21.2	15.1	14.4
42	maize	0-15		3.4	3.8	2.4	0.9	1.3	1.3
		15-30		6.6	6.2	2.5	2.5	2.8	5.7
		30-50		5.3	6.2	3.9	4.8	5.9	5.6
		50-100		13.0	7.1	14.8	12.1	10.8	8.2
		100-150		14.8	17.5	18.4	14.0	10.6	12.0
		150-200		21.9	13.3	13.6	15.0	9.8	10.7

Table VI.9.1 - continued -

3	weed	0-15	4.8	3.6	7.7	5.6	2.3	2.3
		15-30	4.6	4.7	4.8	5.1	3.8	4.0
		30-50	4.8	7.9	9.1	5.8	6.6	5.1
		50-100	19.6	22.9	18.3	16.4	23.2	12.6
		100-150	19.7	20.1	13.6	15.4	31.1	13.9
		150-200	22.6	22.6	17.9	14.8	25.4	10.0
2	weed	0-15	2.7	2.7	11.4	6.0	4.4	3.2
		15-30	3.7	2.5	14.5	6.1	5.0	3.9
		30-50	4.9	3.6	16.6	6.5	9.1	5.6
		50-100	10.7	15.2	23.3	13.8	24.5	12.0
		100-150	12.7	19.5	21.6	18.1	20.6	13.0
		150-200	11.3	18.0	24.3	26.8	25.0	15.3
2	weed	0-15	3.9	1.9	2.0	3.3	2.4	2.6
		15-30	3.8	2.8	2.6	2.8	2.8	4.2
		30-50	3.3	4.0	7.9	2.6	4.2	5.3
		50-100	13.0	17.3	13.7	7.5	11.7	8.4
		100-150	12.2	16.5	15.9	18.6	14.3	9.7
		150-200	14.4	13.3	10.7	11.7	19.4	11.9
3	weed	0-15	5.2	2.5	2.6	2.0	2.5	2.6
		15-30	3.8	3.5	2.9	1.9	2.9	4.3
		30-50	7.8	6.8	6.8	2.8	3.1	8.7
		50-100	12.4	12.7	7.6	8.4	15.0	9.1
		100-150	16.3	12.2	10.0	12.2	17.1	10.9
		150-200	16.6	10.5	14.3	16.8	13.0	9.9
4	bare	0-15	3.3	2.5	1.7	1.4	2.6	4.7
		15-30	6.2	5.4	3.1	2.4	3.9	6.6
		30-50	5.8	4.6	4.0	5.5	7.3	6.5
		50-100	19.2	16.4	17.4	14.7	23.9	19.3
		100-150	18.4	13.6	15.1	16.2	22.4	19.7
		150-200	13.4	19.7	17.7	10.9	24.0	14.3
3	bare	0-15	3.1	2.5	2.6	3.2	2.1	3.9
		15-30	6.1	3.6	3.6	2.9	2.5	6.0
		30-50	5.2	5.8	4.9	6.3	5.8	8.0
		50-100	12.6	15.9	12.8	15.8	18.7	14.4
		100-150	11.6	14.1	20.3	14.2	20.3	13.9
		150-200	10.2	15.2	17.4	14.9	16.7	12.2
3	bare	0-15	1.6	1.4	2.3	1.7	1.2	2.3
		15-30	4.0	4.6	2.9	3.4	2.0	3.2
		30-50	6.8	6.8	6.0	3.1	5.4	6.5
		50-100	15.0	15.1	16.7	14.9	15.8	13.4
		100-150	13.0	15.3	16.8	11.7	19.7	13.0
		150-200	12.4	15.8	17.2	17.2	17.0	9.5
1	bare	0-15	2.9	1.7	1.6	1.2	1.6	3.9
		15-30	7.0	4.2	2.7	3.2	3.3	5.0
		30-50	5.4	6.6	3.8	2.9	4.4	5.1
		50-100	13.1	11.6	8.9	13.4	10.8	10.4
		100-150	13.2	15.5	8.2	4.6	8.9	8.7
		150-200	11.3	14.9	10.4	7.7	6.7	8.9

Table VI.9.2: Soil nitrate data, expressed in kg Nha^{-1}, during the short rains 1994

plot no.	land use system	depth (cm)	position (sesbania only)	date: 090994	111094	031194	221194	131294	130195
				NO3 (kg N/ha).					
12	sesbania	0-15	18.75 cm	1.2	1.3	2.9	4.9	4.3	4.2
		15-30	from	0.3	0.3	1.7	3.1	0.0	1.3
		30-50	plant row	0.6	0.5	14.1	0.5	0.6	0.5
		50-100		6.2	1.4	4.9	5.2	0.9	1.3
		100-150		9.5	5.8	3.8	4.7	2.9	0.9
		150-200		5.1	1.8	3.5	5.4	4.3	0.9
12	sesbania	0-15	56.25 cm	0.9	0.9	7.0	5.0	2.2	2.2
		15-30	from	0.5	1.1	4.0	3.5	0.8	1.2
		30-50	plant row	0.9	0.3	3.9	3.0	1.8	0.5
		50-100		5.8	0.9	13.2	4.2	1.2	1.8
		100-150		9.0	2.2	4.8	3.6	6.4	3.8
		150-200		4.6	2.2	3.5	2.7	5.6	3.4
12	sesbania	0-15	93.75 cm	1.3	1.4	9.7	3.4	1.7	2.3
		15-30	from	0.9	1.1	3.4	1.3	0.7	1.1
		30-50	plant row	0.8	1.6	2.7	0.7	0.4	1.0
		50-100		5.3	1.3	5.8	3.7	3.1	0.9
		100-150		5.2	2.6	4.7	5.8	6.5	2.6
		150-200		3.7	1.3	7.0	3.6	0.2	3.4
21	sesbania	0-15	18.75 cm	2.7	3.3	11.2	5.9	3.8	5.0
		15-30	from	0.5	0.9	8.3	0.1	1.0	2.4
		30-50	plant row	0.3	0.7	5.3	4.7	1.2	1.8
		50-100		1.8	5.5	15.6	14.8	0.0	3.1
		100-150		11.0	6.4	20.2	12.1	3.6	6.0
		150-200		3.5	5.5	11.7	10.9	0.0	10.3
21	sesbania	0-15	56.25 cm	3.1	3.7	6.8	6.8	2.7	3.7
		15-30	from	0.5	1.1	14.2	3.8	1.0	1.4
		30-50	plant row	1.2	2.1	10.3	5.5	1.2	2.1
		50-100		6.8	9.9	22.1	5.9	7.8	13.1
		100-150		6.2	9.1	16.4	15.9	12.0	3.9
		150-200		1.3	4.7	9.7	11.4	11.1	9.6
21	sesbania	0-15	93.75 cm	1.5	3.4	10.3	8.7	4.8	3.7
		15-30	from	0.8	1.2	4.3	4.4	0.8	2.2
		30-50	plant row	1.0	1.3	5.7	5.8	2.4	1.9
		50-100		7.1	10.1	19.8	7.5	18.2	18.6
		100-150		4.3	8.8	10.9	12.6	16.9	10.7
		150-200		8.2	4.3	11.8	4.2	9.8	3.9
34	sesbania	0-15	18.75 cm	2.4	2.0	5.6	5.7	3.7	7.7
		15-30	from	1.8	0.7	3.6	3.8	1.8	6.5
		30-50	plant row	3.3	0.9	4.1	6.7	1.7	4.5
		50-100		12.8	9.5	17.7	19.4	12.2	18.6
		100-150		10.7	7.7	2.6	13.4	13.5	12.7
		150-200		5.1	3.4	2.1	6.3	6.3	11.1
34	sesbania	0-15	56.25 cm	1.4	3.9	6.1	6.1	2.9	9.1
		15-30	from	2.1	0.6	0.9	3.6	1.8	6.2
		30-50	plant row	4.9	1.2	4.9	5.4	2.1	3.8
		50-100		19.5	8.2	17.7	10.4	25.4	15.2
		100-150		18.3	3.9	8.9	8.1	11.8	15.3
		150-200		12.7	3.0	3.0	5.9	3.8	8.2
34	sesbania	0-15	93.75 cm	2.2	1.6	4.8	5.9	3.9	4.4
		15-30	from	2.0	0.6	4.8	3.4	1.4	2.8
		30-50	plant row	5.9	1.8	10.4	5.6	3.9	5.4
		50-100		16.3	5.9	25.2	9.9	13.2	14.3
		100-150		6.7	2.9	8.7	8.1	14.4	8.9
		150-200		9.8	7.6	1.3	3.4	2.8	8.0

Table VI.9.2 - continued -

sesbania	0-15	18.75 cm from plant row	1.0	1.0	10.0	8.2	3.8	7.4
	15-30		1.2	0.6	6.0	5.2	2.2	9.7
	30-50		1.3	1.1	5.6	5.9	1.0	5.5
	50-100		5.1	6.1	9.6	4.3	2.3	9.7
	100-150		6.8	3.3	5.4	6.1	2.7	8.3
	150-200		4.1	1.5	3.2	4.3	1.8	3.1
sesbania	0-15	56.25 cm from plant row	1.0	2.1	5.5	6.5	4.3	7.9
	15-30		0.5	0.7	5.3	4.7	2.8	8.8
	30-50		3.4	0.8	5.7	4.7	2.8	5.6
	50-100		4.1	2.0	10.2	12.0	7.4	14.1
	100-150		5.4	2.3	3.2	8.5	3.1	5.6
	150-200		2.8	1.9	2.3	5.2	2.2	4.8
sesbania	0-15	93.75 cm from plant row	1.7	1.2	6.8	7.7	5.9	9.1
	15-30		0.4	0.7	4.8	5.7	1.2	8.2
	30-50		1.7	0.9	6.1	5.8	3.3	8.9
	50-100		3.8	5.4	10.2	10.1	8.4	18.3
	100-150		5.1	1.9	5.3	5.3	2.2	6.9
	150-200		1.9	1.5	3.1	3.1	4.8	6.0
maize	0-15		12.9	8.3	13.1	5.9	6.6	16.0
	15-30		6.6	6.4	7.1	7.2	7.4	14.2
	30-50		17.3	7.3	24.6	10.7	5.7	12.1
	50-100		32.5	36.6	64.0	49.3	51.0	52.6
	100-150		15.7	29.7	37.9	30.4	37.9	44.8
	150-200		24.9	21.2	24.9	22.1	2.0	30.8
maize	0-15		14.9	19.1	19.3	8.8	9.1	16.8
	15-30		9.8	7.5	14.6	11.7	12.6	19.6
	30-50		25.9	16.0	22.0	24.4	14.1	23.2
	50-100		86.3	85.6	93.2	97.3	118.2	85.1
	100-150		41.6	42.6	44.4	46.3	42.7	39.1
	150-200		16.6	30.3	13.8	21.2	21.9	19.3
maize	0-15		13.6	15.9	14.2	11.8	5.3	21.1
	15-30		9.8	13.4	17.0	9.6	8.2	17.8
	30-50		18.1	18.5	20.6	13.8	12.6	16.7
	50-100		39.5	40.1	58.8	50.6	37.5	48.4
	100-150		19.2	29.8	31.3	30.0	30.8	28.4
	150-200		14.2	18.3	14.6	15.2	14.7	15.7
maize	0-15		13.8	13.6	14.1	6.9	8.7	20.1
	15-30		8.3	11.4	10.5	13.1	11.0	13.3
	30-50		15.1	18.1	24.0	17.7	13.9	15.1
	50-100		71.6	46.2	17.7	56.6	65.8	72.9
	100-150		34.8	48.0	39.2	56.9	58.9	50.3
	150-200		20.4	25.0	75.0	30.1	23.9	14.4

Table VI.9.2 - continued -

13	weed	0-15	0.7	0.6	4.2	1.1	1.2	0.4
		15-30	0.4	0.3	3.5	1.1	1.0	0.2
		30-50	0.7	0.0	0.8	0.9	1.2	0.8
		50-100	0.5	1.3	4.9	2.8	1.9	2.6
		100-150	3.1	0.4	2.6	1.8	0.9	0.9
		150-200	4.1	0.0	1.3	2.7	3.6	1.3
22	weed	0-15	0.8	0.8	6.8	0.9	0.5	2.1
		15-30	0.4	0.8	3.5	1.5	1.1	1.6
		30-50	0.7	0.3	2.4	1.9	0.9	1.5
		50-100	1.8	1.4	3.4	2.5	1.4	2.7
		100-150	1.3	0.4	5.4	2.9	2.7	2.2
		150-200	1.3	0.4	1.1	2.5	0.9	3.5
32	weed	0-15	1.0	0.9	4.3	2.6	1.2	3.3
		15-30	0.5	0.5	5.0	3.6	1.6	3.8
		30-50	1.7	1.0	3.7	4.8	0.8	4.2
		50-100	6.3	0.9	8.7	10.7	3.8	6.4
		100-150	6.7	0.4	2.6	5.3	2.0	1.5
		150-200	8.8	0.4	1.3	5.8	2.9	1.1
43	weed	0-15	1.7	1.5	3.5	3.0	2.0	3.7
		15-30	0.6	0.3	4.0	3.0	0.8	2.7
		30-50	0.4	1.0	3.3	4.2	11.6	2.2
		50-100	2.3	0.9	11.8	7.4	5.2	5.0
		100-150	6.6	9.0	17.5	12.2	20.2	2.8
		150-200	2.2	20.2	5.4	11.8	8.1	9.7
14	bare	0-15	15.9	39.7	45.4	28.1	17.8	90.2
		15-30	41.4	53.1	93.5	64.3	68.2	110.6
		30-50	94.4	53.7	118.5	118.8	127.9	119.6
		50-100	75.6	268.1	158.5	233.5	192.4	115.2
		100-150	64.4	37.2	45.8	48.7	61.0	0.9
		150-200	25.0	18.8	19.5	25.8	18.8	18.7
23	bare	0-15	47.9	77.8	81.6	61.0	53.4	102.8
		15-30	80.8	95.6	99.9	103.8	89.6	109.0
		30-50	92.6	116.5	128.0	115.5	136.9	157.2
		50-100	96.3	132.2	131.3	118.7	177.4	106.1
		100-150	24.6	26.8	41.7	47.6	43.2	14.3
		150-200	12.6	14.3	21.3	26.5	19.4	13.1
33	bare	0-15	47.0	58.3	51.6	37.1	27.6	63.4
		15-30	105.3	84.0	58.4	80.2	61.5	103.7
		30-50	88.5	111.3	96.6	106.9	111.0	109.0
		50-100	74.3	35.6	153.7	98.6	116.0	144.7
		100-150	50.2	20.3	25.1	28.1	23.9	40.5
		150-200	28.1	40.5	15.4	19.5	16.4	23.8
44	bare	0-15	64.9	84.5	82.6	63.2	83.2	121.7
		15-30	92.4	78.9	119.6	106.9	99.5	134.7
		30-50	72.3	96.3	104.6	122.0	101.9	123.9
		50-100	56.3	54.7	86.6	81.5	54.3	82.3
		100-150	20.2	37.2	27.3	35.1	23.3	32.4
		150-200	14.6	16.2	14.5	22.1	13.8	18.5

endix VI.10: Data on nutrients in runoff

le VI.10.1: Nitrogen (measured as ammonium, nitrate and total N in mg/l) and phosphorus (measured as total P in mg/l) in runoff during the short rains 1994

date	rep.	ammonia (mg N/l)	nitrate (mg N/l)	total N (mg N/l)	total P (mg N/l)	runoff (mm)
9-11-94	sesb. 1	1.31	2.87	8.55	0.234	0.0233
	weed 1	0.41	7.18	9.97	0.088	0.0266
	sesb. 2	-	-	-	-	0.0155
	weed 2	0.31	7.25	9.97	0.094	0.0225
	weed 3	2.14	0.29	4.17	0.434	0.037
	sesb. 3	1.57	1.48	6.15	0.738	0.0707
	sesb. 4	1.43	1.5	6.07	0.736	0.0259
	weed 4	-	-	-	-	0.0244
16-11-94	sesb. 1	0.14	0.37	1.1	0.034	0.0611
	weed 1	0.13	0.52	0.86	0.008	0.0533
	sesb. 2	0.11	0.2	0.43	0.004	0.047
	weed 2	2.91	0.4	-	-	0.0466
	weed 3	3.36	0.06	-	-	0.0974
	sesb. 3	0.14	0.06	-	-	1.0318
	sesb. 4	0.08	0.32	-	-	0.0814
	weed 4	0.14	0.165	-	-	0.0852
27-11-94	sesb. 1	0.785	9.71	14.1	0.1	0.0285
	weed 1	2.53	0.23	5.3	0.34	0.0193
	sesb. 2	1.515	12.69	19.2	0.08	0.0311
	weed 2	4.405	0.24	12.6	0.36	0.0255
	weed 3	2.565	0.22	3.8	0.36	0.0641
	sesb. 3	3.175	0.4	5.8	0.04	0.0944
	sesb. 4	0.705	3.92	6.8	0.16	0.017
	weed 4	1.665	0.14	4.7	0.82	0.0193
4-12-94	sesb. 1	0.545	4.05	7.11	0.116	0.0489
	weed 1	0.225	3.79	5.89	0.094	0.0496
	sesb. 2	0	6.77	9.31	0.05	0.0696
	weed 2	0.175	0.17	2.99	0.55	0.0318
	weed 3	0.565	0.19	2.11	0.332	0.1044
	sesb. 3	0.215	0	0.6	0.014	0.7481
	sesb. 4	0.825	2.5	4.55	0.12	0.0388
	weed 4	0.415	0.25	2.93	0.366	0.0637

Appendix VI.11: Sediment loss data

Table VI.11.1: Total sediment losses (in kg/ha) as determined by sediment losses in the jerrycan (in g) and the through of the tipping bucket (in g)

	8-11-1994			11-11-1994			17-11-1994		
plot	trough losses (g)	jerrycan losses (g)	total loss (kg/ha)	trough losses (g)	jerrycan losses (g)	total loss (kg/ha)	trough losses (g)	jerrycan losses (g)	total loss (kg/ha)
sesb. 1	0.992	0.000	0.441	n.d.	0.198	14.626	0.445	0.219	28.995
sesb. 2	1.329	0.000	0.591	n.d.	1.037	82.499	0.984	0.782	90.454
sesb. 3	6.195	0.464	52.588	n.d.	0.000	0.000	23.418	0.000	10.408
sesb. 4	2.081	0.000	0.925	n.d.	0.335	38.272	2.943	0.382	36.961
weed 1	4.469	0.000	1.986	n.d.	0.000	0.000	1.817	4.801	288.214
weed 2	1.665	0.000	0.740	n.d.	0.000	0.000	0.827	0.595	0.632
weed 3	3.400	0.000	1.511	n.d.	0.191	9.381	1.019	0.151	0.520
weed 4	2.151	0.000	0.956	n.d.	0.064	4.814	3.239	0.528	54.702

Table VI.11.1 - continued -

	24-11-1994			1-12-1994			8-12-1994		
plot	trough losses (g)	jerrycan losses (g)	total loss (kg/ha)	trough losses (g)	jerrycan losses (g)	total loss (kg/ha)	trough losses (g)	jerrycan losses (g)	total loss (kg/ha)
sesb. 1	0.396	0.194	12.485	0.403	0.280	0.304	0.342	0.150	0.219
sesb. 2	0.308	0.201	17.614	0.220	0.206	0.189	0.219	0.201	0.187
sesb. 3	4.858	0.000	2.159	0.856	0.159	0.451	4.773	0.186	22.530
sesb. 4	0.411	0.059	7.121	0.225	0.147	0.165	0.252	0.123	0.167
weed 1	0.536	0.073	0.271	1.167	0.667	0.815	0.848	0.000	0.377
weed 2	0.385	0.028	1.270	0.311	0.160	0.209	0.293	0.259	0.245
weed 3	0.816	0.091	5.930	0.411	0.216	0.279	0.588	0.309	0.399
weed 4	0.644	0.074	6.697	0.329	0.401	0.324	0.500	0.172	0.299

Table VI.11.2: Nutrient losses due to erosion in composite samples collected during the 4th season. Nutrient concentrations are given in %.

trt	sample	date	N	P
weed	through	08/11/94	0.65	0.112
weed	jerrycan	08/11/94	0.96	0.137
sesbania	through	08/11/94	0.65	0.109
sesbania	jerrycan	08/11/94	0.75	0.100
weed	through	17/11/94	0.70	0.128
weed	jerrycan	17/11/94	0.24	0.050
sesbania	through	17/11/94	0.24	0.054
sesbania	jerrycan	17/11/94	0.22	0.050
weed	jerrycan+through	24/11/94	0.26	0.040
sesbania	jerrycan+through	24/11/94	0.37	0.067
weed	through	01/12/94	0.79	0.128
weed	jerrycan	01/12/94	0.90	0.140
weed	jerrycan+through	08/12/94	0.69	0.126
sesbania	jerrycan+through	08/12/94	0.37	0.065

pendix VI.12: Denitrification data

le VI.12.1: Denitrification rates as a function of depth as measured as the rate of nitrate disappearance in an anaerobic incubation

depth	rep.	moisture content (g/g dw)	nitrate t=0 (mg/kg)	nitrate t=7 (mg/kg)	denitr. rate (mg/kg/d)	fraction denitr. (-)
0-15 cm	maize 1	0.295	14.54	0.00	2.08	1.00
	sesb. 1	0.427	0.28	0.00	0.04	1.00
	sesb. 1	0.325	5.23	0.00	0.75	1.00
	sesb. 1	0.283	7.87	0.12	1.11	0.98
	weed 1	0.326	3.10	0.00	0.44	1.00
	bare 1	0.289	39.49	4.73	4.97	0.88
	sesb. 2	0.310	11.81	0.12	1.67	0.99
	sesb. 2	0.306	10.00	0.13	1.41	0.99
	sesb. 2	0.346	11.83	0.13	1.67	0.99
	weed 2	0.299	1.96	0.00	0.28	1.00
	bare 2	0.216	1.26	0.12	0.16	0.91
	maize 2	0.303	11.03	0.00	1.58	1.00
	maize 3	0.243	13.58	0.00	1.94	1.00
	weed 3	0.304	2.43	0.13	0.33	0.95
	bare 3	0.234	40.54	112.56	-10.29	-1.78
	sesb. 3	0.235	8.57	0.46	1.16	0.95
	sesb. 3	0.239	8.34	0.00	1.19	1.00
	sesb. 3	0.304	7.72	0.13	1.08	0.98
	sesb. 4	0.277	12.51	0.12	1.77	0.99
	sesb. 4	0.251	11.49	0.12	1.62	0.99
	sesb. 4	0.251	11.55	0.00	1.65	1.00
	maize 4	0.227	4.15	0.00	0.59	1.00
	weed 4	0.270	5.20	0.00	0.74	1.00
	bare 4	0.320	70.35	70.00	0.05	0.00
15-30 cm	maize 1	0.283	4.21	0.39	0.55	0.91
	sesb. 1	0.303	2.46	0.13	0.33	0.95
	weed 1	0.302	11.83	0.00	1.69	1.00
	bare 1	0.296	74.94	100.29	-3.62	-0.34
	sesb. 2	0.275	5.39	0.00	0.77	1.00
	weed 2	0.302	2.08	0.00	0.30	1.00
	bare 2	0.278	135.29	129.15	0.88	0.05
	maize 2	0.288	10.87	0.69	1.45	0.94
	maize 3	0.239	4.57	0.41	0.59	0.91
	weed 3	0.291	-0.18	0.00	-0.03	1.00
	bare 3	0.284	83.26	105.58	-3.19	-0.27
	sesb. 3	0.280	4.96	0.30	0.67	0.94
	sesb. 4	0.278	5.24	0.00	0.75	1.00
	maize 4	0.248	14.92	0.99	1.99	0.93
	weed 4	0.279	3.79	0.00	0.54	1.00
	bare 4	0.285	102.16	0.00	14.59	1.00

Table VI.12 - continued -

30-50 cm	maize 1	0.282	9.53	2.34	1.03	0.75
	sesb. 1	0.315	2.53	1.59	0.13	0.37
	weed 1	0.318	1.32	0.00	0.19	1.00
	maize 1	0.293	102.89	115.51	-1.80	-0.12
	sesb. 2	0.289	4.28	0.71	0.51	0.83
	weed 2	0.307	1.94	1.57	0.05	0.19
	bare 2	0.302	109.13	100.15	1.28	0.08
	maize 2	0.294	19.39	9.27	1.45	0.52
	maize 3	0.277	11.77	5.70	0.87	0.52
	weed 3	0.292	3.15	0.31	0.41	0.90
	bare 3	0.275	86.42	91.46	-0.72	-0.06
	sesb. 3	0.275	4.13	0.59	0.51	0.86
	sesb. 4	0.304	3.58	6.22	-0.38	-0.74
	maize 4	0.286	12.71	7.85	0.69	0.38
	weed 4	0.318	2.96	1.57	0.20	0.47
	bare 4	0.304	92.76	93.77	-0.14	-0.01
50-100 cm	rep. 1	0.317	23.68	27.00	-0.47	-0.14
	rep. 2	0.298	20.90	22.82	-0.27	-0.09
	rep. 3	0.303	12.76	12.81	-0.01	-0.00
	rep. 4	0.356	9.28	8.67	0.09	0.07
100-150 cm	rep. 1	0.309	6.69	6.99	-0.04	-0.04
	rep. 2	0.300	8.89	9.78	-0.13	-0.10
	rep. 3	0.332	5.39	5.99	-0.09	-0.11
	rep. 4	0.299	7.95	8.53	-0.08	-0.07
150-200 cm	rep. 1	0.092	3.55	3.86	-0.04	-0.09
	rep. 2	0.281	4.24	4.12	0.02	0.03
	rep. 3	0.281	3.47	3.77	-0.04	-0.09
	rep. 4	0.289	4.81	5.38	-0.08	-0.12
200-250 cm	rep. 1	0.261	4.15	4.59	-0.06	-0.11
	rep. 2	0.262	2.70	2.78	-0.01	-0.03
	rep. 3	0.254	2.16	2.68	-0.07	-0.24
	rep. 4	0.253	3.65	3.69	-0.00	-0.01
250-300 cm	rep. 1	0.244	1.82	1.93	-0.02	-0.06
	rep. 2	0.239	2.17	1.93	0.04	0.11
	rep. 3	0.250	1.67	2.03	-0.05	-0.21
	rep. 4	0.237	1.17	0.00	0.17	1.00
300-350 cm	rep. 1	0.216	2.05	1.25	0.11	0.39
	rep. 2	0.207	1.19	0.06	0.16	0.95
	rep. 3	0.233	1.73	0.37	0.19	0.79
	rep. 4	0.227	1.77	1.60	0.03	0.10
350-400 cm	rep. 1	0.198	1.68	1.97	-0.04	-0.17
	rep. 2	0.202	1.06	1.70	-0.09	-0.59
	rep. 3	0.209	0.46	0.68	-0.03	-0.48
	rep. 4	0.216	1.90	1.35	0.08	0.29

ble VI.12.2: Denitrification rates as a function of depth and moisture content as measured as the rate of nitrate disappearance in a laboratory incubation

depth	WFPS t=0 (in %)	WFPS t=10 (in %)	nitrate t=0 (mg/kg)	nitrate t=10 (mg/kg)	denitr. rate (mg/kg/d)
0-15 cm	81.93	78.65	27.44	5.99	2.15
	81.91	73.26	28.59	12.22	1.64
	80.73	76.80	27.44	7.11	2.03
	78.73	69.30	24.22	5.13	1.91
	72.98	63.79	30.26	12.00	1.83
	71.82	65.04	17.37	13.65	0.37
	69.35	66.72	13.23	7.29	0.59
	67.69	59.54	33.84	7.71	2.61
	65.18	62.44	6.76	7.78	-0.10
	64.89	60.53	19.05	7.83	1.12
	63.46	65.07	10.66	8.37	0.23
	61.77	58.77	2.81	3.92	-0.11
	61.64	56.78	9.62	3.08	0.65
	59.01	57.72	4.82	4.14	0.07
15-30 cm	89.19	91.83	24.45	5.61	1.88
	87.21	91.86	8.10	3.80	0.43
	87.19	85.27	24.45	3.72	2.07
	80.65	73.37	32.58	8.13	2.44
	78.43	77.40	23.84	11.36	1.25
	74.75	70.13	14.06	9.67	0.44
	73.06	69.49	23.24	7.21	1.60
	72.70	71.83	23.21	19.24	0.40
	71.54	66.90	10.95	12.26	-0.13
	70.93	62.45	32.47	13.42	1.90
	68.64	69.41	27.33	10.66	1.67
	68.41	75.01	10.46	8.59	0.19
	67.00	67.24	18.38	10.61	0.78
	66.30	60.34	17.99	13.95	0.40
30-50 cm	87.57	91.27	10.21	9.06	1.11
	84.98	79.27	25.10	13.67	1.14
	84.86	84.85	29.89	7.45	2.24
	82.28	89.36	28.28	18.64	0.96
	81.75	81.59	29.32	20.04	0.93
	81.72	83.11	28.71	18.81	0.99
	79.78	84.85	38.72	23.10	1.56
	79.67	73.59	23.29	15.81	0.75
	79.02	74.26	37.10	7.70	2.94
	76.58	78.65	20.48	3.14	1.73
	74.63	66.08	20.41	5.61	1.48
	73.61	68.13	17.70	4.83	1.29
	61.14	58.25	17.36	7.94	0.94

Table VI.12.2 -continued -

50-100 cm	90.11	86.97	10.61	0.72	0.99
	85.50	88.17	11.37	4.73	0.66
	82.18	77.87	27.80	15.00	1.28
	82.08	77.67	25.84	10.03	1.58
	80.11	84.61	10.61	0.97	0.96
	78.15	75.40	21.10	22.97	-0.19
	76.47	74.29	34.41	1.55	3.29
	74.91	76.51	29.65	12.20	1.74
	73.70	72.50	8.28	5.26	0.30
	73.49	71.84	16.28	4.33	1.19
	72.11	68.62	11.55	3.49	0.81
	70.90	73.53	19.14	9.83	0.93
	68.27	73.21	18.45	18.64	-0.02
	62.46	66.10	15.70	13.43	0.23
100-150 cm	89.50	91.04	8.55	1.00	0.76
	88.50	83.86	8.55	0.43	0.81
	87.43	88.35	6.84	0.88	0.60
	83.79	87.01	9.79	6.66	0.31
	81.17	77.42	8.78	2.74	0.60
	78.06	71.37	7.38	1.08	0.63
	77.71	65.69	8.18	0.91	0.73
	74.00	77.55	8.02	1.44	0.66
	72.31	67.28	10.27	4.22	0.60
	71.99	71.02	6.44	1.50	0.49
	70.43	67.72	9.86	1.52	0.83
	67.87	66.83	9.43	3.55	0.39
	66.53	67.06	9.54	1.95	0.76
	64.60	70.50	5.91	1.67	0.42
150-200 cm	88.83	79.87	3.82	1.03	0.28
	86.83	80.37	3.82	0.74	0.31
	83.86	88.27	4.30	0.46	0.38
	83.73	80.70	1.63	4.81	-0.32
	78.25	72.97	3.91	0.94	0.30
	77.85	81.07	2.88	0.80	0.21
	77.42	76.48	2.68	0.83	0.18
	76.02	82.60	4.01	0.93	0.31
	72.97	71.47	4.47	0.97	0.35
	72.62	66.33	4.82	2.57	0.22
	70.85	70.12	5.40	0.81	0.46
	68.41	70.01	4.01	0.62	0.34
	67.42	61.24	3.38	1.07	0.23
	65.11	71.57	2.91	1.58	0.13

Appendix VII: Soil carbon, soil nitrogen and soil phosphorus data

Table VII.1: Organic carbon, total nitrogen, total phosphorus and organic phosphorus in the soil during the experiment

depth (m)	time	Initial soil sampling			Beginning of 4th season				10 November 1994			End of the 4th season		
		C (%)	N (%)	P (%)	C (%)	N (%)	P (%)	P_org (%)	C (%)	N (%)	P (%)	C (%)	N (%)	P (%)
e 0-0.15	average	1.495	0.161	0.049	1.370	0.148	0.045	0.031	1.458	0.157	0.047	1.568	0.169	0.051
	S.D.	0.034	n.d.	n.d.	0.075	0.008	0.002	0.002	0.083	n.d.	n.d.	0.098	n.d.	n.d.
0.15-0.30	average	1.343	0.143	0.044	1.220	0.130	0.040	0.030	1.390	0.148	0.046	1.445	0.154	0.048
	S.D.	0.074	n.d.	n.d.	0.062	0.007	0.001	0.003	0.098	n.d.	n.d.	0.152	n.d.	n.d
0.30-0.50	average	1.020	0.113	0.037	0.903	0.100	0.033	0.024	1.030	0.114	0.038	1.068	0.118	0.039
	S.D.	0.117	n.d.	n.d.	0.055	0.000	0.002	0.001	0.056	n.d.	n.d.	0.140	n.d.	n.d.
0.50-1.00	average	0.590	0.072	0.033	0.578	0.070	0.032	0.016	0.698	0.085	0.039	0.648	0.078	0.036
	S.D.	0.070	n.d.	n.d.	0.026	0.000	0.001	0.001	0.064	n.d.	n.d.	0.033	n.d.	n.d.
1.00-1.50	average	0.523	0.050	0.033	0.498	0.048	0.031	0.013	0.540	0.052	0.034	0.563	0.054	0.035
	S.D.	0.033	n.d.	n.d.	0.066	0.004	0.002	0.001	0.027	n.d.	n.d.	0.008	n.d.	n.d.
1.50-2.00	average	0.450	0.036	0.026	0.538	0.043	0.032	0.013	0.568	0.045	0.033	0.475	0.038	0.028
	S.D.	n.d.	n.d.	n.d.	0.079	0.004	0.002	0.001	0.042	n.d.	n.d.	0.032	n.d.	n.d.
2.00-2.50	average	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.533	n.d.	n.d.	n.d.	n.d.	n.d.
	S.D.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.128	n.d.	n.d.	n.d.	n.d.	n.d.
2.50-3.00	average	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.548	n.d.	n.d.	n.d.	n.d.	n.d.
	S.D.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.086	n.d.	n.d.	n.d.	n.d.	n.d.
3.00-3.50	average	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.503	n.d.	n.d.	n.d.	n.d.	n.d.
	S.D.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.118	n.d.	n.d.	n.d.	n.d.	n.d.
3.50-4.00	average	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.463	n.d.	n.d.	n.d.	n.d.	n.d.
	S.D.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.096	n.d.	n.d.	n.d.	n.d.	n.d.
. 0-0.15	average	1.495	0.158	0.048	1.415	0.150	0.045	0.031	1.448	0.153	0.047	1.528	0.162	0.049
	S.D.	0.034	n.d.	n.d.	0.056	0.071	0.021	0.003	0.061	n.d.	n.d.	0.040	n.d.	n.d.
0.15-0.30	average	1.343	0.146	0.044	1.128	0.13	0.041	0.028	1.278	0.139	0.042	1.378	0.150	0.045
	S.D.	0.074	n.d.	n.d.	0.124	n.d.	n.d.	0.002	0.138	n.d.	n.d.	0.100	n.d.	n.d.
0.30-0.50	average	1.020	0.111	0.040	0.815	0.10	0.031	0.020	0.947	0.103	0.037	0.938	0.102	0.037
	S.D.	0.117	n.d.	n.d.	0.138	n.d.	n.d.	0.003	0.174	n.d.	n.d.	0.118	n.d.	n.d.
0.50-1.00	average	0.590	0.065	0.031	0.549	0.07	0.030	0.014	0.623	0.069	0.033	0.603	0.067	0.032
	S.D.	0.070	n.d.	n.d.	0.046	n.d.	n.d.	0.001	0.058	n.d.	n.d.	0.066	n.d.	n.d.
1.00-1.50	average	0.523	0.048	0.032	0.560	0.05	0.033	0.013	0.585	0.054	0.035	0.505	0.047	0.030
	S.D.	0.033	n.d.	n.d.	0.048	n.d.	n.d.	0.004	0.043	n.d.	n.d.	0.018	n.d.	n.d.
1.50-2.00	average	0.450	0.036	0.026	0.562	0.04	0.028	0.014	0.568	0.045	0.034	0.708	0.057	0.043
	S.D.	n.d.	n.d.	n.d.	0.069	n.d.	n.d.	0.003	0.055	n.d.	n.d.	0.446	n.d.	n.d.
2.00-2.50	average	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.559	n.d.	n.d.	n.d.	n.d.	n.d.
	S.D.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.050	n.d.	n.d.	n.d.	n.d.	n.d.
2.50-3.00	average	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.529	n.d.	n.d.	n.d.	n.d.	n.d.
	S.D.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.041	n.d.	n.d.	n.d.	n.d.	n.d.
3.00-3.50	average	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.448	n.d.	n.d.	n.d.	n.d.	n.d.
	S.D.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.063	n.d.	n.d.	n.d.	n.d.	n.d.
3.50-4.00	average	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.413	n.d.	n.d.	n.d.	n.d.	n.d.
	S.D.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.048	n.d.	n.d.	n.d.	n.d.	n.d.
0-0.15	average	1.495	0.169	0.044	1.418	0.160	0.042	0.030	1.495	0.169	0.044	1.525	0.172	0.045
	S.D.	0.034	n.d.	n.d.	0.035	0.010	0.002	0.002	0.057	n.d.	n.d.	0.161	n.d.	n.d.
0.15-0.30	average	1.343	0.149	0.044	1.128	0.125	0.037	0.031	1.375	0.152	0.045	1.375	0.152	0.045
	S.D.	0.074	n.d.	n.d.	0.077	0.005	0.001	0.004	0.057	n.d.	n.d.	0.111	n.d.	n.d.
0.30-0.50	average	1.020	0.109	0.043	0.798	0.085	0.034	0.019	1.048	0.112	0.044	1.060	0.113	0.045
	S.D.	0.117	n.d.	n.d.	0.151	0.015	0.002	0.004	0.097	n.d.	n.d.	0.047	n.d.	n.d.
0.50-1.00	average	0.590	0.060	0.030	0.638	0.065	0.032	0.017	0.733	0.075	0.037	0.643	0.066	0.032
	S.D.	0.070	n.d.	n.d.	0.058	0.005	0.001	0.002	0.110	n.d.	n.d.	0.025	n.d.	n.d.
1.00-1.50	average	0.523	0.047	0.031	0.505	0.045	0.030	0.011	0.595	0.053	0.035	0.575	0.051	0.034
	S.D.	0.033	n.d.	n.d.	0.050	0.005	0.004	0.002	0.071	n.d.	n.d.	0.049	n.d.	n.d.
1.50-2.00	average	0.450	0.036	0.026	0.493	0.040	0.031	0.012	0.643	0.052	0.040	0.588	0.048	0.036
	S.D.	n.d.	n.d.	n.d.	0.060	0.010	0.001	0.000	0.041	n.d.	n.d.	0.162	n.d.	n.d.
2.00-2.50	average	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.545	n.d.	n.d.	n.d.	n.d.	n.d.
	S.D.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.030	n.d.	n.d.	n.d.	n.d.	n.d.
2.50-3.00	average	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.500	n.d.	n.d.	n.d.	n.d.	n.d.
	S.D.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.061	n.d.	n.d.	n.d.	n.d.	n.d.
3.00-3.50	average	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.480	n.d.	n.d.	n.d.	n.d.	n.d.
	S.D.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.079	n.d.	n.d.	n.d.	n.d.	n.d.
3.50-4.00	average	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.440	n.d.	n.d.	n.d.	n.d.	n.d.
	S.D.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.073	n.d.	n.d.	n.d.	n.d.	n.d.
0-0.15	average	1.495	0.166	0.048	1.330	0.148	0.043	0.029	1.463	0.162	0.047	1.480	0.164	0.047
	S.D.	0.034	n.d.	n.d.	0.025	0.008	0.001	0.002	0.154	n.d.	n.d.	0.083	n.d.	n.d.
0.15-0.30	average	1.343	0.147	0.045	1.093	0.120	0.037	0.026	1.173	0.129	0.039	1.288	0.141	0.043
	S.D.	0.074	n.d.	n.d.	0.115	0.010	0.001	0.002	0.214	n.d.	n.d.	0.094	n.d.	n.d.
0.30-0.50	average	1.020	0.110	0.038	0.790	0.085	0.030	0.021	0.943	0.101	0.035	0.808	0.087	0.030
	S.D.	0.117	n.d.	n.d.	0.108	0.005	0.000	0.001	0.191	n.d.	n.d.	0.155	n.d.	n.d.
0.50-1.00	average	0.590	0.068	0.033	0.563	0.065	0.032	0.015	0.643	0.074	0.036	0.678	0.078	0.038
	S.D.	0.070	n.d.	n.d.	0.033	0.005	0.004	0.001	0.090	n.d.	n.d.	0.092	n.d.	n.d.
1.00-1.50	average	0.523	0.038	0.030	0.550	0.040	0.032	0.012	0.588	0.043	0.034	0.495	0.036	0.029
	S.D.	0.033	n.d.	n.d.	0.064	0.000	0.001	0.002	0.090	n.d.	n.d.	0.029	n.d.	n.d.
1.50-2.00	average	0.450	0.036	0.026	0.475	0.035	0.029	0.014	0.523	0.039	0.032	0.523	0.039	0.032
	S.D.	n.d.	n.d.	n.d.	0.040	0.005	0.001	0.002	0.068	n.d.	n.d.	0.063	n.d.	n.d.
2.00-2.50	average	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.538	n.d.	n.d.	n.d.	n.d.	n.d.
	S.D.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.047	n.d.	n.d.	n.d.	n.d.	n.d.
2.50-3.00	average	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.540	n.d.	n.d.	n.d.	n.d.	n.d.
	S.D.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.074	n.d.	n.d.	n.d.	n.d.	n.d.
3.00-3.50	average	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.490	n.d.	n.d.	n.d.	n.d.	n.d.
	S.D.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.058	n.d.	n.d.	n.d.	n.d.	n.d.
3.50-4.00	average	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.400	n.d.	n.d.	n.d.	n.d.	n.d.
	S.D.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.068	n.d.	n.d.	n.d.	n.d.	n.d.

Table VII.2: Organic carbon, total nitrogen and total phosphorus in the soil at the end of the 4th season in the topsoil

trt.	depth (m)		C (%)	N (%)	P (%)
maize	0-5 cm	mean	1.68	0.1575	0.0415
		S.D.	0.0578	0.0083	0.0026
	5-15 cm	mean	1.6075	0.1675	0.044
		S.D.	0.1117	0.0148	0.0012
sesbania	0-5 cm	mean	1.6375	0.185	0.04175
		S.D.	0.0130	0.0087	0.0036
	5-15 cm	mean	1.5575	0.18	0.045
		S.D.	0.1312	0.0235	0.0037
weed	0-5 cm	mean	1.735	0.18	0.04075
		S.D.	0.0568	0.01	0.0004
	5-15 cm	mean	1.66	0.16	0.0435
		S.D.	0.0548	0.0071	0.0011
bare	0-5 cm	mean	1.68	0.1575	0.04225
		S.D.	0.0765	0.0083	0.0019
	5-15 cm	mean	1.6275	0.1625	0.04375
		S.D.	0.0826	0.0109	0.0011

Table VII.3: Exchangeable phosphorus (in mg/kg) as determined by a modified Olsen method during the experiment

trt.	depth	initial sampling		10 November 1994		end of 4th season	
		mean	S.D.	mean	S.D.	mean	S.D.
maize	0-15 cm	2.00	0.000	0.98	0.396	0.88	0.148
	15-30 cm	1.25	0.433	0.88	0.249	0.75	0.377
	30-50 cm	0.25	0.433	1.20	0.552	0.45	0.112
	50-100 cm	1.00	0.000	1.15	0.357	1.48	0.179
	100-150 cm	2.00	0.000	1.30	0.660	1.90	0.453
	150-200 cm	n.d.	n.d.	1.25	0.439	1.93	0.342
sesbania	0-15 cm	2.00	0.000	1.65	0.838	0.75	0.150
	15-30 cm	1.25	0.433	1.48	0.377	0.53	0.148
	30-50 cm	0.25	0.433	1.10	0.354	0.50	0.158
	50-100 cm	1.00	0.000	0.95	0.550	1.13	0.249
	100-150 cm	2.00	0.000	1.05	0.482	1.85	0.260
	150-200 cm	n.d.	n.d.	0.55	0.112	1.75	0.180
weed	0-15 cm	2.00	0.000	1.53	0.676	0.90	0.320
	15-30 cm	1.25	0.433	1.63	0.166	0.68	0.148
	30-50 cm	0.25	0.433	1.33	0.292	0.53	0.187
	50-100 cm	1.00	0.000	1.55	0.449	1.50	0.255
	100-150 cm	2.00	0.000	1.08	0.277	1.80	0.303
	150-200 cm	n.d.	n.d.	0.83	0.277	1.38	0.217
bare	0-15 cm	2.00	0.000	1.08	0.192	1.20	0.255
	15-30 cm	1.25	0.433	0.75	0.269	0.70	0.187
	30-50 cm	0.25	0.433	0.58	0.238	0.55	0.377
	50-100 cm	1.00	0.000	0.68	0.148	0.98	0.192
	100-150 cm	2.00	0.000	1.38	0.626	1.78	0.554
	150-200 cm	n.d.	n.d.	1.35	0.610	1.60	0.158