NITROGEN MINERALIZATION AND MAIZE YIELD FROM A THREE YEARS FALLOW OF *PROSOPIS CHILENSIS*

BY

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ABSTRACT

The study was conducted to assess the effect of three-year old fallow of *Prosopis chilensis* (Molina Stuntz) on general soil properties, nitrogen mineralization and maize yield on an on-going agroforestry experiment at Gairo, Morogoro, Tanzania. The design of the experiment was a completely randomized block design with three treatments: Trees alone (T), Maize (M) alone and Trees plus maize (T+M) each replicated four times. Soil samples were collected at the beginning and at the end of the experiment at 0-15 and 15-30 cm depth. Soil samples for N mineralization were collected at three weeks intervals from maize sowing up to tasselling stage.

The results from the soil analysis at the beginning of the experiment showed that K^+ differed significantly between treatments. The trees alone treatment had the highest level (1.0 cmol (+) kg^{-1}) than other treatments which had the lowest level (0.7 cmol (+) kg^{-1}). Magnesium differed significantly between treatments, with the maize alone treatment having the highest level of Mg^{2+} (2.0 cmoles(+) kg^{-1}) and the treatment with trees alone having the least (1.6 cmoles (+) kg^{-1}). Total P differed significantly between ($P<0.05$) treatments with the trees-alone treatment having the highest total P (229.6 ppm) and treatment with maize alone having lowest value (159 ppm). Total N, organic C, available P, inorganic P, organic P, Na^+ and Ca^{2+} were not significantly affected by treatments. Total N and available P decreased significantly ($P<0.05$) with soil depth. In contrast, Mg^{2+} and Ca^{2+} were higher in the subsoil than in the top soil. At the end of the experiment, none of the nutrient analyzed differed significantly between treatments. Results from N mineralization under laboratory conditions in all sampling periods did not show any significant difference between treatments. In contrast, changes in mineral N under field conditions showed that the treatment with trees alone had the highest release of mineral N and was dominated by nitrate. Maize yield did not differ significantly between treatments.

It is concluded that a three-year fallow of *P. chilensis* was not long enough for soil fertility improvement even though there was a significant difference on total P and release of mineral N.

DECLARATION

I, Jean de Dieu UWIZEYIMANA 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 to a degree in any other university.

Signature ....

Date ....18/9/1997.........

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DEDICATION

To those innocent Rwandese civilians who died in the civil war in 1994 especially my mother Colette MUKARUTAMU and my young brother Antoine NIYONSABA, and all those who are still suffering the consequences of that war.

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SUA: Sokoine University of Agriculture

SAREC: Swedish Agency for Research with Developing Countries

CHAPTER 1

1.INTRODUCTION

In the traditional african farming systems, farmers mainly relied on long fallow periods to regenerate fertility of the land exhausted during cropping period. However, increasing land pressure due to population growth in many parts of the tropics has led to a shortening of the fallow period used to restore soil fertility (Rao *et al.*, 1990). Fallowing is a period in agricultural system whereby a cultivated land is left idle without being cultivated for a period of time (Mohammed, 1989). During fallow period, farmers cultivated new land and returned to the fallow land after several years. This practice is referred to shifting cultivation. Nye and Stephen (1962) in Kass *et al.* (1993) proposed improved fallow as a management alternative to shifting cultivation in the tropics. According to Reintree and Warner (1986) there are two types of fallows:

(i) Economically improved fallow where trees producing economically valuable products are introduced into the fallow;

(ii) biologically enriched fallow whereby trees (especially nitrogen fixing species) are introduced to control weeds, and enhance the regeneration of soil fertility.

Kass *et al*. (1993), on the other hand, reported some types of fallows within biologically enriched fallow as follows:

(iii) Multispecies fallow similar to natural secondary vegetation, but enriched with certain species;

(iv) less diverse fallow in which one or more species with biological and economic value are introduced in order to shorten the fallow period and / or increase its economic worth. This involves the use of multipurpose trees during fallow periods, either in systems whereby planted fallow alternate with crops (rotational fallow) or by rotational hedge-row intercropping systems, in which a period of hedgerow-intercropping is followed by a period of uninterrupted hedge row without crops.

It has been reported that traditional fallow could be managed by using preferred tree species in order to improve the rate of soil fertility amelioration (Rao *et al*., 1993). When the fallow period becomes too short, as observed in an area with high population densities, either artificial fertilizers have to be used to improve soil fertility or other alternatives which are economically attractive to small farmers have to be included in the production system.

According to Ahlback (1994) for most peasants in developing countries chemical fertilizers are difficult to obtain because they are expensive and in many parts unavailable. Also, recommendations originally developed for optimum fertilizer rate have led to increasing problems of soil acidification and ground water pollution, caused by leaching of NO_3^+-N from agricultural land (Grout and Houba, 1995). In order to reduce the dependency on artificial fertilizers and at the same time respond adequately to the problems of food production, a technically feasible and economically viable technology which can sustain crop production and offer other benefits to the farmers needs to be developed.

Soil fertility can be maintained through biological nitrogen-fixation. Nitrogen fixing trees/shrubs have been used in cropping systems for soil improvement for a long time (Sarrantonio, 1992). Under certain conditions a legume cover or green manure crop can provide biologically fixed nitrogen, increase soil organic matter, provide protection against soil erosion, improve soil structure, make other nutrients more available and interrupt cycles of diseases and insect pests. For any tree/shrub to be incorporated in the fallow, it should establish quickly, grow quickly, fix nitrogen and produce a large amount of biomass. This will be of great importance in developing countries where peasants cannot afford inorganic fertilizers (Ahlback, 1994).

Different leguminous tree species have been reported to grow in arid and semi-arid areas (Felker and Clark, 1980; Habish and Khairi, 1970; Nakos, 1977). One of them is *Prosopis chilensis* (Molina Stuntz) an exotic tree species originating from northern America, central America, Mexico and Antilles. It is cultivated all over the tropics including the Sahel, Mauritania, transition zone to Sudan savanna (Bulkart, 1976). *P. chilensis* belongs to the subfamily of Mimosoideae, of the family Leguminosae. It is a small to medium-sized tree up to 12 m in height and 1 m diameter (Burkart, 1976). Various *Prosopis* spp are drought-resistant, nitrogen-fixers, palatable, and tolerate salt and nutrient-poor soils (Baumer, 1990). *Prosopis* spp are excellent source of firewood and charcoal. In addition, they produce a lot of sweet pods containing up to 27% of glucose and 17% of protein and forage, as well as copious nectar from the third to fourth year which is used for honey production. The wood is hard and durable and is used for posts, stakes, house construction and furniture (Baumer, 1990).

P. chilensis has a potential of increasing soil fertility status through its nitrogen-fixing ability. However, the extent of N_2 fixation by *P. chilensis* and its effect on N mineralization status of semi-arid region of Tanzania are not known. This study assessed the effect of three years fallow of *P. chilensis* on soil nutrient status, N mineralization and maize yield in a semi-arid area at Gairo, central Tanzania with the following specific objectives:

(i) To evaluate the effect of fallow on some soil chemical properties;

(ii) To compare N mineralization under trees alone; trees with maize and maize alone treatments after 3 years;

(iii) To assess maize yield response after three year *P. chilensis* fallow.

CHAPTER 2

2. LITERATURE REVIEW

2.1. General

2.1.1. Restoration of soil fertility under fallow

Shifting cultivation and short rotational fallow have been used for many years to restore soil fertility (Whyte and Trumble, 1953; Nye and Greenland, 1960; Cooke, 1967 and Rao *et al.*, 1990). In this practice a temporary and short cropping phase is followed by fallow period during which the land is left under natural vegetation and is expected to regain soil fertility (Ahn, 1979; Mohammed, 1989). However,it has been shown that fallows require long period (10-20 years) to restore soil fertility and is therefore not feasible where the population density is high.

Improved fallow planted with trees or shrubs have been shown to have the capability of improving soil fertility, especially those with N-fixing and high foliage biomass production (Kwesiga, 1992). Improved fallow is able to restore fertility comparable to, or better than, the natural regrowth vegetation, and provide the farmer with economic returns, such as timber or fire wood for sale, or forage for animals, which would compensate for the extra work of planting fallow (Mongi and Huxley, 1979). Rao (1989) speculated that if trees/shrubs are established at high densities and retained on the ground for 1 to 3 years the land can be enriched and brought back to food production. On the other hand Kang *et al.* (1990) found 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.

One of the crucial factors for the success of improved farming system is the efficient recycling of organic materials, which exploit the full biological potential of the agro-ecosystem (Kachaka *et al.*, 1993). This recycling is an essential feature in the design of many agroforestry systems aimed primarily at a compromise between continuous cropping and long fallow period (Juo and Lal, 1987; Kang and Duguma, 1985).

Soil fertility changes under fallow are linked closely to the amount of litterfall that provides humus which helps to hold exchangeable cations, store large amounts of P and S and is the sole N reservoir (Nye and Greenland, 1960). The study carried out in humid and sub-humid tropics at Ibadan showed significant effects of fallow on mostly soil chemical properties, in particular pH, Boron and Phosphorous (Cobbina, 1992). Juo and Lal *in* Nair (1993) compared the effect of *Leucaena leucocephala* fallow against bush fallow on selected soil chemical properties of an Alfisol in western Nigeria, where after three years *L. leucocephala* biomass was cut annually and returned to the soil as mulch. Cation exchange capacity, levels of exchangeable Ca and K were significantly higher in the *L. leucocephala* fallow than in the bush fallow.

Rao (1989) suggested that the rate and extent of soil fertility through litterfall production and accumulation depends on length of fallow period, the nature of fallow vegetation, soil properties, management practices and climatic factors. However, the most important factor is the rate of nutrient accumulation in the vegetation store (Norman, 1979).

Better fallow and residues management can help accelerate soil restoration and improve and stabilize traditional cropping systems (Mutsaers *et al.*, 1981; Prinz, 1986, Bowen *et al.*, 1988; Rocheleau *et al.*, 1988). It is assumed that planted fallow if properly managed, will add substantial amount of fixed N and organic matter to the soil, recycle nutrients from subsoil, provide effective cover against erosion, suppress weeds and pests, and improve soil physical conditions (IITA, 1985; Francis *et al.*, 1986; Prinz, 1986; Hulugalle, 1988).

2.1.2. Restoration of soil fertility using green manure

Green manure is a bulk of plant materials which are returned to the soil either directly or after some sort of processing. In tropical and subtropical soils and sandy soils where degradation of organic matter is high the use of organic manure is important (Johnson *et al.*, 1995). It is claimed that herbaceous legumes contribute 40 to 200 kg N ha^{-1} yr^{-1} (IRRI, 1988; Peoples and Herridge, 1990). Sangiga *et al.* (1989) reported an addition of 98-134 kg N ha^{-1} of *L. leucocephala* in 6 months in an Alfisols, at IITA in Ibadan, Nigeria. Rundel *et al.* (1982) reported 25-30 kg N ha^{-1} yr^{-1} by *Prosopis glandulosa*, and *Prosopis tamango* has been reported fixing 200 kg N kg ha^{-1} yr^{-1} (Nair, 1984).

Mulching with crop residues and other vegetative matter have been reported as a successful practice of restoring soil fertility (Nair, 1993; Sarrantonio, 1992; Carsky and Ajayo, 1992). The use of organic manure has the following advantages:

- to prevent soil nutrients from leaching;
- to fix and hold soil nutrients in an insoluble organic form which when mineralized by soil microorganism, supply the plant with 'a gentle stream' of nutrient throughout their life period;
- to increase soil nitrogen from N- fixation;
- to supply some organic matter which persists in the form of humus in the soil and improve its physical properties;
- to provide a wide spectrum of plant nutrients;
- to encourage insects and worms to burrow into the ground thus improving permeability to a large extent.

The presence of organic manure on the soil surface has some effects on soil physical properties such as:

- reducing impact of rain drop on soil surface which might cause splash erosion;
- reducing evaporation;
- reducing excessive heating;
- allowing microbiological activity to occur at optimum temperature.

2.2. Effect of Multipurpose Trees on Soil Chemical Properties

2.2.1. Nitrogen mineralization

The knowledge of nitrogen transformations and their effects on soil fertility following tropical forest clearing is critical for understanding the long term implications of human-induced land-use changes (Piccolo *et al.*, 1994). Nitrogen is required by plants in large amounts. It occurs in the atmosphere (78% by volume) and in small amounts in the soil (2-5%). Soil N is mostly held to the organic matter and concentrated in top soil (Maliondo, 1993). Nitrogen is added to the soil through biological fixation, atmospheric wet and dry deposition and fertilizer and organic manure input. The gaseous form of Nitrogen (N_2) can not be used unless fixed by N fixers. Plants can only take inorganic N compounds: NH_4-N and NO_3-N from the soil. The process of transforming organic N to inorganic N is called mineralization, and is mediated by enzyme activities from microorganisms. Thus mineralization of nutrients from dead organic matter is the critical process that determines N supplies and soil productivity (Waring and Schlesinger, 1985). The rate of N mineralization and nitrification and the total quantity of N in tropical soils are indicators of soil fertility and affect the ability of these soils to retain N following disturbance such as forest cutting (Piccolo *et al.*, 1994). Information on N mineralization from different plant materials is available (Fox *et al.*, 1990; Palm and Sanchez, 1991; Oglesby and Fowns, 1992; Tian *et al.*, 1992; Kachaka *et al.*, 1993; Constantinides and Fownes, 1994; Handayanto *et al.*, 1994).

The results from Oglesby and Fowne's (1992) study on seven tropical tree species namely *Calliandra calothyrsus*, *Senna siamea*, *Gliricidia sepium*, *Cassia reticulata*, *Leucaena leucocephala*, *Inga edulis* and *Sesbania sesban* using mesh bag method or open frames (which assume that the disappearance of N from recoverable plant materials is equivalent to mineralization), carried at the University of Hawaii showed that the cumulative percent green manure N mineralized over 12 weeks ranged from 9.6% for *I. edulis* to 65% for *G. sepium* and the shape of N release curves differed among species. *G. sepium*, *S. siamea*, *L. leucocephala* and *S. sesban* followed an exponential release for the first four weeks, whereas *S. siamea* had a net immobilization during the first week. *C. calothyrsus* and *I. edulus* appeared to show net immobilization during 1 and 2.5 weeks. *G. sepium*, *S. sesban*, *C. calothyrsus* and *I. edilus* showed a relatively little change between 4 to

12 weeks whereas *C. reticulata* and *L. leucocephala* had net immobilization between 8 and 12 weeks, and *S. siamea* had increased mineralization between week 8 and 10.

Rubaduka *et al.* (1993) conducted a study at Rwerere in Rwanda on three types of soil to assess N mineralization from pruning of woody legumes and N uptake by maize when pruning had been incorporated into the soil. The species used were *C. callothyrsus*, *L. diversifolia*, *L. leucocephala* and *S. sesban*. The mineralization from pruning was rapid and at least 59% of total N released was mineralized within two weeks. Another study done at Ibadan in Nigeria aiming at comparing the decomposition and mineralization of different plant residue in the laboratory revealed that after 112 days of incubation, 50% of the added N was mineralized for *S. siamea*, 69% for *L. leucocephala*, 24% of *F. macrophylla* whereas 54% of added N was immobilized for *D. barteri*. In a great number of decomposing litter materials, several authors have observed that there is a phase of N accumulation, followed by a phase of N release and finally by the loss of N (Aber and Melillo, 1980; Staaf and Berg, 1982; Bossata and Berendse, 1984).

2.2.2. Effect of some multipurpose tree species

In many semi-arid and sub-humid tropical areas soils are rapidly degrading because of over-grazing and too short periods of fallow in agriculture (Johnson *et al.*, 1995). Methods to improve and/or maintain soil fertility are of a great interest. Favourable effects of trees, both N_2-fixing and non N_2-fixing on soil characteristics have been reported by many authors (Belsky *et al.*, 1989, 1993; Bernhard-Reversat, 1982; Bosch and Van Wyk, 1970; Campbell *et al.*, 1988; Dunhum, 1991; Ernest and Tolsma, 1989; Gerakis and Tsangarakis, 1970; Isichei and Muoghalu, 1992; Kellman, 1979; Kessler, 1992). Charreau and Vidal (1965) *in* Jama and Getahun (1991) reported an increase of organic matter, water holding capacity and cation exchange capacity in soil under *Fadherbia albida*. Atta-Krah *et al.* *in* Nair (1993), reported that soil under alley cropping had higher organic matter and N content than soil without trees. Another study done on *F. albida* in Ethiopian highland vertisols revealed that organic matter, N, P, K levels were higher under tree canopy than outside in all directions and depth studied (Kamara and Haque, 1992); and that soil pH, exchangeable Ca, Na and Mg under canopy and outside were similar, but available water holding capacity was 1.5 to 2 times greater under than outside the trees.

Orchard and Darb (1956) noted an increase in soil N under *Acacia mollissima* stands compared to soils from adjacent *Cercidium floridium* in South Africa.

2.2.3. Effect of *Prosopis* species

Mann and Shankarnarayan (1980) noted an increase in soil P, N and organic C, but a decrease of both soil pH (towards neutrality) and $CaCO_3$ under both *Acacia nilotica* and *Prosopis cineraria* growing on alkaline soils in India. Tiedmann and Klemmedson (1973a; 1973b) found changes in soil physical and chemical properties under *P. juliflora* in the Arizona Sonoran Desert. Bulk density under the trees was lower at the surface, but increased with depth, indicating increased water infiltration and leaching under the trees. In addition, they found increased organic matter, total and available N, available P, S and soluble salt under the trees. Barth and Klemmedson (1978) found a negative correlation between soil N and C and distance from *P. juliflora*. They also found a greater accumulation of N and C under *P. juliflora* than under *Cercidium floridium*. Virginia and Jarrel (1983) found a significant increase in total N, NO_3-N, NH_4-N , organic C, extractable PO_4^{3-} and saturation extract K under *P. juliflora* canopies in the California Sonoran desert. They also found significantly lower soil Na^+ and Cl^- under the trees. Sereno and Hang (1992) showed that analysis of samples taken immediately under and at some distance from *Prosopis* spp showed that soil inorganic P fractions were not affected by the presence of trees, the total P, organic P and available P were higher in their immediate vicinity in an alluvial soil. A study done at the Biomass Centre Banhra in India on *P. juliflora* and *A. nilotica* on a sodic soil revealed a preferential nutrient accumulation in *P. juliflora* compared to *A. nilotica*. Exchangeable Na and soil pH decreased under both species and there was a reduction in surface soil (0-15 cm) bulk density.

From the above studies, the nitrogen fixing trees have the potential to improve soil fertility. In addition there are indications that they are more effective than non-nitrogen fixing trees.

CHAPTER 3

3. MATERIAL AND METHODS

3.1. Study Site

The experiment reported in this study was carried out at Sokoine University of Agriculture/Swedish Agency for Research Cooperation with Developing countries (SUA/SAREC) agroforestry research project located in Gairo division, Morogoro Region, Tanzania. Gairo lies between 6^0 and 8^0 S, and 36^0 and 38^0 E, altitude varies from 1076 to 1631 m above sea level; and a topography consisting of several small hills throughout the area, but with no major rivers except for a few seasonal streams. Rainfall is unevenly distributed, and varies from year to year, with the rain season starting in November and ending in May. The average annual rainfall is 499 mm. The soils in Gairo are quite varied with grey clay soils in low area, and loam on higher ground. The study area has a loam soil with the following properties: mean soil pH of 6.4, organic matter content of 0.15%, total nitrogen 0.069%, Bray I available P 5.5 mg/kg and CEC 13.3 cmole(+) kg^{-1} (Chamshama *et al.*, 1994). The vegetation cover of Gairo is scarce, and consists mostly of shrubs and a few scattered trees.

3.2. Experimental Design

The experiment was established in 1989 as a completely randomized block design with four replications of the following treatments:

A: tree at 1 m * 5 m spacing, (T)

B: tree at 1 m * 5 m plus maize, (T+M)

C: maize alone at 90 cm * 30 cm spacing (M).

The total area is one hectare and there are twelve plots separated from each other by a five-metre space, and blocks are separated by three-metre space.

After the experiment was established, it was realized that competition for light, moisture and nutrients between *P. chilensis* trees and maize during the early years of growth was very intense (Maliondo personal communication, 1996). After three years of intercropping it was decided to leave the experiment for a period of three years to make a fallow.

3.3. Site Preparation

In treatment A and B all trees were felled and leaves incorporated into the soil. Nothing was incorporated in treatment C. Land preparation was done manually and maize was planted in all treatments.

3.4. Sampling

3.4.1. Soil sampling

Soil sampling for routine analysis was collected at the beginning and end of growing season at 0-15 cm and 15-30 cm soil depths in each plot. For each plot soil was collected from five randomly selected points, composited by sampling depth, mixed thoroughly and then sub-sampled.

Soil samples for N mineralization analysis were collected every three weeks starting from the beginning of the experiment up to the maize tasselling stage at 0-15 and 15-30 cm soil depth.

3.4.2. Tree foliage sampling

Before incorporating biomass into the soil, the total fresh foliage biomass was weighed to know the amount applied. Sub-samples of foliage were collected and packed loosely in paper bags for oven drying. Before drying, samples were washed using distilled water, after which they were transferred to small paper bags and dried at 70^0 C to constant weight. The material was ground in a 1 mm sieve mill. The powder was thoroughly mixed, packed in polythene bags, and stored under dry condition prior to chemical analysis.

3.4.3. Maize sample

A square plot of 10 x 10 metres was selected and all maize plants within the square were harvested and dried. After, maize were shelled, weighed and expressed as tone per hectare.

3.5. **Soil Physical Properties**

Soil texture was determined by hydrometer method as described by Bouyoucos (1962). Soil bulk density was determined near field capacity as recommended by London (1991). Soil samples were collected with coring cylinder of 5 cm length and 5 cm diameter. Soil samples from the core were weighed and then dried in the oven at 105^0 C for 24 hours. Bulk density were calculated according to Blake and Hartage (1986).

3.6. **Soil Chemical Properties**

3.6.1. Routine soil analysis

Total nitrogen was determined by semi-micro Kjedahl procedure according to Bremner and Mulvaney (1982). Organic carbon was determined by titration as described by Anderson and Ingram (1993). Soil exchangeable cations and cation exchange capacity (CEC) were determined by saturation methods (Urio and Singh, 1979). A 1:10 ammonia 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. Calcium and Mg^{2+} were determined by atomic absorption spectroscopy. Cation Exchange Capacity was determined using ammonia acetate (pH 8.2) method. Available phosphorous was determined by the Bray I methods as described by Anderson and Ingram (1993). Total phosphorous, organic phosphorous and inorganic Phosphorous were determined according to Page *et al.* (1982). Soil pH was determined potentiometrically by a glass-electrode pH-metre using 1:2.5 soil:water suspension and in 0.01M $CaCl_2$ (London, 1991).

3.6.2. Nitrogen mineralization

From each soil sample 5 g were taken for aerobic incubation. Soil moisture for each sample was adjusted to 60% air-filled pore space and kept in dark incubators for two weeks at room temperature. Every day the incubators were opened for 5 minutes to allow aeration and, at the same time moisture correction was made after weighing of a few samples. At the beginning of the incubation, two portion of soil from each sample were taken for determination of initial inorganic nitrogen content. The extraction was made using 1M of K_2SO_4 for nitrate and ammonium determination as described by Anderson and Ingram (1993).

3.7 **Data Analysis**

Analysis of variance was done on plot means, and means separation was done by Duncan's Multiple Range Test for all soil chemical properties analyzed including N mineralization, as well as maize yield according to the statistical software programs in SAS (1991).

CHAPTER 4

4. RESULTS

4.1. Amount of Biomass and Nutrients Added

The amount of biomass and nutrients added through the application of *Prosopis* foliage are shown in Table 1. The incorporation of maize before the fallow period was initiated had no effect on foliar biomass production and nutrient contents of *Prosopis* during fallow period.

Table 1: Amount of biomass and nutrients added through application of *Prosopis* foliage

Trt	Biomass	N	P	K
	kg ha^{-1}			
T	773a	22.3a	2.8a	16.5a
T+M	871a	20.9a	2.9a	16.9a
SE±	ns	ns	ns	ns

ns= means with the same letter within the same column are not significantly different (P<0.05)

4.2. Soil Properties

4.2.1. Soil physical properties

In general, soil texture of Gairo is sandy clay loam composed of 55% sand; 38% clay and 7 % silt. The average bulk density was 1.37 g cm^{-2}.

4.2.2. Soil chemical properties

4.2.2.1. Soil pH, total N, organic carbon, available P

Table 2: Soil pH, total N (TN) , available P (AP) and organic C (OC) after fallow

Trt	pH	TN	OC	AP
		——%——		ppm
M	6.2 a	0.18 a	2.4 a	2.1 a
T	6.4 a	0.16 a	2.7 a	2.2 a
T+M	6.3 a	0.16 a	2.5 a	2.3 a
SE±	ns	ns	ns	ns

ns=Means with the same letter within the same column are not significantly different ($P< 0.05$)

Soil pH, total N, organic carbon and available P were not significantly different among treatments (Table 2).

4.2.2.2. Total, organic and inorganic Phosphorous

Total P differed significantly between treatments. The treatment with *Prosopis* alone had significantly higher total P (229.6 ppm) while the maize treatment had the least (159 ppm). Inorganic P did not differ significantly between treatments. The average inorganic P were 40.3, 44.9 and 30.5 ppm in M, T and T+M treatments, respectively (Table 3). Similarly there was no significant difference in organic P between treatments, and averaged 121.52, 184.69 and 160.84 ppm in M, T and T+M treatments, respectively.

Table 3: Soil inorganic P (IP), organic P (OP) and Total P (TP) after fallow

Trt	IP	OP	TP
		ppm	
M	40.33a	121.52a	159.48b*
T	44.9a	184.69a	229.63a*
T+M	30.48a	160.84a	191.33ab*
SE±	ns	ns	20.2

ns= means with the same letter within the same column are not significantly different (P<0.05)
*= means with the same letter within the same column are significantly different (P<0.05)

4.2.2.3. Cation Exchange Capacity (CEC) and Exchangeable Cations and base saturation

Cation Exchange Capacity, exchangeable Sodium and Calcium were not significantly affected by the different treatments (Table 4). In contrast, exchangeable potassium was significantly higher in the *Prosopis* treatment than in the other treatments, whereas exchangeable Magnesium was significantly higher in the maize and *Prosopis* plus maize than in the *Prosopis* alone treatment.

Table 4: Cation exchange capacity, exchangeable cations and base saturation after fallow

Trt	Na^+	K^+	Ca^{2+}	Mg^{2+}	CEC	BS
	cmol(+) kg^{-1}					%
M	0.5a	0.7b*	3.0a	2.0a*	10.6a	58
T	0.6a	1.0a	3.0a	1.6b	12.0a	52
T+M	0.5a	0.7b	2.5a	1.9a	8.7a	64
SE±	ns	0.09	ns	0.08	ns	

ns= means with the same letter within the same column are not significantly different ($P < 0.05$)
* = Means with the same letter within the same colunm are significantly different ($P<0.05$)

4.2.3. Soil nutrients at different depth

Table 5a shows the that total N and available P were significantly higher in the 0-15 cm soil depth than in the 15-30 cm depth while total P, organic P, inorganic P, organic C were not significantly different between the top soil and sub-soil .

Table 5a: Total nitrogen, Available phosphorous, Organic phosphorous, Total phosphorous, Organic carbon at different soil depth

Depth	TN	OC	AP	IP	OP	TP
cm	%		ppm			
0-15	0.18 a	2.8 a	3.3 a	41.6 a	166.4 a	202 a
15-30	0.13 b	2.0 a	1.2 b	35.6 a	147.8 a	185 a
SE±	0.01	ns	ns	ns	ns	ns

ns= means with the same letter within the same column are not significantly different ($P < 0.05$)

Table 5b showed that Mg^{2+} and Ca^{2+} were significantly higher in the subsoil soil.

Table 5b: CEC, Na^+, K^+, Ca^{2+} and Mg^{2+} at different soil depth

Depth	CEC	Na^+	K^+	Mg^{2+}	Ca^{2+}
Cm	Cmoles(+) kg^{-1}				
0-15	10.4 a	0.5 a	0.9 a	1.5 b	2.5 a
15-30	10.4 a	0.5 a	0.7 a	2.2 a	3.1 b
SE±	ns	ns	ns	0.07	0.19

ns= means with the same letter within the same column are not significantly different ($P < 0.05$)

4.2.4. Effect of different treatments on N mineralization under field and laboratory incubation

Figure 1 shows the N mineralization under field condition. During the first six weeks, a slight mineral N release was observed under *Prosopis* alone treatments while the maize alone and maize plus trees treatments showed a negative mineral N levels. Between six to nine weeks, the rate of mineral N formation increased very fast under *Prosopis* treatment and decreased markedly under the other two treatments. Between nine to twelve weeks, treatments containing *Prosopis* showed a positive rate of mineral N formation with *Prosopis* alone treatment showing the highest level of mineral N release. It is important to note that throughout the study the treatment with tree alone had positive N release while the maize alone treatment immobilized N throughout.

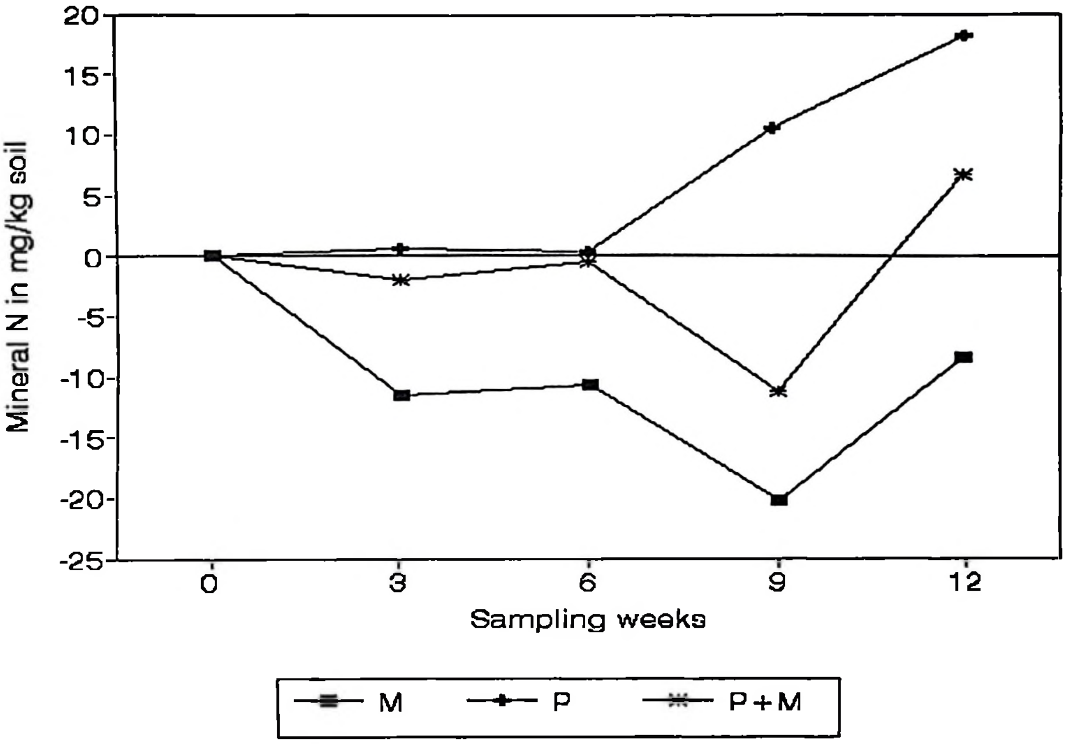

Figure 1: Changes in mineral N with sampling period under field conditions.

Under laboratory conditions net ammonification and net nitrification were not significantly affected by the different treatments (Table 6). In general mineral N declined with sampling period in all treatments with the strongest decline in the maize + trees treatments.

Table 6: Effect of treatments on net ammonification and net nitrification under laboratory conditions

	First sampling		Second sampling		Third sampling	
Treat	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+
	ppm					
M	38.3a	18.1a	26.7a	3.6a	22.1a	12.2a
T	35.5a	19.5a	22.6a	7.8a	19.6a	19.8a
T+M	41.7a	11a	27.4a	9.4a	9.8a	8.1a
SE±	ns	ns	ns	ns	ns	ns

ns=means with the same letter within the same column are not significantly diffirent at $P<0.05$

4.2.5. Soil mineral N at different depth

Nitrification was significantly higher during the first and second sampling in the sub-soil than in the topsoil, but this trend was reversed during the third sampling (Table 7).

Table 7: Net ammonification and net nitrification at different soil depth

	First sampling		Second sampling		Third samping	
Depth (cm)	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+
0-15	31b	17.1a	21.9a	6.9a	34.8a	7.7a
15-30	46a	15.3a	29.2a	7a	-0.2b	13.1a
SE±	3.06	ns	ns	ns	4.52	ns

ns=means with the same letter within the same column are not significantly different at $P<0.05$

4.2.6. Effect of treatments on soil chemical properties after harvesting

Most of the nutrients analyzed did not differ significantly between treatment (Table 8), although treatments with trees had higher P content. With respect to soil depth, only available P was significantly higher in the top soil (Table 9).

Table 8: Effect of treatments on IP, OP, OC, TN, AP and K^+ after harvesting

Trt	AP	IP	OP	TP	TN	OC	K^+
	ppm				%		Cmol(+) kg^{-1}
M	0.7 a	24.5 a	66.3 a	88.9 a	0.1 a	0.8 a	0.7 a
T	0.6 a	38.5 a	73.8 a	122.3 a	0.1 a	0.9 a	0.6 a
T+M	2.6 a	32.5 a	78.2 a	112.6 a	0.1 a	0.9 a	0.8 a
SE±	ns	ns	ns	ns	ns	ns	ns

ns= means with the same letter within the same column are not significantly different at P<0.05

Table 9: Soil chemical properties at different depth after harvesting

Dpt	AP	IP	OP	TP	TN	OC	K^+
0-15	3.3 a	30 a	78.3 a	105.4 a	0.1 a	0.9 a	0.6 a
15-30	1.8 b	33.8 a	70.1 a	110.5 a	0.1 a	0.8 a	0.7 a
SE±	0.38	ns	ns	ns	ns	ns	ns

ns= means with the same letter within the same column are not significant different (P <0.05)

4.3. Effect of treatments on maize grain yield.

Maize yield between treatments were not significantly different. The average maize yield was 1.69 t ha^{-1} and was only slightly higher by 100 kg ha^{-1} in the *Prosopis*-alone treatment (Table 10).

Table 10: Effect of treatments on maize grain yield (t ha^{-1})

Treatments		
M	T	T+M
1.6 a	1.7 a	1.6 a

Means with the same letter are not significantly different ($P<0.05$)

CHAPTER 5

5. DISCUSSION

5.1. Maize yield

According to literature, *Prosopis* species have been shown to have some effects on some soil properties mainly through its ability to fix N (Felker *et al.*, 1981; Jarrel *et al.*, 1982; Mann and Shakarnarayan, 1980; Orchard and Darb 1956; Sharrif *et al.*, 1982; Tiedmann and Klemmedson 1973a, 1973b; Virginia and Jarrel 1983, Zoller 1986). However, results from this study showed that there was no significant effect on maize yield. The lack of statistically significant effect of *Prosopis chilensis* on maize yield could be due to several reasons including low soil N and P availability. Although the addition of *Prosopis* biomass was expected to increase soil N availability, the amount of biomass and hence N added was too low (22 kg ha^{-1}). According to Sanchez (1976), 7 tones ha^{-1} maize crop require 200 kg N ha^{-1}. In order to obtain 1.6 t ha^{-1} of maize, 48.57 kg N ha^{-1} should therefore have been added. Actually the amount added in this study was less than the half of that required. Furthermore, deep leaching of NO_3^- released by mineralization of added biomass could also have reduced the amount of N available to the maize crop.

No nodules were detected under *Prosopis* trees in this study, indicating that N fixation was limited and that trees mostly utilized the soil native N. The lack of nodules could be due to the low soil P availability (2.2 ppm) which is known to restrict N fixation in tropical soils (Sanchez and Palm, 1996). In addition, *P. chilensis* stores most of its N in the woody biomass (Abrams *et al.*, 1995) and since only leaves and twigs were added in this study, much of the N remained locked-up in the stems.

Similar to N, the amount of P added by foliar biomass application (2.9 kg P ha^{-1}) was also too low to increase soil available P. According to Sanchez and Palm (1996), leguminous mulches and green manures applied at a realistic rate of 4 tones ha^{-1} provide only 8 to 12 kg P ha^{-1}. This is about half of the P requirement of a maize crop yielding 4 tones of grain per ha, which accumulate 18 kg of P. In this study, in order to obtain 1.6 tones per hectare of maize, an amount of 7.2 kg P ha^{-1} should have been added. However, only amount of 2.9 kg P ha^{-1} was added. This is less than half of what should have been added.

5.2. Effect of *Prosopis chilensis* on Soil Chemical Properties

5.2.1. Nitrogen mineralization

During the whole period of maize growth there was a marked increase rate of N mineralization under *Prosopis* alone treatment, and considerably less nitrogen under *Prosopis* plus maize and maize alone treatments. The higher mineral nitrogen under *Prosopis* alone treatment could be due to a higher content of mineralizable N accumulated during the fallow period. Decay of dead roots and leaves and microbial activity, under fallow, are possible reasons for the elevated mineral N under fallow (Fig.1).

In Gairo, conditions were favourable for nitrification, since most of inorganic N was in NO_3^--N form (Table 6). This indicates that NH_4^+-N in this soil is very unstable and once generated, is oxidized into NO_3^--N. This could be attributed to the presence of an active population of nitrifiers in the soil. This form of mineral N is extremely mobile in the soil solution and hence contributes to high N losses through leaching and denitrification (Piccolo *et al*., 1994). However, in this study there was no soil compaction nor high water contents observed, thus ruling out the possibility of N loss through denitrification. The decrease of NO_3^--N and NH_4^+-N during mineralization could also be explained by maize uptake.

5.2.2. Soil total Nitrogen

In this study, average total N was 0.17 % which is rated low according to Metson (1961) *in* London (1991). Normally, soils under legumes are expected to be more fertile than otherwise. However, the lack of significant differences in total N between maize alone and treatments with trees (Table 2) suggest that the presence of *P. chilensis* did not increase soil total N. Nyberg and Högberg (1995) reported a low N_2 fixing ability of *Prosopis* of 4 to 5 years old trees. Also, low available P (2.2 ppm) and low moisture during dry season are likely to have limited N_2 fixation (Chamshama *et al.*, 1991).

5.2.3. Phosphorous

According to rating done by Cooke (1967) *in* London (1991) the Gairo soil is considered deficient in available P indicating that there were no contribution of *Prosopis chilensis* on soil available P. From the results, there was no significant difference between treatments on available P while total P showed significant difference between treatments.

Nyberg and Högberg (1995) reported low extractable P under *Prosopis* species while total P was significantly affected by treatments. Similar to the findings of this study, Hang and Sereno (1992) reported that the presence of *Prosopis* did not affect the level of inorganic P. In this study available P averaged 2.2 ppm. This is below the level considered deficient for a maize crop according to rating suggested by London (1991).

5.2.4. Potassium

The results showed that K^+ differed significantly between treatments and was higher in the trees alone treatments. The same results was reported by Virginia and Jarrel (1982). The reason could be that the maize crop planted before the three year fallow was started, might have exhausted available K in the maize and maize plus trees treatments.

5.2.5. Magnesium

The results Mg^{2+} showed significant differences between treatments with the trees-alone treatments having the least. Probably this can be explained by the returning back of maize residue in treatments with maize during the first experiments before leaving the experiment as a fallow. Alternatively, most of the Mg^{2+} taken by trees during the fallow period was locked up in the stems and was therefore exported from the site during tree harvesting. According to the rating done by London (1991), Mg^{2+} in Gairo soil was sufficient.

5.2.6. Organic Carbon

Soil organic C is not a requirement for plant growth, but the level of organic matter in soil influences a number of key soil chemical and physical processes (Okalebo *et al.*, 1993). In low external input cropping systems, the mineralization of organic matter contributes significantly to soil fertility. From the results of this study, the soil under *P. chilensis* did not differ significantly from the maize alone treatment, and the average organic C was low according to the rating done by Metson (1961). The same results were reported by Jonhson *et al.* (1995) who showed that the effect of three year fallows of *P. chilensis* were not significant at Mafiga in Morogoro, Tanzania. According to London (1991), interpretation of organic C suffers from drawback as those for N. Although high yields are generally associated with high organic matter in low external input agriculture, the C and N components of organic matter are difficult to interpret.

CHAPTER 6

6. CONCLUSIONS

(a) Results from this study have shown that among the chemical properties analyzed, few of them showed significant differences between treatments. Of the three major macronutrients (N, P, K), total P and K^+ showed significant differences while available P did not, and the level of N and available P were too low to support a good maize crop. Also Mg^{2+} differed between treatments and was least in the tree alone treatments.

(b) There was no increase in soil total N from biological N fixation by *Prosopis*.

(c) Nitrogen mineralization under laboratory conditions did not vary significantly among treatments. However, mineral N measured after immediate extraction of field samples showed that the treatment with trees alone had the highest level followed by treatment with trees plus maize.

(d) Maize yield did not differ significantly between treatments. This is attributed to the lack of soil fertility improvement with low amount of biomass applied.

In summary, the three year fallow of *P. chilensis* did not have a significant effect on maize yield and nitrogen mineralization. This may be due to the fact that *P. chilensis* stores more of its Nitrogen in the stem and it would be advisable to plant *P. chilensis* purposely for biomass production for fuel or construction material rather than for soil fertility improvement. It could also be used for fencing against animals as boundary planting and soil erosion control because of its small thorns and small multiple stems . Probably, *Prosopis glandulosa* which stores more of its Nitrogen in the leaves could be tried in the same area and planted purposely for soil fertility improvement (Abrams *et al.*, 1995)

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