

EVALUATION OF THE POTENTIAL OF ROTATIONAL TREE FALLOWS FOR
SUSTAINING MAIZE PRODUCTION AT MEATU, SHINYANGA, TANZANIA

BY

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ABSTRACT

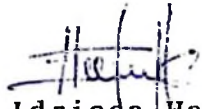
A study was undertaken on on-going agroforestry research at Meatu, Shinyanga, Tanzania to evaluate the potential of short tree fallows on maize yields and soil fertility sustenance. The tree fallows involve three-, four- and five-year old fallows, respectively cropped thrice, twice and once. In each of these tree fallows (experiments) the following three treatments were imposed: (a) maize + trees with prunings removed, (b) maize + trees with prunings removed with 50 kg N kg⁻¹ supplement, and (c) maize + trees with prunings returned back to soil. Each treatment was replicated three times in a complete randomized design. Results from this study have shown that maize yields were usually high at the opening of each experiment, given sufficient rain. In 1993 maize yield was significantly higher ($P < 0.05$) in the four-year fallow than in the three-year fallow. In 1994 cropping season, maize yield was significantly higher ($P < 0.05$) in treatment with prunings than in treatment with N supplement. Results from routine soil analysis showed that soil parameters did not vary significantly between treatments within experiments. However, P quantities in the top-soil were significantly different between experiments. Results from N-mineralization, for the first sampling, showed greater ($P < 0.05$) nitrification rates under treatment with prunings

than under treatment with N supplement in both three- and five-year old fallows. At the second sampling, nitrification rates were significantly lower ($P < 0.05$) in the three-year fallow than in the other two.

Based on the results from this study no firm conclusion can be drawn on the suitability of the current treatments to maintain maize productivity. Nevertheless, preliminary observations indicate that the treatment with prunings seemed to be the best. Comparing the three experiments with respect to maize yield and other soil parameters the four-year old fallow seemed better than others.

DECLARATION

I, IDRISSE HAMIDOU, do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my own original work and has never been submitted for a degree award in any other University.



Idrissa Hamidou

Date: 1996

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ABBREVIATIONS

ANAFE:	African Network for Agroforestry Education
Ap:	<i>Acacia polyacantha</i>
ETP:	Evapotranspiration Potential
Expt:	Experiment
F:	Maize + trees with prunings removed
F+N:	Maize + trees with prunings removed + nitrogen supplement
F+P:	Maize + trees with prunings returned back to the soil
GLM:	General Linear Model
ICRAF:	International Centre for Research in Agroforestry
ICRISAT:	International Crops Research Institute for Semi-Arid Tropics
L1:	<i>Leucaena leucocephala</i>
MCD:	Ministère (Français) de la Coopération et du Développement
OC:	Organic Carbon, %
OM:	Organic matter
P1:	Soil sampling period, before maize planting
P2:	Soil sampling period, during maize flowering stage
SAS:	Statistical Analysis System
SHISCAP:	Shinyanga Soil Conservation and Afforestation Programme
SUA:	Sokoine University of Agriculture

TN: Total Nitrogen, %

Trt: Treatment

UF: Under Fallow

CHAPTER 1

1.0 INTRODUCTION

Tanzania is one of the most underdeveloped countries in the world and its economy is largely dependent on the agriculture sector. Its population is estimated at 23 M with an annual growth rate of 2.8% (Population Census, 1988). The country has been facing chronic problems related to its agricultural production such as insecure harvests caused by wide fluctuations in weather conditions, decline in soil fertility and lack of means to intensify agriculture. These problems are acute in regions like Shinyanga, Tabora, Dodoma, Singida and Mwanza.

In the past Shinyanga was reported to be extensively covered with woodland and bushland species such as *Acacia*, *Brachystegia*, *Albizia*, *Commiphora*, *Dalbergia*, etc. However, massive woodland clearing for extensive agriculture, tse-tse flies and quelleda-quelleda birds control during the 1920s, and overgrazing have caused extensive environmental damage in this region (Otsyina and Asenga, 1993). Deforestation has contributed to soil degradation and decline in soil fertility, and in combination with unreliable rainfall, often accounts for poor crop yields. Shortages of fodder during the dry season, shortages of

fuelwood and construction poles are also crucial problems that people in this region face.

In view of the current environmental and food crisis, the considerable increase in human and animal population, and the high price in mineral fertilizers, farmers in Tanzania, like in other developing countries, are forced to adopt semi-intensive agricultural systems. One approach to land use which holds a great potential to address some of the problems mentioned is agroforestry. Agroforestry has a potential in soil fertility improvement, crop yield enhancement, and supply of fuelwood and fodder to farmers. Among the various agroforestry technologies that have high potential for soil fertility improvement is the planted fallow or improved tree fallow (Rao et al., 1990; Kwesiga, 1994). It involves the use of multipurpose trees during fallow period, either by systems in which planted fallow alternates with crops (rotational fallow) or by rotational hedgerow intercropping systems, in which a period of hedgerow intercropping is followed by a period of uninterrupted hedge growth without crops (Rao et al., 1990). For the improved fallow, fast growing and nitrogen fixing trees are introduced in order to achieve the benefits of natural fallow within a short time (Prinz, 1986).

The present study focuses on rotational mixed *Leucaena leucocephala* and *Acacia polyacantha* fallow system. The rotational woodlot system comprises three phases: the establishment phase, where crops are inter-planted with trees; the fallow phase, where the land is left idle under tree vegetation for a relatively long period; and the post-fallow phase, that involves pruning, cutting the trees to promote coppicing and maize production. This study considers the post fallow phase and evaluates soil fertility maintenance under the current agroforestry technology and overall sustainability of the system.

Most of the effects of trees on soil fertility are based on quantitative factors such as amounts of humus and nutrients in the top soil. Sensitive intensity factors such as nitrogen mineralization rates and available phosphorus have not been used so far. Thus this study was undertaken to evaluate the potential of mixed *L. leucocephala* and *A. polyacantha* on soil fertility improvement and sustenance for maize production in the semi-arid conditions of Shinyanga region.

The goal of the current research is to assess the effects of the treatments applied on soil fertility sustenance during the post-fallow phase. The specific objectives are:

- (a) To determine changes in maize yields in response

to different fallow management practices from year to year;

(b) To evaluate the current status of certain key soil factors (organic C, total N, available P and cations exchange capacity) that determine fertility in the tropics (Karl and Johannes, 1994);

(c) To assess N-mineralization potential in three fallow phases.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1. Soil Fertility

Cooke (1967) defined natural soil fertility as the capacity of that soil to support the climax population of plants and animals (excluding man) above ground, and the associated flora and fauna below ground. In agriculture soil fertility is defined as its capacity to produce the desired crops. The fertility of soil is a complex notion, and depends on several factors. According to Whyte and Trumble (1953) soil fertility is affected by physical condition which favours continuity of supply and an adequate balance of water and air under a sufficient rainfall or irrigation, and a sufficiency in available form of all essential soil nutrients to provide for the maintenance of production at a level which climatic and economic conditions permit. The fertility of soil is dynamic, and in agro-ecosystems the inevitable result is the depletion of this fertility because of the exportation of the organic compounds (Cooke, 1967).

2.2. Soil Fertility for Maize Production

All plants require a suitable environment for their optimum growth. Maize requires well-structured, permeable soils with high content of organic matter (Euroconsult, 1989). A good soil for maize crop has, among others, to contain and supply nutrients required by the crop (Ngatunga and Mapua, 1988). As regards nutritional requirements of maize, the crop demands N, P, K, Ca, Mg, and S as major elements, and a variety of micronutrients. Haule (1988) and Palm (1995) have estimated the average nutrient requirement for maize production as shown in Table 1 below.

Table 1. Nutrient requirements for maize production

Source	Nutrients					
	N	P ₂ O ₅	K ₂ O	Ca	Mg	S
Haule (1988)*	24	12	18	4	4	1.6
Palm (1995) a**	50	12	30	6	4	-
b	30	6	36	9	6	-

* = Quantities of nutrients required to produce 1 t maize grain ha⁻¹.

** = Quantities of nutrients required to produce (a) 2 t maize grain ha⁻¹, and (b) 3 t stover ha⁻¹.

2.3. Decline in Soil Fertility

Young (1989) defines the decline in soil fertility as the combined effect of deterioration of soil physical properties, lowering of soil organic matter and nutrient content, and in some cases acidification. The main forms of soil degradation are erosion (both physical, chemical and biological), salinization and pollution. These forms of degradation lead to lowering of soil fertility and consequently to its productivity. In systems such as agricultural systems that involve the harvest of crop products, soil fertility is expected to decline in the short or medium term. Indeed, in these soils fertility depletion does not only originate from the removal of the crops, but also can result from the disturbances caused during soil-working, which increases losses of nutrients either by leaching or run-off.

2.4. Methods for Fertility Restoration or Maintenance

Man has always adopted diverse management practices for maintaining soil fertility. The restoration of soil nutrients through fallowing, which allows a sufficiently long period for vegetative regeneration, or the concentration of biomass in one area under traditional systems such as "Chitemene" in Zaire-Congo watershed in

Africa, represent two ancient methods, one of restoring and the other of augmenting soil nutrients used for crop production (FAO, 1987). The use of animal manure represents another traditional method, still of importance in many farming systems in developing countries. In addition, mixed cropping and crop rotation which include a legume have also been widely used especially in developing countries (FAO, 1987). In the developed countries soil fertility improvement is through the use of inorganic fertilizers. The use of mineral fertilizers is essential when the amount of nutrients supplied via organic recycling or biological nitrogen fixation is not sufficient to sustain the yield required. Agroforestry technologies, that combine trees, crops and/or livestock/pasture constitute a new alternative for soil fertility improvement.

2.4.1. Restoration of fertility using inorganic fertilizers

Inorganic fertilizer refers to the materials, commonly synthetic, which are rich in one or more of the essential plant nutrients (Simpson, 1986). Few soils are sufficiently fertile to provide the nutrients required for even moderate crop yields (FAO, 1987). Fertilizers are a source of nutrients readily or easily assimilable by plants. Long term field experiments started in the 1840s' at Rothamsted Experimental Station, Harpenden in southern England, showed

that crop yields could be maintained under continuous cropping when the required nutrients were applied (Wild, 1993). The use of fertilizers world-wide has increased significantly since the 1950s. For example, Wild (1993) reports that the use of nitrogen fertilizer has increased from about 10 million tons in 1960 to 80 million tons in 1990, and is projected to reach 100 million tons by the year 2000. Even in agroforestry systems, Szott et al. (1993) suggests that the use of fertilizers is inevitable for crops having a high nutrient demand since the capacity of the trees to provide the required elements is limited. However, the positive effect of fertilization may be less than expected due to negative relationship between nitrogen fixation and quantity of inorganic N applied, the increased possibility of N loss through leaching and volatilization, and the tendency of the trees to compete for and sequester nutrients such as P. Although fertilizers could correct soil deficiency in essential elements and thus enhance crop production their long-term use is still questioned because of their cost and polluting effect.

2.4.2. Restoration of fertility using manures

Manures refer to the bulky organic materials, mainly plant residues, animal excreta and urban wastes, which are returned to the soil either directly or after some sort of

processing (Simpson, 1986). Organic matter, including green manure, is of great importance to soil fertility and hence productivity. Mahmoud and El-Sawy (1982) point out that the use of organic manures is inevitable especially in tropical and sub-tropical soils and also in sandy soils where the rate of degradation of organic matter is very high, given the presence of optimal environmental conditions for microbial activities. The function of green manures, is a good means of preserving soil nutrients from leaching, fixing or holding them in an insoluble organic form which when mineralized by soil micro-organisms, supplies the plants with a 'gentle stream' of nutrients throughout their life period in the soil. Further, green manures in addition to fixing available nutrients in the soil in the organic form, increase soil nitrogen and organic matter, gained from nitrogen fixation and photosynthesis. By their nature manures have two functions. They supply some organic matter, which persists in form of humus in the soil and improves its physical properties. Manures also provide a wide spectrum of plant nutrients. Nevertheless, the content of these nutrients is low and, for example to supply some 20-30% of the requirements of a potato crop, Simpson (1986) estimates that 25-40 t ha⁻¹ of manures should be added to the soil.

2.4.3. Restoration of fertility under natural fallow

For centuries shifting cultivation, a universal agricultural practice, had been used to restore soil fertility (Whyte and Trumble, 1953; Nye and Greenland, 1960; Cooke, 1967; Rao et al., 1990). Shifting cultivation refers to a temporary and short cropping phase followed by fallow period during which the land is left under natural vegetation and is expected to regain soil fertility (Ahn, 1979; Mohamed, 1989). Soil fertility changes under fallow are closely linked with the amount of litter-fall that provides humus, helps to hold exchangeable cations, stores large amounts of P and S, and is the sole reservoir of nitrogen (Nye and Greenland, 1960). The rate and the extent of fertility restoration through litter fall production and accumulation depend on the length of the fallow period, the nature of the fallow vegetation, soil properties, the management intensity (Rao, 1989), and climatic factors. The most striking feature of the aggrading phase of fallow is the rate of accumulation of nutrients in the vegetation store (Norman, 1979). To maintain soil organic matter, Young (1989) speculates that land use in humid tropics should add an order of 8 t DM ha⁻¹ yr⁻¹ to the soil; corresponding values for the sub-humid and semi-arid zones are 4 and 2 t DM ha⁻¹ yr⁻¹, respectively. In an earlier study Nye and Greenland (1960) estimated the production of

organic material, after very long periods of fallow (age of the fallow not specified), to be about 16.6 t DM ha⁻¹ yr⁻¹ and 2.4 t DM ha⁻¹ yr⁻¹ in forest ecosystems and moist savanna grassland areas, respectively. The system requires 10 to 20 years to rejuvenate the fertility (Jouve, 1991; Rao et al., 1990).

2.4.4. Soil fertility restoration under Agroforestry

2.4.4.1. Definition of Agroforestry

Agroforestry refers to all land-use systems in which woody perennials are grown in association with agricultural crops, pastures or livestock, and in which there are both ecological and economic interactions between the tree and non-tree components of the systems (Young, 1989). One of the advantages that is usually attributed to agroforestry is the possibility for improvement of fertility status of agricultural lands through additional amounts of nitrogen added to the system by the tree legume component (Nair, 1984). Animals in agroforestry systems can provide a significant amount of nitrogen in their excreta. In agroforestry systems, soil improvement is expected to originate from the woody and animal components; in most cases the production of crops is in fact considered as an exportation from the soil. When designing agroforestry

technologies for soil productivity improvement, the most important thing is to maximize the beneficial effects of trees on the crop component of the system (Nair, 1993).

The shifting cultivation systems are nowadays limited by the shortage of land and the short fallow periods due to demographic pressure. On the other hand the utilisation of inorganic fertilizers is also limited by their availability and their high costs. The use of manures is limited by the quantities of organic materials required. The development of viable technologies for small farmer systems in the tropics is a challenge for today's agricultural scientists (Rachie, 1983). Many experiments carried out or on-going indicate the potential of agroforestry systems to be a promising alternative to the traditional farming systems for soil fertility improvement and conservation.

2.4.4.2. Effects of trees on soil properties

It is well known that trees have some beneficial effects on soil properties. Several traditional agricultural practices such as shifting cultivation and keeping trees on farm are used to support that belief. Young (1989) suggested several hypotheses on how trees may improve soils. It is, for example, a fact that soil fertility declines almost inevitably after a complete forest clearance. Further

evidence of the effects of trees on soils comes from comparing soil properties under the canopy of individual trees with those in the surrounds without a tree cover. The potential of trees for soil fertility improvement can be manifested by the increase in soil organic matter through litter-fall, accretion of nitrogen by nitrogen-fixing trees, nutrient recycling and reduction of losses of nutrients. Litter production and direct addition of leaves and branches as mulches or incorporated in the soil have been shown to increase soil organic matter (Szott et al., 1991). Organic matter is a key factor for high crop production since it acts as a soil conditioner by improving structure, moisture and ion retention, besides being an important source of some nutrient elements (Urio et al., 1979). However, its ability to improve soil physical, chemical and biological properties depends on its quality (Young, 1989, Nair, 1993).

The effects of organic matter on soil physical properties is due in part to the action of organic gums in binding soil particles into stable aggregates, thus leading to an improvement in soil structure with a balanced distribution of pore sizes (Singh et al., 1993). Kang et al. (1985) and Rosecrance et al. (1991) studying some agroforestry systems emphasize the potential of trees to improve soil water-holding capacity and structure.

The contribution of trees to ameliorate soil chemical properties has been widely highlighted; factors such as a balanced nutrient supply, a slow release of nutrients and protection from leaching, and a buffering effect against soil acidity have been reported. Studies carried out in humid and semi-humid areas have shown significant effects of trees, in alley cropping and improved fallow systems, to increase soil pH, B, P (Adesina, 1990), exchangeable K, Ca, Mg and NO_3^- levels in soil solution (Kang et al., 1985; Rosecrance et al., 1991; Singh et al., 1993). It is also reported that organic matter produced by trees has a buffering effect against soil acidity. For example, Young (1989) reports that forest clearance on acid soils commonly leads to a temporary reduction in acidity through the addition of bases in burnt or decomposing litter. However, he expresses doubt on whether tree litter can be a significant means of raising pH on acid soils, except through the release of bases built up during many years of growth. Nevertheless, he indicates that the *Chitemene* system of shifting cultivation found in Zambia does successfully reduce acidity. Other trees are reported to be a means of reclaiming saline and alkaline soils. For example, *Acacia nilotica* and *Eucalyptus tereticornis* are reported to lower the topsoil pH from 10.5 to 9.5 in five years (Nair, 1993).

On the other hand the ecological effect of trees has also been mentioned. The presence of trees has been shown to reduce the density of shade sensitive weeds. For example, Anoka et al. (1991) showed that *Gliricidia sepium* and *L. leucocephala* grown in hedgerow reduce speargrass (*Imperata cylindrica*) density to 67% and 51%, respectively. Similar results have been reported by Rosecrance et al. (1991) in Western Samoa.

2.4.4.3. Potential of agroforestry for crop production

Rao (1989) claims that if trees/shrubs are established in high densities and retained on the ground for 1 to 3 years the land can be enriched and brought back for food production. Studying another agroforestry technology, alley cropping, Kang et al. (1990) suggest that continuous cultivation of annual food crops is possible when fast growing nitrogen-fixing leguminous species with large biomass production are planted in the system. Similarly, Singh (1992) reported that maize grain yield of 2 t ha⁻¹ can be maintained over long period under alley cropping system involving *L. leucocephala* hedgerows. On the other hand Banda et al. (1994) assessed the potential of intercropped maize with closely spaced leucaena hedgerows on soil conservation and maize yield on a steep slopes. They found that soil loss averaged 2 t ha⁻¹ yr⁻¹ on leucaena

plots compared with 80 t ha⁻¹ yr⁻¹ on the unprotected control plot, falling to 27 t ha⁻¹ yr⁻¹ after the top soil had been eroded. Maize yields were maintained at 1.5-2 t ha⁻¹ on the protected plots, compared with 0.8 than 0.5 t ha⁻¹ on the control plot.

However, and despite its high potential to solve some ecological and socioeconomic problems, agroforestry is not a panacea (von Maydell, 1985). Supporting this statement, Nair (1993) asserts that with wrong choice of species combinations, management practices, and a lack of peoples' motivation and understanding, agroforestry will fail to achieve the desired objectives.

2.4.4.4. Limitations of agroforestry

The introduction of trees, especially fast growing legumes, in farmlands may improve soil fertility particularly the status of nitrogen. However, several authors (Jonsson et al., 1988) have reported certain limitations of the systems, in particular in arid and semi-arid areas where trees compete severely with other crops for moisture (Singh, 1992). An experiment conducted at ICRISAT on a shallow Alfisol in semi-arid India showed that *L. leucocephala* competed with crops for water and was not productive enough to make up for the loss in crop yields

(Rao et al., 1992). Roots of leucaena hedges were noted (ICRISAT, 1986) in the top 50 cm of the soil, and they spread laterally competing with crops for moisture. In addition, certain indigenous trees such as *Vitellaria paradoxa* and *Parkia biglobosa* can reduce sorghum grain yields under their canopy by an average of 50% and 70%, respectively, in comparison with yields in the open field (Kessler, 1991).

Despite these limitations, there is a range of agroforestry systems that could potentially improve soil fertility efficiently and maintain it for a relatively long period. Promising tree/shrub species for agroforestry systems are mainly nodulated legumes including *Tephrosia*, *Crotalaria*, *Desmodium*, *Gliricidia*, *Leucaena*, *Sesbania* and some *Acacia*. Many of these species are used in intensive studies on several agroforestry technologies in order to evaluate their significant interactions, both positive and/or negative, between them and their companion components. The present study involves *L. leucocephala* and *A. polyacantha*, thus brief description of these species is important.

2.5. *Leucaena leucocephala* (Lam.) de Wit

Leucaena leucocephala belongs to the family Leguminosae sub family Mimosoideae. It is an ever-green shrub or tree (von

(Rao et al., 1992). Roots of leucaena hedges were noted (ICRISAT, 1986) in the top 50 cm of the soil, and they spread laterally competing with crops for moisture. In addition, certain indigenous trees such as *Vitellaria paradoxa* and *Parkia biglobosa* can reduce sorghum grain yields under their canopy by an average of 50% and 70%, respectively, in comparison with yields in the open field (Kessler, 1991).

Despite these limitations, there is a range of agroforestry systems that could potentially improve soil fertility efficiently and maintain it for a relatively long period. Promising tree/shrub species for agroforestry systems are mainly nodulated legumes including *Tephrosia*, *Crotalaria*, *Desmodium*, *Gliricidia*, *Leucaena*, *Sesbania* and some *Acacia*. Many of these species are used in intensive studies on several agroforestry technologies in order to evaluate their significant interactions, both positive and/or negative, between them and their companion components. The present study involves *L. leucocephala* and *A. polyacantha*, thus brief description of these species is important.

2.5. *Leucaena leucocephala* (Lam.) de Wit

Leucaena leucocephala belongs to the family Leguminosae sub family Mimosoideae. It is an ever-green shrub or tree (von

Maydell, 1986) with a height mostly less than 10 m at maturity. The tree roots deeply, even seedlings develop a comparatively big taproot to resist drought (Kaale, 1984; von Maydell, 1986). The species has many varieties (over 100) which can be classified into three main types (Lulandala, 1985, von Maydell, 1986):

(a) 'Hawaiian-type': These are bushy varieties, up to 5 m high, with a rounded crown. Yields in wood and foliage are low. They are mainly used for marginal land reclamation but may become aggressive weeds due to their abundant seed production. Firewood, charcoal and shade/shelter are the main uses.

(b) 'Salvador-type': The trees are giant, up to 20 m high, with limited branching on the main stems. Trees of this type can produce very high biomass.

(c) 'Peru-type': These are trees or shrubs, sometimes tall (up to 15 m) with many branches and short stems. They produce a maximum of foliage and are recommended for forage production.

L. leucocephala originated from central America, especially in southern Mexico and has been introduced widely throughout the semi-arid to humid zones of the tropics (Kaale, 1984; von Maydell, 1986). *Leucaena* trees are adapted to a wide range of soils except very acid soils

with Al³⁺ toxicity. They grow in broad climatic conditions performing best in tropical and sub-tropical lowlands at altitude below 1000 m, with mean annual temperatures around 20°C and a rainfall range of 400-800 mm/year. *Leucaena* trees prefer well drained, high moisture content, neutral to alkaline clay soils, with a pH of 5.6 to 8 (von Maydell, 1986). *L. leucocephala* is among the fastest-growing trees known. Kaale (1984) reported that the mean annual increment for 2-3 years old stands can be 3 m in favourable conditions. When clearfelled, the resulting coppices can re-grow from 4 to 6 m in one year (Kaale, 1984; James, 1989). Results from different experiments in humid conditions have shown that about 100 kg of elemental nitrogen per hectare or more is fixed biologically in *leucaena* stands with a stocking of 1500 trees/ha or more (Lulandala, 1985; von Maydell, 1986). *Leucaena* has the unrivalled reputation as the most promising agroforestry tree with many uses that James (1989) summarized in these terms: *Leucaena* is "a tree whose products a farmer can eat, feed to livestock, harvest for fuelwood or charcoal, use to build a house, spread as green manure on a maize field or plant to stabilize and enrich soil". Nevertheless, with the spread of *Heteropsylla cubana* (*leucaena* psyllid) in Asia in the mid-1980s (Napompeth, 1989) and its arrival in Coastal Eastern Africa in the early 1990s the importance of *leucaena* is declining. Indeed the psyllid, a sap sucking

pest of the leucaena plant (far from its natural enemies) severely reduces leucaena biomass production. The presence of leucaena psyllid has been reported in several sites in East Africa (Kenya, Tanzania) and in Malawi, Mozambique and Madagascar (Reynolds and Bimbuzi, 1992; Richard, 1992; FRIM, 1994). Madoffe and Massawe (1994) have confirmed the occurrence of leucaena psyllid at Mafiga and Gairo in Morogoro. However, these authors report that the infestation has not reached a critical point.

2.6. *Acacia polyacantha* wild var. *campylacantha* (Hochst. ex *A. rich*)

Acacia polyacantha (Falcon's claw Acacia) belongs to the family Leguminosae sub family Mimosoideae. It is a prickly tree, up to 15 m. *A. polyacantha* is found all over tropical Africa especially in areas with annual rainfall of more than 600 mm. The tree prefers sites with a high ground water table (depressions, river banks) on loam-clay or alluvial soils, but occasionally also grows on stony slopes and compact soils (von Maydell, 1986). It regenerates and naturally with rapid growth in height and crown spread (Otsyina and Asenga, 1993). The average height increment and crown spread after 15 months of growth in association with crops are 244.5 cm and 470.6 cm respectively. The tree also coppices profusely if cut during the rain season,

attaining an average of 8 coppices per stump. At 15 months biomass of fresh prunings ranges from 7 to 9 kg per tree.

Acacia polyacantha produces a hard and durable wood used for fuelwood, making charcoal, and it is used for making agricultural implements. It also provides edible gum. *A. polyacantha* is a nitrogen-fixing tree with a potential for soil fertility improvement. As most of the initial agroforestry experiments in East Africa were based on exotic tree species, the use of *A. polyacantha* in this experiment aims to look at the potential of indigenous species.

CHAPTER 3**3.0 MATERIALS AND METHODS****3.1. The Study Area****3.1.1. Site description**

The study was carried out within an on-going ICRAF/SHISCAP agroforestry trials at Meatu, Shinyanga in Tanzania. The site is located at about 155 km East of Shinyanga town, at 34°19' E Longitude; 3°31' S Latitude and 1000-1500 m above sea level. The area has a semi-arid climate with a unimodal rainfall of about 600 to 800 mm per year falling between November and April. The mean annual rainfall for the last 24 years (1971-94) is estimated at 790 mm. Monthly maximum temperatures vary between 27.6 and 30.2°C, and monthly minimum between 15 and 18.3°C. Evapotranspiration (ETP) is reported to range from 6 to 8 mm per day (Otsyina and Asenga, 1993). The area is extended on gently undulating plateau soils and on dune tops the soils are mainly reddish brown, stony, sandy loam (Ferric Acrisols) and well drained. They are greyish brown and sandy clay, relatively vertic and moderately well drained (Hathout, 1983).

3.1.2. Background of Agroforestry research in Meatu

Shinyanga is one of the Tanzanian regions that underwent massive deforestation. Parts of Meatu district in Shinyanga region exemplify typical ecosystem degradation that occurred particularly between 1940 and 1965 (Rumbeli, 1988). Several attempts have been made to reduce the impact of this degradation. For example, in 1986 the Shinyanga Soil Conservation and Afforestation Programme (SHISCAP) agreed with the village council for some afforestation actions on one of the completely degraded areas around the village. In July 1987 the site was allocated to SHISCAP, fenced for two years to allow natural regeneration and in November 1989 the area was planted with some multipurpose trees (*L. leucocephala*, *A. polyacantha*, *A. nilotica*, and *A. tortilis*) for the initial purpose of soil conservation and fuelwood production (Otsyina and Asenga, 1992). For the first year of tree establishment maize was inter-planted with trees at 30x90 cm spacing. In the following year, the site was left as fallow, with however, one spot weeding around the trees. With the arrival of the International Centre for Research in Agroforestry (ICRAF) in 1991 the objectives of the plantation were re-oriented towards research. Three experiments incorporating three-year old fallow (experiment I), four-year old fallow (experiment II), and five-year old fallow (experiment III) were

established during the cropping seasons 1991/92, 1992/93 and 1993/94 respectively, on a mixed *L. leucocephala* and *A. polyacantha* woodlot.

3.2. Management during the Post-fallow Phase

At the commencement of the experiments soil samples were collected and sent to Ukiriguru Research Station (Mwanza) for physical and chemical analysis. Tables 2 and 3 show soil characteristics of the three-year and five-year fallows sites, respectively; soil samples were not taken from the four-year old fallow. These data form a baseline from which comparison can be made with the results of the present study. Trees were harvested at 0.5 m above ground and all the biomass taken out. Pruning supplement started at the second cutting that followed the clearfelling of the fallow. Table 4 summarizes the biomass applied from the establishment of each experiment up to 1995.

At the beginning of the cropping season trees are cut and leaf and twig biomass produced on the plots with pruning treatment spread on the soil surface of the respective plots. Thereafter the land is ploughed using oxen ploughs and planted with maize (variety 'Katumani'), at 60x60 cm spacing. Both *L. leucocephala* and *A. polyacantha* coppice profusely during the wet season (Otsyina and Asenga, 1994),

and to avoid adverse effects of trees on crops the coppices are cut for the second time and the biomass mulched on plots with pruning treatment and taken out from the other plots. Nitrogen at 50 kg urea ha⁻¹ is usually applied to the relevant treatment, as side dressing, just before the second cutting. At the end of the cropping season maize is harvested and stover taken out from all plots.

Table 2. Some soil physical and chemical properties at 0-30 cm depth of a clearfelled three-year old fallow at Meatu.

Sand (%)	53.0
Silt (%)	12.0
Clay (%)	35.0
pH (1:2.5 soil:water ratio)	7.8
Organic Carbon (%)	2.5
Total N (%)	0.3
Available P (mg kg ⁻¹ soil)	4.0
Electrical Conductivity ($\mu\text{s cm}^{-1}$)	26.8
K (cmol(+) kg ⁻¹ soil)	0.59
Ca (cmol(+) kg ⁻¹ soil)	50.8
Na (cmol(+) kg ⁻¹ soil)	0.62
Mg (cmol(+) kg ⁻¹ soil)	1.48
CEC (cmol(+) kg ⁻¹ soil)	53.5

Source: Otsyina & Asenga (1992)

Table 3. Some soil chemical properties of a clearfelled five-year old fallow at Meatu.

Parameters	Depth		
	0-10 cm	10-20 cm	20-30 cm
pH (1:2.5 soil:water ratio)	7.70	7.80	7.90
Electrical Conductivity ($\mu\text{s cm}^{-1}$)	18.00	18.00	7.00
Organic Carbon (%)	2.23	1.99	1.69
Total N (%)	0.22	0.21	0.21
Available P (mg kg ⁻¹ soil)	3.80	1.80	0.00
K (cmol(+) kg ⁻¹ soil)	1.30	1.04	0.78
Ca (cmol(+) kg ⁻¹ soil)	18.11	20.31	19.76
Na (cmol(+) kg ⁻¹ soil)	*	*	*
Mg (cmol(+) kg ⁻¹ soil)	2.26	1.81	1.36
CEC (cmol(+) kg ⁻¹ soil)	21.70	23.20	22.00

* = not available

Source: Otsyina unpublished

Table 4. Leaf and twig biomass (t DM ha⁻¹) returned back to plots with pruning treatment at different cuttings.

Season	Cut	Expt. I		Expt. II		Expt. III	
		Ll	Ap	Ll	Ap	Ll	Ap
1991/92	1	0	0	UF	UF	UF	UF
	2	0.1	0.1	UF	UF	UF	UF
	<i>Total</i>		<i>0.2</i>				
1992/93	1	0.07	0.02	0	0	UF	UF
	2	0.24	0.15	0.24	0.15	UF	UF
	<i>Total</i>		<i>0.48</i>		<i>0.39</i>		
1993/94	1	nd	nd	nd	nd	0	0
	2	0.33	0.11	0.22	0.11	0.13	0.32
	<i>Total</i>		<i>0.44</i>		<i>0.33</i>		<i>0.45</i>
1994/95	1	0.38	0.03	0.42	0.04	0.48	0.04
	2	0.05	0.03	0.06	0.03	0.06	0.03
	<i>Total</i>		<i>0.49</i>		<i>0.55</i>		<i>0.61</i>

Notes:

UF= under fallow; nd = not determined

1 = first cut; 2 = second cut

Ll = *L. leucocephala*; Ap = *A. polyacantha*

3.3. Experimental Design

The study was conducted on-station in an existing woodlot planted in 1989 with *L. leucocephala* and *A. polyacantha* in alternate rows at 4 x 2 m spacing. The current study is based on three experiments, these are:

- (a) Experiment I - three year old fallow cropped thrice;
- (b) Experiment II - four year old fallow cropped thrice;
- (c) Experiment III - five year old fallow cropped twice.

Each of these experiments consists of three treatments applied to 10 x 10 m plots replicated three times in complete randomized design. The treatments are: maize plus trees with prunings removed, maize plus trees with prunings removed with 50 kg urea ha⁻¹ supplement, and maize plus trees with prunings (leaves and twigs) returned back to the soil.

3.4. Soil Sampling and Analysis

3.4.1. Soil bulk density

Soil bulk density was determined near field capacity as recommended by Landon (1991). Five spots on each plot were

selected randomly, avoiding as much as possible compacted places, and saturated the spots with water one day before sampling. Soil samples, between 0-10 and 10-20 cm depth, from the spots were collected with coring cylinder of 5 cm length and 5 cm diameter. Soil from each core was emptied into a paper bag, well sealed and dried in the oven at 105°C for 24 hours. Bulk density (g/cm^3) of the soil was calculated by dividing the oven - dry weight of the removed soil by the volume of the coring cylinder (Blake and Hartge, 1986).

3.4.2. Soil samples for routine analysis

One composite soil sample from 10 sub-samples per treatment plot at 0-10 and at 10-25 cm depths was collected according to the following procedure: three sub-samples at about 50 cm close to one *Leucaena* tree and three close to one *Acacia* tree, and four in the central part of the plot. Soil samples were air-dried and carried in black polythene bags to SUA Forest Biology Laboratory for analysis. They were first sieved using a 2 mm sieve. Soil texture was determined by hydrometer method as described by Bouyoucos (1962). Soil pH was determined potentiometrically by a glass-meter using 1:2.5 soil: water ratio and 1:2.5 soil: 0.01M KCl ratio (Landon, 1991). Soil electrical conductivity was measured with a conductivity-meter using

1:2.5 soil: water ratio (Richards, 1954). Soil organic carbon was determined by colorimetric method as described Anderson and Ingram (1993). About 0.5 g ground soil was oxidized at 105°C for 30 min with a mixture of 10 ml 5% potassium dichromate and 20 ml 36N H₂SO₄. After cooling, 50 ml 0.4% BaCl₂ was added to the mixture, gently mixed and allowed to stand overnight. Then the clear supernatant was measured at 600 nm. To get the organic matter content the percentage organic carbon is multiplied by 2.28. Soil total nitrogen was determined by semi-micro Kjeldahl as described by Bremner and Mulvaney (1982). Soil available phosphorus was measured by Olsen's method using 0.5M NaHCO₃ adjusted to pH 8.5 and using 1:5 soil: extractant ratio. Soil exchangeable cations and CEC were determined by saturation method (Grant, 1982). A 1:10 soil: ammonium acetate at pH 7 was used to saturate the colloidal complex with ammonium. The displaced exchangeable cations K⁺ and Na⁺ were measured by flame emission spectroscopy while, Ca²⁺ and Mg²⁺ were determined by atomic absorption spectroscopy. The pH of the soils being slightly alkaline, total CEC was determined by summing up the values of the above exchangeable basic cations.

3.4.3. Soil samples for nitrogen mineralization

One composite soil sample from five sub-samples down to 10 cm depth was collected on each plot on 06/1 and 27/3 1995. Samples were kept in black polythene bags at 2°C and were brought to SUA in a cooler box containing ice blocks. They were stored in a refrigerator at 2°C for three and one weeks for the first and second sampling, respectively. From each soil sample a portion was taken for water content determination. Soil pore space was determined using the following formula:

$$\text{Porosity} = (1 - (\text{Bulk Density}/2.65)) \times 100.$$

From each sample 10 g soil were taken in duplicate for aerobic incubation. Soil moisture for each sample was adjusted to 60% air-filled pore space and kept in a dark incubator for two weeks at 26°C. Every day the incubator was opened for 5 minutes to allow aeration and, at the same time moisture correction was made. At the beginning of the incubation, two portions of soil from each sample were taken for determination of initial inorganic nitrogen content. From each sample a duplicate sub-sample was extracted with 1M KCl and the extract was used to measure NH_4^+ by steam distillation and titration. Another duplicate sub-sample was extracted with 2M K_2SO_4 and NO_3^- in the extract were measured colorimetrically (Anderson and

Ingram, 1993). Following the incubation each sample was analyzed for NH_4^+ and NO_3^- as described above. Initial values were subtracted from final readings to get net mineralization and nitrification, and the rates of mineralization and nitrification.

3.5. Statistical Analysis

General Linear Models (GLM) procedures (SAS, 1991) were used to perform the statistical analysis for all soil variables studied (except texture). Duncan's Multiple Range Test was used to discriminate means. Paired-comparison t test was used to compare means of soil variables in the experiments.

CHAPTER 4

4.0 RESULTS

4.1. Performance of the Trees

Both *L. leucocephala* and *A. polyacantha* were doing well on that site. Despite the threat by leucaena psyllid (*Heterosylla cubana*) attack on *L. leucocephala* that foresters had during woodlot establishment, and hence the incorporation of *A. polyacantha*, *Leucaena* performed very well and has not shown any problems. *A. polyacantha*, although in its ecological zone, showed some weakness vis a vis termite attack probably due to the repeated cutting. Twelve per cent of *A. polyacantha* trees died in all three experimental blocks against 4 per cent of *L. leucocephala*.

4.2. Effect of Management on Maize Grain Yields

Results of maize yields for the previous years have been taken from Otsyina and Asenga (1993, 1994).

4.2.1. Maize yields in a three-year old fallow cropped for three consecutive years

Maize yields for the three-year old fallow cropped thrice are presented in Figure 1. Drought in 1992 severely affected maize growth. Yields were almost nil and are not reported. For 1993 and 1994, maize yields were not significantly different between treatments. Maize yield was not significantly affected by nitrogen supplement nor addition of prunings after of fallow.

4.2.2. Maize yields in four-year old fallow cropped three consecutive years

Figure 2 illustrates maize yield results on the four-year old fallow cropped in 1993, 94 and 95. For the 1993 and 1995 cropping seasons, maize yields recorded under different treatments did not differ significantly, however, in 1994 maize yields for fallow (F) and fallow + prunings (F+P) were significantly higher than in fallow + urea (F+N). In all treatments maize yields were decreasing drastically with time.

4.2.3. Maize yields in a five-year old fallow cropped twice

As shown in Figure 3 maize grain yields on the five-year fallow cropped in 1994 and 1995 under various treatments were not significantly different within the same cropping season. In 1994, the treatment with prunings showed a slightly higher maize yield than the other treatments. There was a decrease in maize yield of about 30% between 1994 and 1995 cropping season.

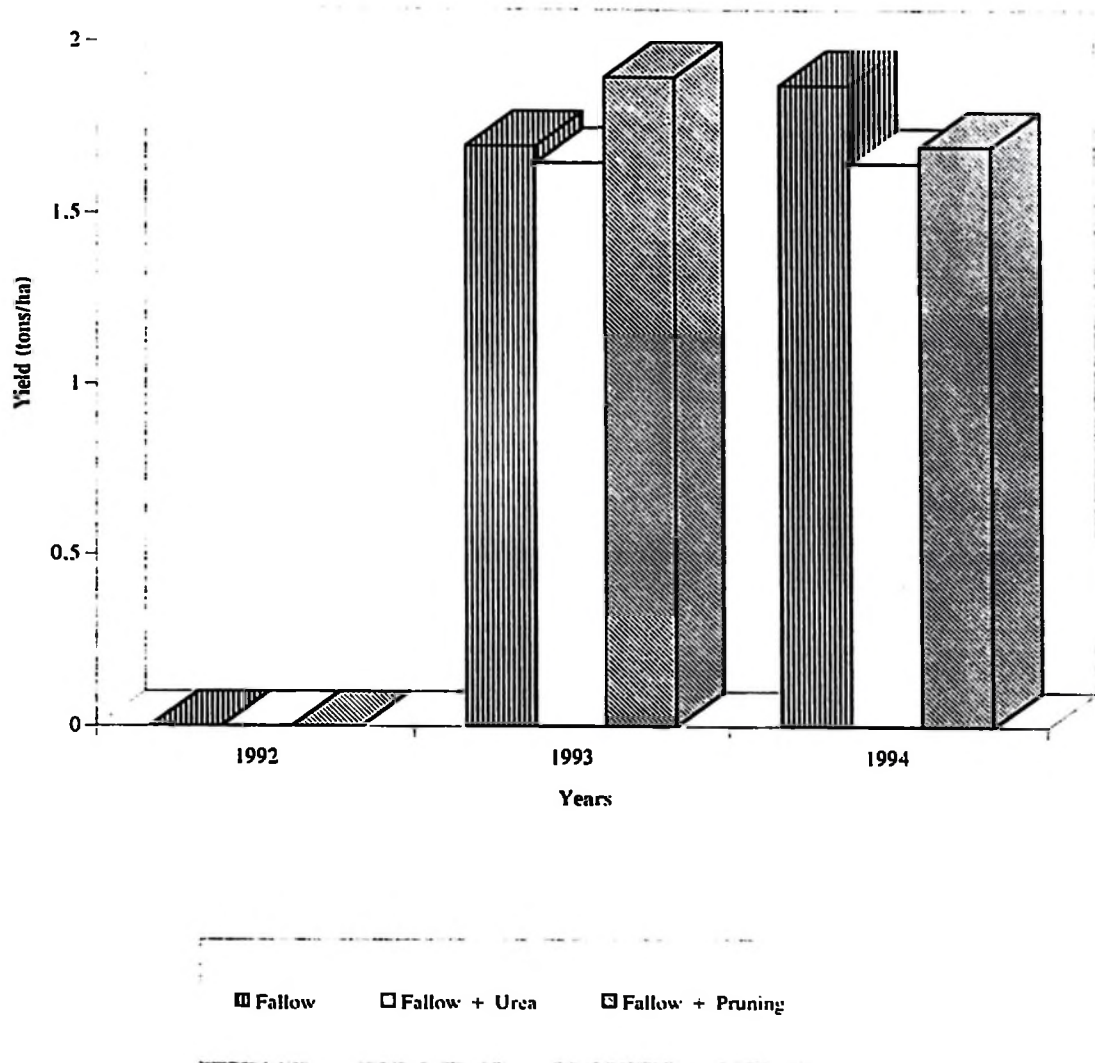


Figure 1. Maize yields in experiment I -

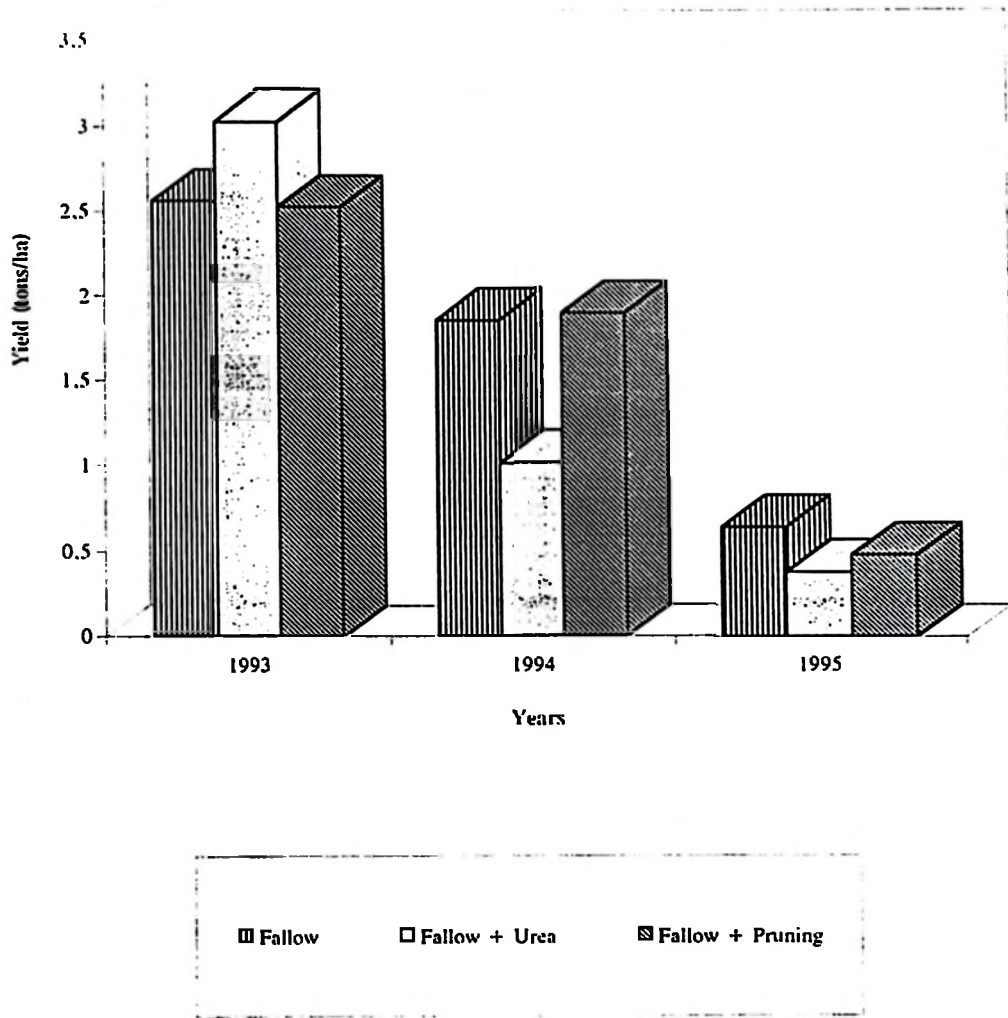


Figure 2. Maize yields in experiment II .

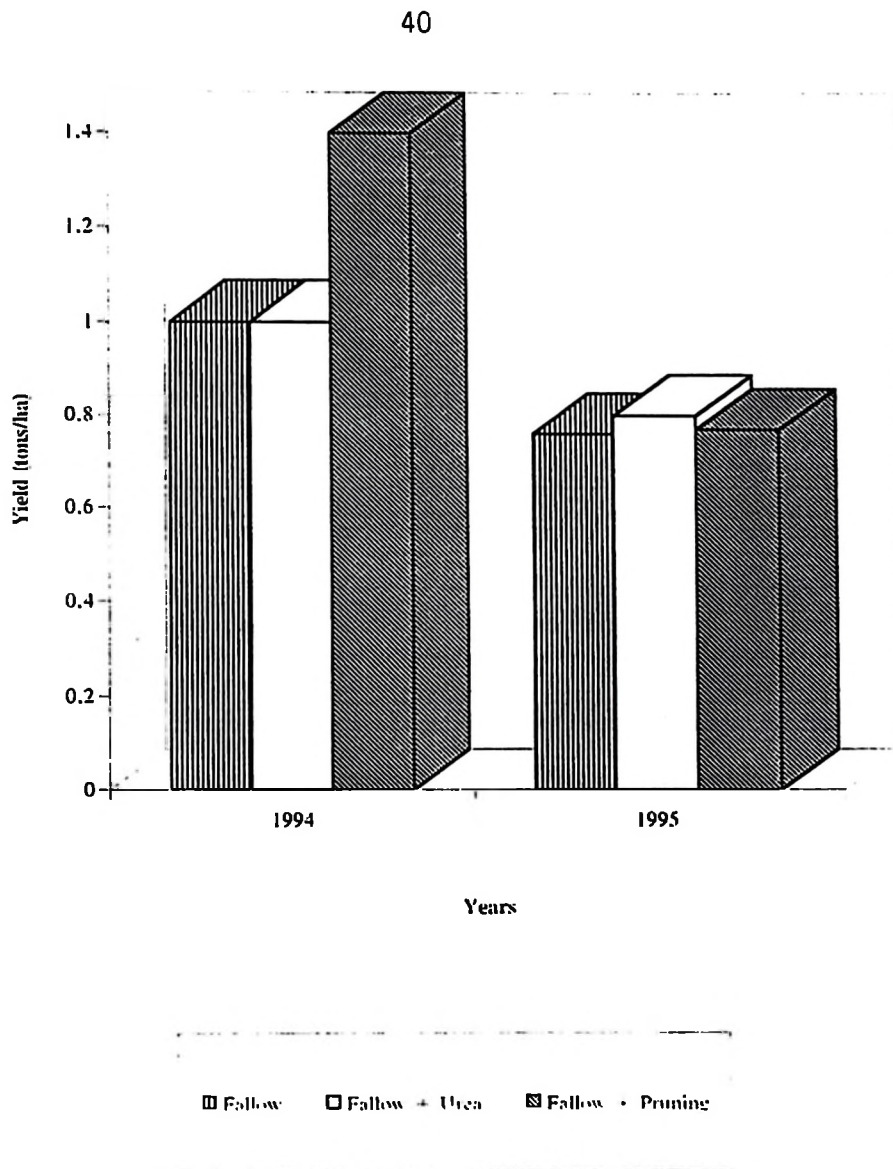


Figure 3. Maize yields in experiment III.

4.3. Status of some Soil Properties under Different Management Practices

Initial soil analysis data indicated that the experimental site has adequate organic matter, total N and exchangeable cations levels. Levels of P were comparatively very low, i.e., 4 and 2.8 mg kg⁻¹ soil in experiment I and III, respectively.

Changes in soil chemical properties as a result of treatments applied on the experimental plots opened after short fallows and cropped with maize will be presented in detail in the following sections.

4.3.1. Effect of treatments on soil organic C

Mean soil organic C levels the different experiments, I, II and III are presented in Figure 4. The level of organic C did not vary significantly in any of the treatments. Average organic C levels in the top soil (0-10 cm) were 1.65, 1.63 and 1.60 per cent in experiments I, II and III, respectively. Corresponding organic C values in 10-25 cm depth were 1.10, 1.43 and 1.36 per cent. As expected however, organic C was significantly ($P < 0.05$) higher at the 0-10 profile level compared to the 10-25 cm soil depth.

Comparing C content of the soil before the cropping phase of the rotational woodlot (2.5%) with the present results it appears that the organic matter decreased drastically in all experimental sites (1.6%) during cropping.

4.3.2. Effect of treatments on soil total N

Mean soil total N levels as influenced by different management practices are shown in Figure 5. Neither treatment with N supplement nor with prunings showed changes on total N levels compared to the fallow only treatment. In the top 10 cm soil total N was slightly lower in experiment I (0.18%) than in others (0.21 and 0.20% for experiments II and III, respectively). In the 10-25 cm soil the amount of total N was also slightly higher in experiment III (0.18%) than in the others (0.15%), but this difference was not significant. After three years of maize cropping on the three-year old fallow, total N declined to 50%. One year of cultivation on a five-year old fallow did not affect N levels.

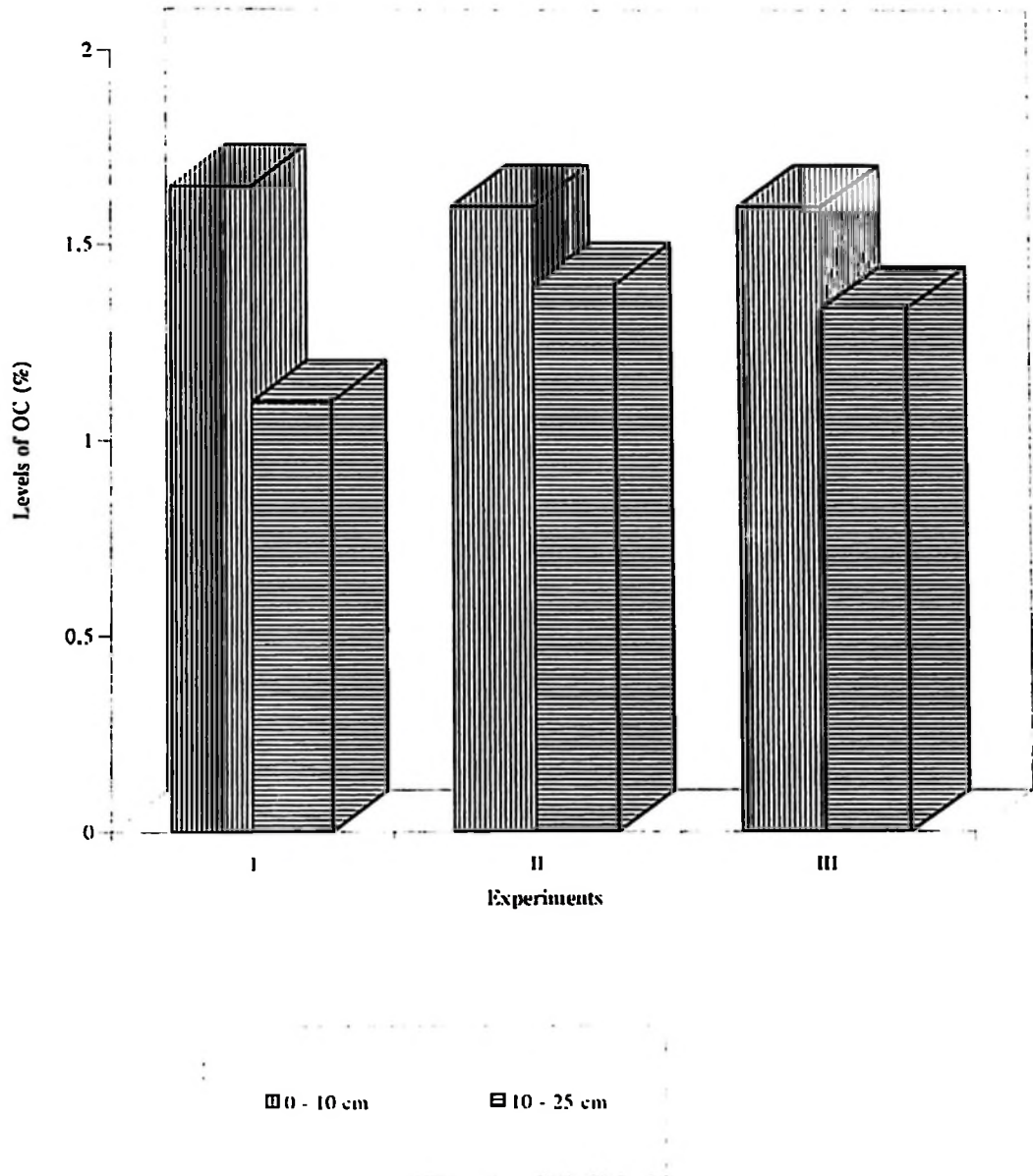


Figure 4. Organic C status in experiments I, II and III .

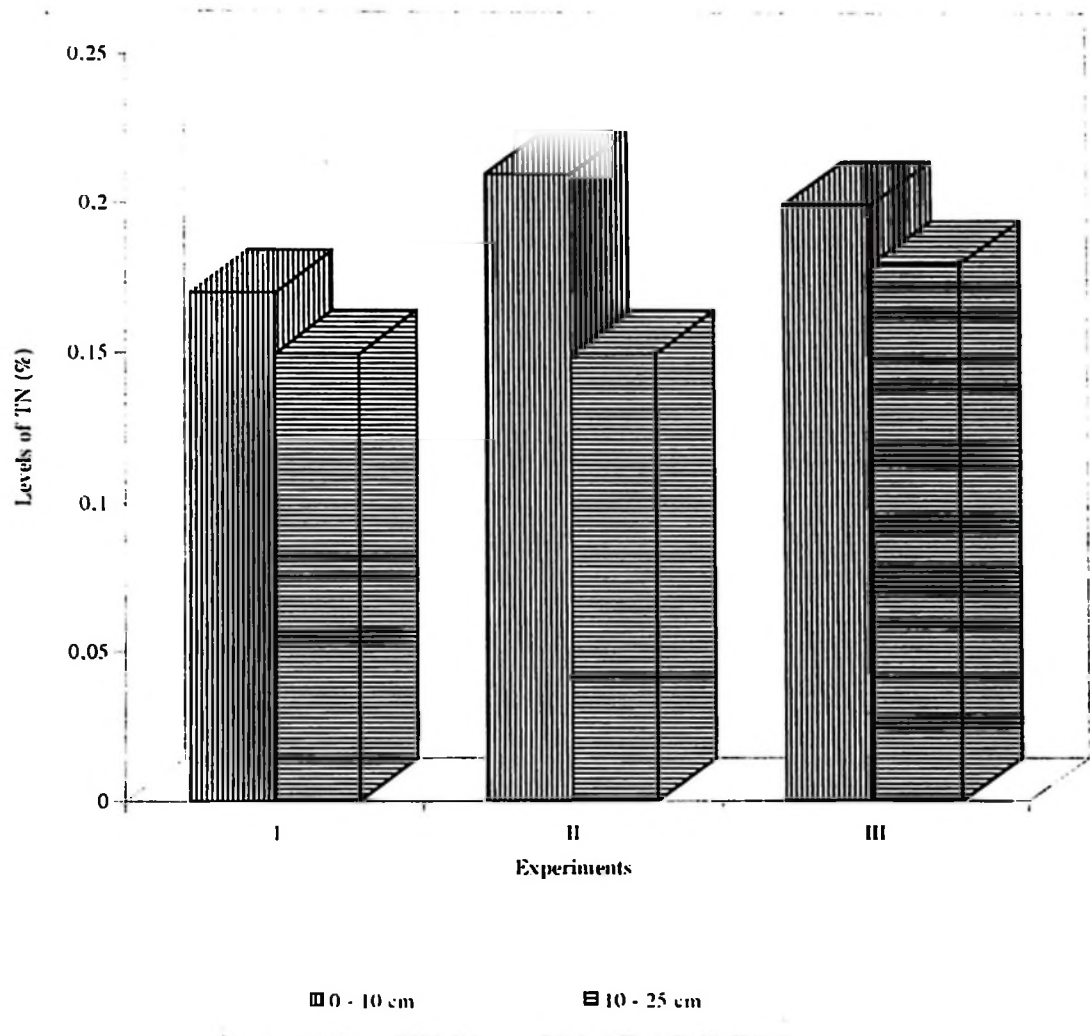


Figure 5. Total N status in experiments I, II and III .

4.3.3. Effect of treatments on soil available P

Changes of soil available P in response to treatments applied are presented in Table 5. No statistical differences among treatments were found in any experiment. Averages of available P at 0-10 cm soil depth were 4.4, 6.14 and 2.95 mg kg⁻¹ soil under experiments I, II and III, respectively. Corresponding values in the subsoil (10-25 cm) were 2.1, 3.82 and 1.68 mg kg⁻¹ soil (Fig. 6). In all three experiments available P contents were also not affected by maize cropping.

Table 5. Soil available P status in experiments I, II and III.

Experiment	Treatment	Available P (mg kg ⁻¹ soil)	
		0-10 cm	10-25 cm
Experiment I			
	F	4.7±0.574	1.8±0.63
	F+N	4.1±0.574	1.7±0.63
	F+P	4.4±0.574	2.9±0.63
	<i>Mean</i>	4.4	2.1
Experiment II			
	F	6.6±0.783	4.5±0.474
	F+N	5.7±0.783	3.0±0.474
	F+P	6.0±0.783	3.9±0.474
	<i>Mean</i>	6.14	3.82
Experiment III			
	F	3.4±0.82	1.4±0.38
	F+N	2.3±0.82	2.0±0.38
	F+P	3.1±0.82	1.6±0.38
	<i>Mean</i>	2.95	1.68

*: F = maize + trees with prunings removed (control); F+N = maize + trees with prunings removed + N supplement; F+P = maize + trees returned back to soil.

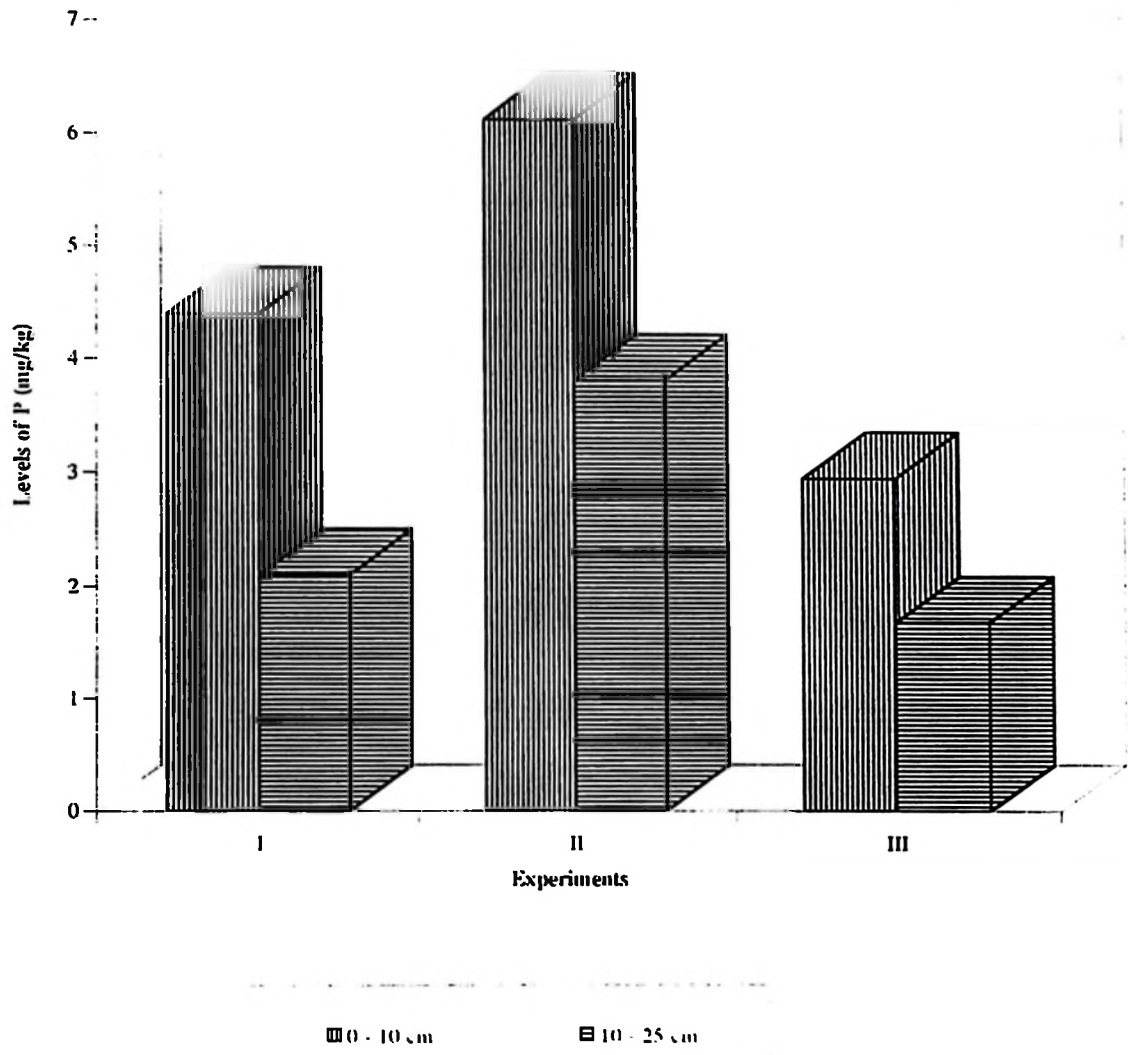


Figure 6. Available P in experiment I, II and III

4.3.4. Soil exchangeable cations and CEC

There were no significant differences in exchangeable cations and CEC between treatments in the three-year fallow (Table 6). Average exchangeable cations were 0.69, 26.4, 1.37 and 0.28 cmol(+) kg⁻¹ soil in top 0-10 cm depth for K, Ca, Mg and Na, respectively; corresponding values in 10-25 cm layer were 0.5, 35.42, 1.42 and 0.46 cmol(+) kg⁻¹ soil. Levels of total CEC were 28.7 and 37.8 cmol(+) kg⁻¹ soil in 0-10 and 10-25 cm soil depth, respectively.

Similar to the three-year old fallow, treatments in the four-year fallow did not induce significant changes on soil exchangeable bases (Table 7). Means of exchangeable cations were 1.3, 33.1, 1.83 and 0.34 cmol(+) kg⁻¹ soil in 0-10 cm depth, and 0.8, 35.77, 1.56 and 0.28 cmol(+) kg⁻¹ soil in 10-25 cm depth for K, Ca, Mg and Na, respectively. Average CEC levels were 36.5 and 38.5 cmol kg⁻¹ soil in top 10 cm and 10-25 cm soil depth, respectively.

Like in the other experiments, treatments effects were statistically non-significant in the five-year fallow (Table 8). Average exchangeable cations were 1.25, 20.9, 2.17 and 0.46 cmol(+) kg⁻¹ soil in 0-10 cm layer for K, Ca, Mg and Na, respectively. They were 0.7, 36.7, 1.41 and 0.25 cmol(+) kg⁻¹ soil in 10-25 cm down soil layer.

Table 6. Soil exchangeable cations and CEC (cmol(+) kg⁻¹ soil) status in a three-year fallow cropped thrice.

Trt	K		Ca		Mg		Na		CEC	
	0-10 cm	10- 25cm	0-10 cm	10- 25cm	0-10 cm	10- 25cm	0-10 cm	10- 25cm	0-10 cm	10- 25cm
F*	0.68	0.58	26.0	31.5	1.42	1.47	0.27	0.53	28.5	34.0
F+N	0.65	0.48	28.2	41.7	1.42	1.45	0.29	0.47	30.6	44.0
F+P	0.75	0.45	24.8	33.0	1.26	1.33	0.27	0.39	27.1	35.2
<i>Mean</i>	<i>0.69</i>	<i>0.50</i>	<i>26.4</i>	<i>35.4</i>	<i>1.37</i>	<i>1.42</i>	<i>0.28</i>	<i>0.46</i>	<i>28.7</i>	<i>37.8</i>
<i>SE</i>	<i>0.27</i>	<i>0.17</i>	<i>2.18</i>	<i>6.35</i>	<i>0.12</i>	<i>0.29</i>	<i>0.04</i>	<i>0.17</i>	<i>2.51</i>	<i>6.74</i>

Note: Trt = treatment; *: see footnote Table 5

Table 7. Soil exchangeable cations and CEC (cmol(+) kg⁻¹ soil) in a four-year-fallow cropped twice.

Trt	K		Ca		Mg		Na		CEC	
	0-10cm	10-25cm	0-10cm	10-25cm	0-10cm	10-25cm	0-10cm	10-25cm	0-10cm	10-25cm
F'	1.17	1.09	33.3	35.6	1.77	1.50	0.27	0.50	36.4	38.7
F+N	1.42	0.64	37.7	36.9	1.97	1.56	0.46	0.36	41.6	39.4
F+P	1.33	0.70	28.3	34.8	1.75	1.62	0.28	0.38	31.6	37.4
<i>Mean</i>	<i>1.30</i>	<i>0.81</i>	<i>33.1</i>	<i>35.8</i>	<i>1.83</i>	<i>1.56</i>	<i>0.34</i>	<i>0.41</i>	<i>36.5</i>	<i>38.5</i>
<i>SE</i>	<i>0.12</i>	<i>0.2</i>	<i>2.57</i>	<i>3.72</i>	<i>0.14</i>	<i>0.18</i>	<i>0.03</i>	<i>0.06</i>	<i>2.67</i>	<i>3.90</i>

Note: Trt = treatment; * : see footnote in table 5

Table 8. Soil exchangeable cations and CEC (cmol(+) kg⁻¹ soil) in a five-year-fallow cropped once.

Trt	K		Ca		Mg		Na		CEC	
	0-10 cm	10- 25cm	0-10 cm	10- 25cm	0-10 cm	10- 25cm	0-10 cm	10- 25cm	0-10 cm	10- 25cm
F*	1.06	0.65	22.0	37.0	2.29	1.44	0.60	0.25	24.3	41.0
F+N	1.12	0.75	21.9	35.0	1.98	1.56	0.32	0.27	24.5	38.5
F+P	1.20	0.70	18.8	37.8	2.25	1.25	0.46	0.24	21.1	41.8
<i>Mean</i>	<i>1.12</i>	<i>0.70</i>	<i>20.9</i>	<i>36.7</i>	<i>2.17</i>	<i>1.41</i>	<i>0.46</i>	<i>0.25</i>	<i>23.3</i>	<i>40.4</i>
<i>SE</i>	<i>0.16</i>	<i>0.05</i>	<i>2.82</i>	<i>3.12</i>	<i>0.24</i>	<i>0.11</i>	<i>0.12</i>	<i>0.03</i>	<i>2.88</i>	<i>3.48</i>

Note: Trt = treatment; * : see footnote in Table 5

4.3.5. Nitrogen mineralization rates

In all experimental sites, only traces of soil ammonium ($\text{NH}_4^+\text{-N}$) were observed. Pools of $\text{NH}_4^+\text{-N}$ did not vary significantly during incubation, and thus, nitrogen mineralization potential was quasi-represented by nitrification potential. Results of nitrogen mineralization potential expressed as rates, for the three experiments, are presented in Table 9. Results from soil samples collected before maize planting (P1) show the residual effect of the previous treatments, while those from maize flowering stage give the effect of treatment three months after application.

In the three-year old fallow, soil samples collected in January 1995 (just before maize planting, P1) and incubated gave significantly greater ($P < 0.05$) nitrification rates under addition of pruning (F+P) than addition of urea N (F+N) treatments. Results from soil collected in March (at maize flowering stage, P2) did not show any significant differences between treatments. Comparing the two periods, nitrification rates were not significantly different, despite the rates being higher in P1 than in P2. Rates of N-nitrification did not significantly differ between treatments at any period nor between periods in the four-year old fallow (Table 9).

Similar to experiment I, N-nitrification rates observed in experiment III at P1, were significantly higher ($P < 0.05$) under treatment with pruning (F+P) than under treatment with N supplement (F+N), while the control (F) was not different from the other two (Table 9). At P2, there was no significant differences detected between treatments. While N mineralization rates were the same at P1 and P2 under treatments F and F+N, mineralization rates under F+P decreased from 1.7 at P1 to $0.8 \mu\text{g g}^{-1} \text{d}^{-1}$ at P2.

Table 9. N-nitrification and N-mineralization rates under different treatments in experiments I, II and III.

Expt/Treatment	N-nitrification rates ($\mu\text{g g}^{-1} \text{d}^{-1}$)		N-mineralization rates ($\mu\text{g g}^{-1} \text{d}^{-1}$)	
	P1 ¹	P2	P1	P2
Experiment I				
F [*]	1.14ab ²	0.86	1.139ab	0.864
F+N	0.55b	0.72	0.558b	0.721
F+P	1.27a	0.61	1.273a	0.616
Experiment II				
F	1.53	1.43	1.535	1.428
F+N	1.63	1.66	1.634	1.668
F+P	1.80	1.71	1.797	1.716
Experiment III				
F	1.39ab	1.14	1.392ab	1.14
F+N	1.10b	1.06	1.06b	1.061
F+P	1.70a	0.80	1.702a	0.809

* = see footnote in Table 5

¹ = soil sampling before maize planting (P1) and during maize flowering (P2)

² = means in the same column, under each experiment, with different letters are statistically different ($P < 0.05$)

4.4. Comparison of the Performance of three, four and five-year-old Fallow for Sustaining Maize Production

This section summarizes the results from the previous sections in order to have an overview of the performance of individual experiments. Annual average maize yields for the three experiments, for the same cropping season, were compared in pairs by t-test and the results are presented in Table 10.

In 1993 cropping season maize yield under the four-year fallow was significantly higher ($P < 0.05$) than in the three-year fallow. In 1994 maize yields in all experiments were not significantly different, although the differences between experiment III and the other two might be economically important. In 1995 maize yields were also the same in experiments II and III.

Table 10. Comparison of maize yields for the same cropping season under experiments I, II and III.

Experiment	Maize yields, t ha ⁻¹		
	1993	1994	1995
Expt I	1.75b*	1.74a	-
Expt II	2.70a	1.59a	0.49a
Expt III	-	1.13a	0.77a

* = means in the same column with different letters are significantly different (P<0.05)

Levels of organic C and total N did not vary significantly between experiments at both two soil depths. The amounts of P in the topsoil (0-10 cm) varied significantly ($P < 0.05$) between the experiments (Table 11). It was highest in experiment II (6.14 mg kg^{-1}) and lowest in experiments I (4.4 mg kg^{-1}) and III (2.95 mg kg^{-1}). Levels of P in the three experiments averaged 2.8 mg kg^{-1} soil at 10-25 cm depth.

Table 11. Comparison of amounts of organic C, total N and available P in experiments I, II and III *

Experiment	Organic C (%)		Total N (%)		Available P (mg kg^{-1})	
	0-10	10-25	0-10	10-25	0-10	10-25
Expt I	1.65a*	1.1a	0.18a	0.15a	4.4b	2.1a
Expt II	1.6a	1.4a	0.21a	0.15a	6.14a	3.82a
Expt III	1.6a	1.34a	0.20a	0.18a	2.95c	1.68a

* = means in the same column with different letters are significantly different ($P < 0.05$)

Amounts of K and Mg were significantly lower ($P < 0.05$) at 0-10 cm soil depth in experiment I than in the other two, no significant differences were found at 10-25 cm soil depth (Table 12). Levels of C and CEC, in the topsoil were higher ($P < 0.05$) in experiment I and II than in experiment III; they did not vary in the subsoil. Sodium did not vary between experiments at 0-10 cm depth, however, it was significantly lower ($P < 0.05$) in experiment III than in the other two trials at 10-25 cm depth.

Table 12. Average exchangeable cations and CEC in experiments I, II and III.

	0-10 cm soil depth			10-25 cm soil depth		
	Expt. I	Expt. II	Expt. III	Expt. I	Expt. II	Expt. III
K	0.69b*	1.30a	1.12a	0.50a	0.81a	0.70a
Ca	26.4a	33.1a	20.9b	35.4a	35.8a	36.7a
Mg	1.37b	1.83a	2.17a	1.42a	1.56a	1.41a
Na	0.28a	0.34a	0.46a	0.46a	0.41ab	0.25b
CEC	28.7a	36.5a	23.3b	37.8a	38.5a	40.4a

* = means in the same row under the same soil depth with different letters are significantly different ($P < 0.05$)

Rates of nitrification were not statistically different (about $1.34 \mu\text{g g}^{-1} \text{d}^{-1}$) between the experiments at the first sampling, P1 (Table 13). However, at the second sampling (P2), the rates were significantly lower ($P < 0.05$) in the three-year fallow than in the other two.

Table 13. Average rates of nitrification in experiments I, II and III.

	Nitrification rates ($\mu\text{g g}^{-1}$ soil)	
	First sampling	Second sampling
Experiment I	0.98a*	0.73b
Experiment II	1.65a	1.6a
Experiment III	1.39a	1.0a

* = values in the same column with different letters are significantly different

CHAPTER 5

5. DISCUSSION

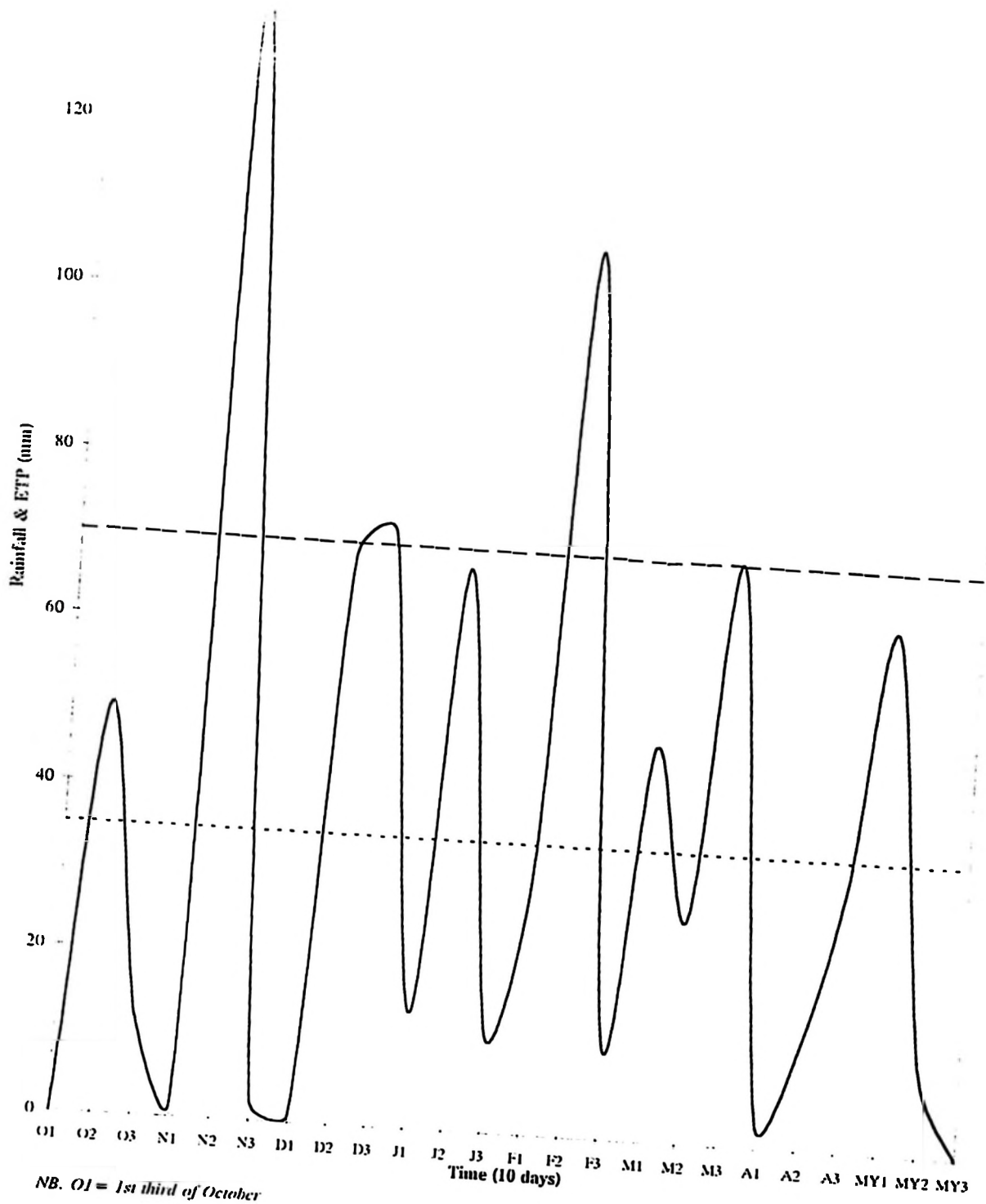
5.1. Rainfall at Meatu

The overall aim of this study is to identify a management practice which could best ensure sustainable maize production. Maize production is, however, a function of several factors, those controllable by human beings, and others, such as rain, temperature and radiation outside human control. In semi-arid areas like Meatu, rainfall and soil fertility constitute the key factors that determine crop productivity. It is therefore, important, when discussing the sustainability of maize production, to have a brief 'aperçu' on certain characteristics of the rainfall, notably average annual rainfall and its distribution.

A rain gauge was installed, for the first time, at Meatu in October 1992, and the amounts of rain recorded during 1992/93, 1993/94 and 1994/95 seasons were 853, 491.7 and 695 mm, respectively. Figures 7, 8 and 9 give an illustration of the ten-days rainfall distribution over the seasons. Average daily evapotranspiration potential (ETP)

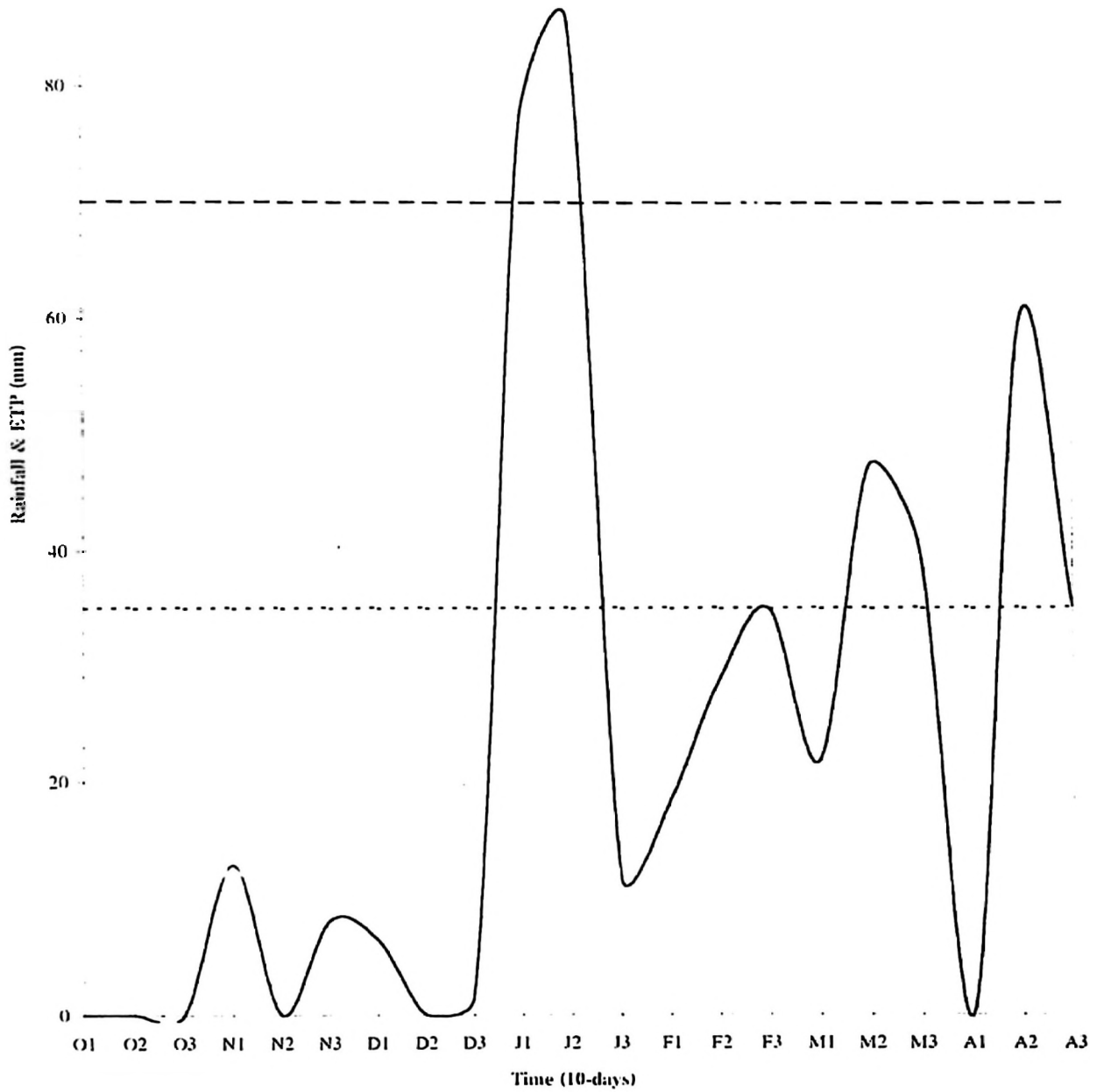
is reported to be 7 mm (Otsyina and Asenga, 1992). Assuming that ETP was constant, curves for ETP and 1/2 ETP have been plotted with each rainfall curve. As interpreted in 'Mémento de l'agronome' (MCD, 1991) the period during which rainfall curve is above ETP curve is considered as potentially wet and correspond to the vegetative growth period, while periods during which rainfall is below 1/2 ETP are considered critical, i.e., when water is extracted from the soil by plants with difficulty.

According to the above simplified interpretation, the Figures 7, 8 and 9 could indicate how rainfall distribution do affect maize yields. Rainfall distribution was better in 1992/93 season than in 1993/94 and 1994/95; although, no significant 'wet' period was observed. Rainfall curve was maintained above the 1/2 ETP. Under those well textured soils of the Meatu site (sandy clay), water holding capacity is expected to be good, hence water for crops would not be a limiting factor. The 1993/94 and 1994/95 seasons were characterized by periods of short drought (Fig. 8 and 9) which, certainly did affect maize grain yields. Worst was the 1994/95 season when about half of the rain fell between December and early January, and consequently maize yielded poorly.



--- ETP 1/2 ETP ——— Rainfall

Figure 7. Rainfall and Evapotranspiration potential at Meatu, 1992/93



NB. O1 = 1st third of October

--- ETP 1/2 ETP ——— Rainfall

Figure 8. Rainfall and Evapotranspiration potential at meatu, 1993/94.

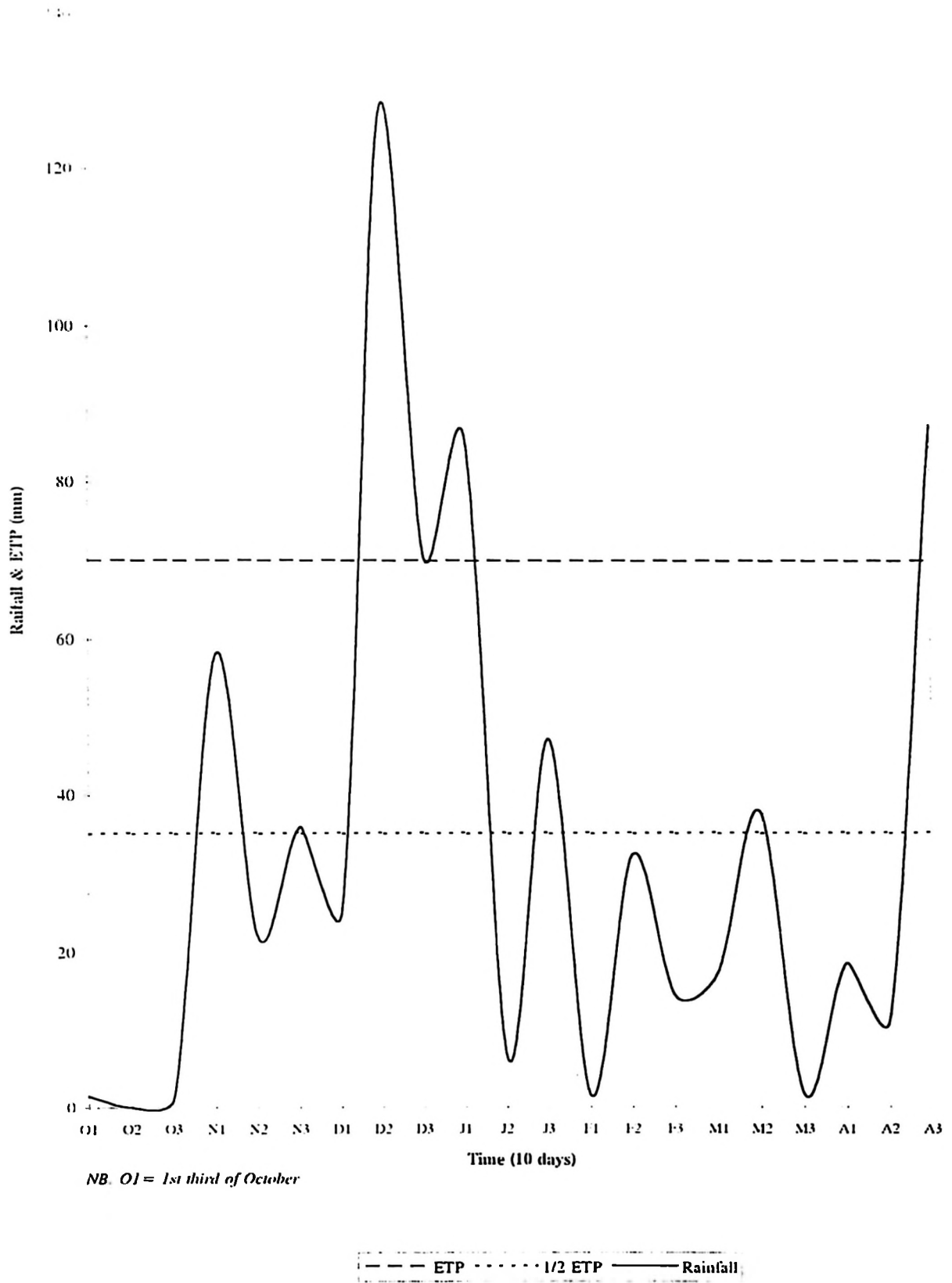


Figure 9. Rainfall and evapotranspiration potential at Meatu, 1994/95

5.2. Maize Yields

5.2.1. Effect of three-year old fallow

Maize grain yields obtained in experiment I under different treatments did not vary. Mean annual maize production recorded in 1993 and 1994 fluctuated around 1.75 t ha⁻¹, and were in the range of 1.5-2.0 t ha⁻¹ reported by Banda *et al.* (1994) in Malawi in a system designed for soil conservation where maize was intercropped with closely spaced leucaena hedgerows. These results agree also with the findings of Kang *et al.* (1990) and Singh (1992) on the possibility of maintaining constant maize yield (around 2 t ha⁻¹) in maize/legumes intercropping systems.

Since nitrogen appeared not to be limiting on the site, the poor performance of maize under F+N could be due to probably short periods of drought which occurred during the seasons and consequently reduced maize yield.

5.2.2. Effect of four-year old fallow

In 1993 maize yields under the different treatments were statistically similar. Yields recorded during that period were relatively higher than the results obtained by other workers (Rao, 1989; Kang *et al.* 1991; Singh, 1994). In 1994

maize yields decreased considerably from about 2.7 t ha⁻¹ in 1993 to 1 t ha⁻¹ under F+N and to 1.9 t ha⁻¹ on F and F+P. The decrease became more serious in 1995 when only an average of 0.5 t ha⁻¹ of maize grain was recorded. The high yields obtained in 1993 could be related to relatively high nutrient content in the soil as a result of fallow, and also because the rainfall was well distributed over the season (Fig. 7). The gradual decrease of maize yield in 1994 was probably a consequence of nutrient depletion, low rainfall (491.7 mm) and its poor distribution (Fig. 8). The poor maize yields observed in 1995 are probably due to delay in maize planting (4 January 1995 instead of early December 1994). At maize flowering stage, rainfall became scarce for the rest of cropping season and consequently yields were low. Such wide fluctuations of crop yields were also observed by Chamshama *et al.* (1994) under maize/*Acacia albida* (*Faidherbia albida*) intercropping system in Gairo, and by Mureithi *et al.* (1994) under maize alley cropped with leucaena at Mtwapa, Kenya; in both cases trees were reported to compete with crops for limited soil moisture and nutrients.

5.2.3. Effect of five-year old fallow

Maize yields recorded in 1994 were very low, despite that the fallow was cleared for the first time. Most probably

the pronounced P deficiency (Table 9) observed on that experimental plot could be one of the reasons that might explain the low maize yield. In 1995, though the rainfall was erratic and poorly distributed, maize yields did not decrease considerably relative to the yields of 1994.

5.3. Soil Chemical Properties

5.3.1. Soil organic carbon

No consistent influence of treatments on soil organic C was observed. Soil sampling was done 11 months after the treatments were applied, and hence the results of this study expressed the residual effect of the treatments. The similar amounts of organic C observed under all management practices may be attributed to intensive soil microbial activity that led to rapid decomposition and mineralization of organic materials, reducing levels of organic C to a certain equilibrium. Another factor that might explain the similarity of the treatments is that the organic materials gained on each plot was very low even in plots that received prunings. The mean tree biomass added on each F+P plot during the last cropping cycles were 0.37, 0.36, and 0.45 t DM yr⁻¹ for experiments I, II and III, respectively, while 2 t DM ha⁻¹ yr⁻¹ is required to maintain soil organic matter in semi-arid zones (Young, 1989).

The decrease of organic C registered under experiments I and III may be related to the cropping, and particularly to the soil working that involved repeated turning of the soil and hence, favouring incorporation of organic materials into soil and their decomposition/mineralization. The removal of crop residues from all plots during harvesting are also responsible for lowering organic matter in the soil. Nevertheless, the averages organic matter of 3.66% in top 10 cm soil and 2.9% in 10-25 cm soil layer are medium (NSS, 1991 and Landon, 1991) and may moderately support maize production.

5.3.2. Soil total N

Soil total N did not vary significantly between treatments in all experiments. As the last treatments was applied 11 months ago, it is likely that their effects on soil total N content have been exhausted due to losses through N uptake by the crop, and leaching losses of NO_3^- -N that dominates in this soil.

The pronounced decrease of total N compared to organic C observed in experiment I is an indication that the quality of the soil organic matter is deteriorating (van der Meersch et al., 1993). Periodic tree cuttings that expose

surface soil to radiation, high temperature and aeration could account for the deterioration of soil organic matter.

Average total N under experimental sites was low (around 0.2%) in 0-10 cm soil depth; and decrease with depth as expected. Thus, N could potentially be a limiting factor in those sites under the current soil management.

Ratios C/N indicate the quality of the organic matter and give more information about the availability of N. They range from 7.3 to 10.0 in the surface soil (0-10 cm) and from 7.1 to 9.1 in subsoil (10-25 cm). This indicates that organic matter is of good quality and highly mineralizable. Thus, it appears that the lack of N in those soils is mostly related to the low quantity of organic materials applied.

5.3.3. Soil available P

None of the treatments affected significantly the levels of P in any of the experiments. The failure of pruning addition to improve available P was most likely due to the low amount of organic materials and hence P incorporated.

Comparing the P levels measured during this study with those observed at the beginning of the cropping phase of

each experiment, it appears that there was no changes in P content. Despite the removal of crop residues and the exportation of maize grain, P content did not significantly decline in each experiment. Most likely, conditions for microbial activity have been improved, hence organic P was mineralized and released in available form of P. Unlike in experiments I and II, P content, in experiment III, decreased slightly from 3.8 to 2.9 mg kg⁻¹ soil in the surface 10 cm soil and from 1.8 to 1.6 mg kg⁻¹ soil in 10-25 cm. This decline of P may be a result of the last maize cropping, or probably P was locked up either in organic form in the tree biomass in the soil as Ca phosphate which is less soluble.

Amounts of extractable P measured in all experiments were low to medium, 8 mg kg⁻¹ soil being the adequate rate for maize production according to Landon (1991). Below this level a supplemental P is necessary to get enhanced maize productivity.

5.3.4. Soil exchangeable cations and CEC

None of management practices significantly affected the levels of exchangeable bases in any of the three experiments.

Calcium was the highest element observed in all experiments. Its level varied from 30 cmol(+) kg⁻¹ soil in surface soil (0-10 cm) to 36 cmol(+) kg⁻¹ soil in the sub-soil (10-25 cm). This high content of Ca could be related to the observed presence in the soil of considerable concretions of Ca carbonate. The greater amount of Ca measured in sub-soil than in the surface soil indicates that Ca originates from a Ca-rich parent material. This is a good sign that exchangeable acidity will not be a threat in the long term. However, as reported Landon (1991), with a high pH (pH>8), in the presence of Ca, P is converted to Ca phosphate, reducing availability of P to plants. Nevertheless this risk may not manifest in this case because of the presence in the soil of moderate fraction of Na that may activate the solubility of P even if the soil pH is greater than 8.5 (Landon, 1991).

Average K contents in the soils studied were high, thus K could not be considered as a limiting factor for crop production.

Levels of Mg were high (>0.5 cmol(+) kg⁻¹ soil) at both two depths in all experiments. However, due to the high Ca/Mg ratios ranging from 9.6 to 19.3 in the top soil and from 22.9 to 26.0 in the sub-soil, Mg may be unavailable. The

critical Ca/Mg ratio above which Mg uptake may be affected is 5 according to Landon (1991).

When comparing the current levels of K and Mg with those at the start of each experiment, they did not appear to be affected by the previous croppings. This could be explained on the basis of the following hypotheses: (a) that maize harvests being low, exportation of those nutrients might be compensated by their recycling through litter fall of the stand (and prunings for the plots with pruning treatment); (b) that the relatively high proportions of clay (>35%) and organic matter in the soils constitute a good trap of exchangeable bases and thus reduces leaching.

Sodium is not an essential plant nutrient and its absence or presence in very small quantities is usually not detrimental to plant nutrition (Landon, 1991). However, when abundant, Na may have adverse effects on many crops and also on soil physical properties, notably structure. Quantities of Na in the soils of the study sites are rated low to medium (NSS, 1991); and since they are less than 1 cmol(+) kg⁻¹ soil the risk of sodicity is low.

Soil effective CEC was high under all treatments and in all experiments. It is mostly dominated by Ca. The high CEC is a consequence of clay and organic matter content. None of

the treatment has significant effect on the levels of total CEC. However, even though the differences observed were not statistically different, their biological effect may likely be different. For example, differences of $10 \text{ cmol}(+) \text{ kg}^{-1}$ soil observed between F+N and other treatments in experiment I (10-25 cm), and between F+N and F+P in experiment II (0-10 cm) are likely to be biologically significant. Nevertheless, all treatments had optimum CEC, and these differences may not affect crop development.

5.3.5. N-mineralization Rates

Levels of NH_4^+ -N measured in soil samples collected in January (P1) and March (P2) were very low ($<0.005 \mu\text{g g}^{-1}$ soil) in all sites. This indicates that NH_4^+ -N, in those soils, is very unstable and once generated, is oxidized into NO_3^- -N. Unlike NH_4^+ -N, NO_3^- -N levels were relatively high, and this may be attributed to the presence of an active population of nitrifiers in the soil. Thus net N mineralization is exclusively dominated by the production of NO_3^- . This form of mineral N, as reported by Piccolo et al. (1994), is extremely mobile in the soil solution and hence influences N losses through leaching and gaseous losses. Average pre-incubation NO_3^- pools were greater in the soil samples collected in January than in those taken in March. The low initial NO_3^- observed in March could be

explained by plant uptake and losses through either leaching or run off or denitrification; while the high amount of NO_3^- measured in January may be related to the presence of readily decomposing materials and adequate conditions of moisture and temperature at that period. The current high nitrification activity noted under moderately alkaline pH (7.7 to 8.0), contradicts the contention by Landon (1991) that high pH decreases bacterial activity and hence nitrification of organic matter. There is, however, no clear relationship between soil pH and the rate of nitrification, and in general over the pH range of 5.5 to 8.0 there is usually little effect of pH (Harris, 1988).

The low N mineralization rate measured under N (urea) supplement treatment (F+N) in experiments I and III is quite different from what was reported by some workers (Sperow and Keefer, 1975; Schmidt, 1982; Harris, 1988). Nitrification of organic nitrogen by decomposing bacteria is usually speeded up by the presence of any source of NH_4^+ , either from the mineralization of organic materials or from inorganic fertilizers. In fact, urea application causes an immediate, but temporary, increase in soil pH, which is believed to favour nitrifiers (Aarnio and Martikainen, 1992). In the present study, pH cannot be considered a limiting factor. Despite urea application, Martikainen

(1985) found that increase in nitrification was not necessarily seen in the incubation experiment.

The high mineralization rate measured under F+P in experiments I and III may be related to the low quantity but high quality of organic matter that is brought to those plots through prunings. The higher mineralization rates observed during the first incubation than the second might have been a result of decomposing materials (litter fall, crop and weed residues) from the preceding crop and weeds and the shedding of tree leaves. These materials may have been fragmented, decomposed, and partly humidified, ready for mineralization process when moisture and temperature conditions were favourable. Soil samples collected in March, at the maize flowering stage, gave low mineralization rates probably due to the exhaustion of readily mineralizable organic matter during the last three wet months.

Nitrogen mineralization rates measured under different treatments in experiment II did not differ significantly at any period. The average mineralization rate during the 14 days of incubation was $1.7 \mu\text{g g}^{-1} \text{d}^{-1}$. The similarity of the results observed during P1 and P2 may be related to the presence in the soil of a decomposed fraction of organic

matter that releases mineral N when moisture and temperature conditions are favourable.

5.4. Comparison of the Performance of three, four and five-year old Fallows for Sustaining Maize Production

The higher maize harvested in 1993 under the four-year old fallow cropped for the first time (experiment II) than under the three-year fallow cropped for the second time (experiment I) may be attributed to the difference in fallow length and the previous management. In 1994 maize yields were statistically similar in all experiments, however, relatively low yield was observed in the five-year old fallow. The poor performance of the five-year old fallow for maize production in its first year might be related to the fact that the stand was too old and trees probably sequestered soil nutrients for their development (e.g., wood production). In 1995 cropping season maize yields were poor and did not vary significantly between experiments. The slightly lower yield (0.49 t ha^{-1}) recorded in the four-year fallow than in the five-year fallow (0.77 t ha^{-1}) cannot be interpreted as a result of soil nutrient depletion. In fact, drought occurred at maize flowering stage, and it is believed that in case of moisture deficiency, soils with high nutrient content such as nitrogen may depress crop yields.

Levels of organic C and total N did not vary at any depth between experiments, however P levels varied strongly ($P < 0.05$) between experiments at 0-10 cm soil depth. The lowest amount of available P observed in experiment III may be attributed to the fact that P was bound in organic form and its mineralization rate might be very low in that medium; or the mature trees have locked up P in the biomass. The lower available P in the three-year fallow might result from depletion by successive cropping, or the stand was too young to generate substantial amount of available P in the topsoil. Unlike in experiments I and III, the substantially high amount of available P in experiment II might be due to favourable conditions for P mineralization in the soil, or probably the age of the stand was the best for soil nutrient improvement. This assertion can be supported by results from soil exchangeable cations and CEC analysis.

Levels of the exchangeable cations or CEC were not significantly affected by fallow period. However, lowest values of K and Mg were observed in the topsoil in the three-year old fallow. Nevertheless, as earlier mentioned, levels of K and Mg were not affected by the previous cropping. Thus, the low quantities of K and Mg in experiment II may be related to the age of the fallow stand. Calcium was by far the element that dominated total

CEC in all experimental sites. Their levels were low at 0-10 cm depth in the five-year old fallow compared to the others. This may be attributed to the intrinsic variation between sites.

Average nitrification rates did not vary between fallow periods at the first sampling. Probably the amounts of organic materials accumulated after the last cropping were substantial in each experiment to give, at least at that starting of rainfall, the same nitrification rates. The low nitrification rates observed in experiment I at the second sampling, could be explained by postulating that the pool of readily mineralizable organic materials in that experiment was lower than in the other experiments and was depleted during the last two wet months (January to March).

CONCLUSIONS AND RECOMMENDATIONS

- Results from this study have shown that maize yields were usually high at the commencement of each experiment given sufficient rain. These yields decreased with time under control, treatment with N supplement and treatment with pruning. The decrease was, however, less pronounced under treatment with prunings, probably due to the effect of those prunings in improving soil fertility status.

- Maize yield decline was strongly related to rainfall and particularly to its distribution over season; and this shows that the most limiting factor was primarily soil moisture and not soil nutrients.

- Soil chemical properties' analysis showed that none of the soil chemical parameters were significantly affected by the treatments. This could mean that the relative performance of treatment with prunings on maize yields was not a result of changes in soil chemical properties, but it is most likely related to a better improvement of soil moisture conditions.

- In effect, and despite the successive croppings, only soil organic matter and total N underwent a severe depletion. However, they did not reach a critical level that can compromise maize productivity. Soil organic matter was still adequate, while total N was slightly lower than

the critical range of 0.21%. Levels of available P were very low, thus this element may be a limiting factor for maize production in those sites. Exchangeable cations were rated high and suitable for maize production.

- Unlike soil chemical properties, soil biological activity appeared to be affected by the current management. Results from soil incubation showed that, in the three and five-year fallows, residual effect of previous treatments generated significantly higher ($P < 0.05$) amounts of mineral N where prunings were added (F+P) than where urea was added (F). In experiment II, N mineralization rates were statistically similar under all treatments; although slightly better rate was recorded in the treatment with prunings.

Based on the results from these experiments, no firm conclusion can be drawn on the suitability of these treatments to maintain maize productivity in Meatu. Firstly, rainfall was shown to be an important limiting factor in that zone and may confound interpretation on the effects of the treatments. Secondly, the experiments were established for two to four years only, which are fairly short periods for making strong conclusions, especially on soil fertility pattern.

Nevertheless, preliminary observations can be made. Based on the results from maize yields and N mineralization, the treatment with pruning seems to be the best. Comparing the experiments, with respect to maize yields and other soil parameters studied, the four-year old fallow seemed better than others.

The present study, also provides indications for re-adjustment of the management and for further studies.

(a) The assessment of the treatment effects on maize productivity could be masked by low rainfall. Thus, it is necessary to extend the research to include more drought resistant crops found in that region e.g., pearl millet, sorghum.

(b) The rapid decrease of organic matter and total N may be compensated by leaving crop residues in the fields. These residues, once mulched, may have advantages of protecting soil from sun heating, and they may contribute to soil moisture and nutrient conservation.

(c) Soils in the experimental area are originally suitable for crop production; only P is critically low. It is therefore recommended to initiate P fertilizer trials on maize productivity.

(d) *Acacia polyacantha* has been introduced in those experiments as an alternative to leucaena which is threatened by leucaena psyllid, and to determine its contribution for

soil fertility improvement. However, this later objective cannot be fully assessed in a mixed stand. Thus, there is a need for further focused studies on the potential of *A. polyacantha* and other indigenous tree and shrub species for agroforestry.

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APPENDICES

Appendix 1. Some soil properties at 0-10 and 10-25 cm depth
of a three-year fallow cropped thrice at Meatu

	0-10 cm	10-25 cm
Sand (%)	54.83	53.08
Silt (%)	11.34	10.02
Clay (%)	33.83	36.90
Bulk Density (g/cm ³)	1.23	1.26
pH (in 1:2.5 soil:water ratio)	7.8	7.9
Electrical conductivity ($\mu\text{s cm}^{-1}$)	0.12	0.16
Organic C (%)	1.65	1.1
Total N (%)	0.18	0.15
Available P (mg kg ⁻¹ soil)	4.4	2.14
Exc. K (cmol(+) kg ⁻¹ soil)	0.69	0.50
Exc. Ca "	26.38	35.41
Exc. Mg "	1.37	1.42
Exc. Na "	0.27	0.46
CEC "	28.7	37.8

Appendix 2. Some soil properties at 0-10 and 10-25 cm depth
of a four-year fallow cropped twice at Meatu

	0-10 cm	10-25 cm
Sand (%)	51.90	50.37
Silt (%)	13.10	12.93
Clay (%)	35.00	36.70
Bulk Density (g/cm ³)	1.23	1.25
pH (in 1:2.5 soil: water ratio)	7.9	8.0
Electrical conductivity ($\mu\text{s g}^{-1}$)	0.14	0.17
Organic C (%)	1.63	1.44
Total N (%)	0.21	0.15
Available P (mg kg ⁻¹ soil)	6.14	3.82
Exc. K (cmol(+) kg ⁻¹ soil)	1.3	0.80
Exc. Ca "	33.1	35.76
Exc. Mg "	1.83	1.56
Exc. Na "	0.34	0.41
CEC "	36.5	38.52

Appendix 3. Some soil characteristics at 0-10 and 10-25 cm depth of a five-year fallow cropped once at Meatu

	0-10 cm	10-25 cm
Sand (%)	52.32	48.96
Silt (%)	11.61	10.75
Clay (%)	36.07	40.29
Bulk Density (g cm ⁻³)	1.17	1.21
pH (in 1:2.5 soil: water ratio)	7.7	7.8
Electrical conductivity ($\mu\text{s cm}^{-1}$)	0.14	0.13
Organic C (%)	1.6	1.33
Total N (%)	0.20	0.18
Available P (mg kg ⁻¹ soil)	2.95	1.68
Exc. K (cmol(+) kg ⁻¹ soil)	1.12	0.70
Exc. Ca "	36.67	20.9
Exc. Mg "	2.17	1.41
Exc. Na "	0.46	0.25
CEC "	40.42	23.31