CHANGES IN SOIL PROPERTIES AND THEIR EFFECTS ON MAIZE PRODUCTIVITY FOLLOWING SESBANIA AND PIGEON PEA IMPROVED FALLOW SYSTEM IN EASTERN ZAMBIA.

BY

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DECLARATION

I, Teddy Shuma Chirwa, hereby declare that all the work presented in this dissertation is my own and has never been submitted for a degree at this or any other university.

Signature. ....

Date. 4 - 11 - 2002

APPROVAL

The University of Zambia approves this dissertation of Mr. Teddy Shuma Chirwa as fulfilling the requirements for the award of the degree of Master of Science in Agronomy.

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ABSTRACT

Soil degradation is a major constraint to sustainable food production in most sub-Saharan African countries. Short fallow rotations of 1-3 years have a potential to increase maize yield without additional inorganic nitrogen fertilizers. The mechanisms responsible for improved maize yield are partially understood. Therefore, the objectives of the study were (1) to quantify some changes in soil properties that may be responsible for improvement in crop productivity under fallow cultivation systems compared with continuously cropped maize system, and (2) to quantify the nitrogen mineralization patterns when mixing litter (dry leaves or senesced leaves) and fresh leaves of fallow species. The experiment was laid out as a randomised complete block design with three replications on a sandyloam (Typic kandiustalf) in eastern Zambia. The treatments compared were two-year-old planted improved fallow of *Sesbania sesban* (L.) Merr. (*S. sesban*) and *Cajanus cajan* (L.) Millsp (pigeonpea); respectively, natural vegetation fallow (Nf), continuous fertilized (M+f) and unfertilized maize (M-f) (*Zea mays* L.) monoculture.

The following parameters were measured: growth (performance) of trees, N mineralization patterns, soil mineralizable inorganic nitrogen, dry matter (DM) accumulation, maize yields, soil bulk density, soil porosity, soil organic carbon, soil penetration resistance, water aggregate stability and distribution, infiltration rate and soil water content.

The highest survival rates were recorded in *S. sesban* (92%), while pigeonpea had only 31%.). At the end of the 10-week incubation period, the N mineralization of *S. sesban* (fresh leaves + litter), reached 59.4 mg N kg^{-1} soil as compared with 5.1 mg N kg^{-1} soil for pigeonpea (litter). Natural fallow had a cumulative net immobilization of 0.8 mg N kg^{-1} soil. M+f had the highest pre-season soil inorganic nitrate-N and total inorganic N in0-20 cm soil depths but were not significantly different with pigeonpea and *S. sesban* land use systems (LUSs). A polynomial regression model between maize grain yield and pre-season soil inorganic nitrate-N for 0-20 cm, 0-40 cm and 0-60 cm soil layers showed that the amount of pre-season inorganic nitrate-N in the soil layer accounted for70%, 67% and 69%, respectively, of the maize yield. As was the case with pre-season soil nitrate-N, total inorganic N in 0-20 cm, 0-40 cm and 0-60 cm soil depths were significantly correlated with grain yield (R^2 = 0.70, 0.66 and 0.70, respectively).

The maximum N accumulation in maize above ground biomass at 24 WAP averaged 156.9 kg N ha^{-1} and 77.0 kg N ha^{-1} for M+f and the *S. sesban,* respectively, with grain yields of 5.51 and 3.02 t ha^{-1}, correspondingly. The highest total biomass was recorded in the M+f (9.52 t ha^{-1}), followed by *S. sesban* (6.02 t ha^{-1}), but was not significantly different at $p \leq 0.05$.

Penetrometer resistance measured at 4 WAP at 5 cm soil depth ranged from 0.65 MPa to 1.15 MPa for pigeonpea and M-f land use systems, respectively. The highest wet mean weight diameter (WMWD) was recorded in the pigeonpea LUS at both fallow clearing and crop harvest. The percentage of water stable aggregates (> 2.00 mm) at fallow clearing was highest (83%) in *S. sesban* and lowest (61%) in M-f land use systems. On the other hand at crop harvest the percentage of aggregates (> 2.00 mm) was highest (77%) in pigeonpea and lowest (44%) in M-f land use systems. At fallow clearing, the equilibrium infiltration rate was highest (31.8 cm hr^{-1}) in natural vegetation and lowest (12.6 cm hr^{-1}) in M-f land use systems. On the other hand at crop harvest the equilibrium infiltration rate was highest (23.4 cm hr^{-1}) in *S. sesban* and lowest (10.2 cm hr^{-1}) in M-f. Similarly, cumulative water intake after 3 hours at fallow clearing was in the order of: Nf = pigeopea ≥ *S. sesban* > M+f ≥ M-f. On the other hand at crop harvest, the cumulative water intake after 3 hours was in the order of: *S. sesban* > Nf = pigeopea = M+f = M-f. Soil water storage in 0-70 cm soil layer at 8 WAP was highest (236 mm) in *S. sesban* and lowest (209mm) in M+f. The improved soil condition and nitrogen contribution of *S. sesban* and pigeonpea fallows to subsequent crop was evidenced by increased maize yields after these fallows as compared to no tree treatments. Mixing of litter (low quality) with fresh leaves (high quality) from the same tree species at fallow clearing had an effect on maize N uptake. Therefore there is need to carefully manipulate the quantities of materials (fresh leaves and litter) at fallow clearing so as to get the maximum N utilization by maize plants in improved planted fallow systems.

DEDICATION

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CHAPTER ONE

INTRODUCTION

Rapid population growth and increased demand for food and fuel wood is outstripping the natural resources base. Resultant of uncontrolled exploitation of resources and unsustainable agricultural practices is a decline in soil fertility and crop productivity. Some of the noticeable results of land degradation are deforestation, habitat destruction, loss of animal and plant species, desertification, floods and increased erosion (Chipungu and Kunda, 1994).

Recent structural adjustment programs (SAP) including the removal of subsidies on agricultural inputs have resulted in increased costs of purchased inorganic fertilizers and other inputs. These costs are out of reach of resource poor farmers. Where inorganic fertilizers are available, they are usually used in amounts insufficient for increasing crop yields. In addition, due to high cost and distribution problems, the use of inorganic fertilizers in sub-Saharan Africa is still limited (Kormawa *et al.,* 1999). On the other hand, Buresh *et al.,* (1998) reported that fertilizer use in many small holder, resource poor tropical agricultural systems remain insufficient to meet crop N demand as well as to sustain soil fertility due to critical financial constraints. However, long-term continuous cultivation on kaolinitic and oxidic soils in the high rainfall tropics often resulted in a rapid decline in soil pH and increases in soluble and exchangeable aluminium (Kormawa *et al.,* 1999).

Under traditional farming systems, farmers have relied on long natural or shrub fallows (15 years or more) to grow their maize and other crops. In eastern part of Zambia, this fallow system is locally known as 'cisala' (Kwesiga *et al.,* 1997). The fallow system in eastern Zambia varies between 1 and 5 years (Kwesiga and Chisumpa 1990). Nye and Greenland (1960) also reported that natural fallows have long been a way to overcome soil fertility depletion that results from continuous cropping with no nutrient inputs. The fallow period may vary from five to twenty years. However, long fallow periods have become impractical because of increasing human and livestock populations. Losses of mineral nutrients during the cultivation phase, through runoff, erosion, leaching and crop removal, can no longer be restored by short periods of bush fallow (Brady, 1996). The processes of natural soil fertility restoration are not completed with short duration bush fallows of between 1-5 years, and this has necessitated the need for improved planted fallows.

The availability of nitrogen limits crop production over large areas of Zambia. The main sources of plant-available N are mineralization of SOM, biological N_2 fixation, inorganic fertilizers and organic inputs (e.g., plant residues, composts and manures) (Giller *et al.,* 1997). Fallow systems have been shown to increase crop yields. However, the processes responsible for increased crop yield and improved soil fertility on nitrogen limiting soils under fallow systems are only partially understood (Barrios *et al.,* 1997). Some of the explanations include high amount and quality of biomass produced by fallow species during the fallow phase. The improvement in soil physical properties could be another reason for yield improvement, but little quantitative data exist on these changes. Soil physical properties, such as bulk density and soil texture, are difficult, time consuming, and expensive to measure, hence their importance often receives insufficient research attention. Recent reviews (Rhoades, 1997; Young, 1997) on the soil improvement effects of trees have largely concentrated on studies of soils under forest stands or along transects under individual trees. In natural agroforestry system litter (senesced leaves) and fresh leaves are normally mixed, especially at fallow clearing. Therefore the effect on nutrient release and long-term changes in soil fertility resulting from application of prunings of different quality (litter and fresh leaves) is a subject, which has received little attention to date. Whilst the response of maize growth and yield in improved fallow systems has received much attention, the processes in tree and post fallow phase are not usually elaborated. Hence, the study was undertaken with the following objectives:

1. To quantify some of the changes in soil properties that may be responsible for improvement in crop productivity under planted fallow systems compared to the continuously cropped maize system.

2. To quantify the nitrogen mineralization patterns of mixing litter (senesced leaves) and fresh leaves of fallow species.

To address the above objectives, the following hypotheses were drawn:

1. The effects of two years old *S. sesban* and pigeonpea planted fallows on subsequent maize growth and yield are due to improvement in soil properties.
2. Continuous cropping of maize with or without fertilizer will lead to deterioration of soil properties, and hence low maize yield compared with improved planted fallow system.

CHAPTER TWO

LITERATURE REVIEW

According to Lundgren (1982), agroforestry is defined as a land use system in which trees are grown on the same land as agricultural crops or animals. This may either be in a spatial arrangement or a time sequence, where both ecological and economic interactions between the tree and non-tree components exist. Kwesiga and Coe (1994) tested one technology (improved fallow) that can be used to replenish soil fertility in Eastern Zambia where bush and grass fallows of 1-5 years are common. The aim of this technology is to make these short fallow periods more efficient in nutrient cycling through the use of leguminous-planted species. Prinz (1986) defined an improved fallow as a targeted use of plant species in order to achieve the aims of natural fallow within a short time or a smaller area. Improved fallows utilize fast growing trees or shrubs, and commonly leguminous species that fix atmospheric nitrogen (Kwesiga *et al.,* 1997).

Buresh and Tian (1997) reported that the major soil chemical changes that take place under tree fallows are increases of labile pools of SOM, N stocks, exchangeable cations and extractable P. Sanchez (1995) showed that below ground biomass accumulation by tree roots could be very high, being as much as 3 to 6 t ha^{-1} yr^{-1}, which can make a substantial contribution to soil organic matter carbon and nutrient cycling.

Van Noordwijk (1989) reported that trees with deep roots could potentially intercept nutrients leaching down soil profiles and capture nutrients accumulated in subsoil below the rooting depth of annual crops. Similarly, Scroth (1995) reported that nutrients captured by trees from outside the rooting zone of annual crops can potentially be transferred to surface soil in the form of leaf litter, roots and pruning of tree leaves and branches. Buresh (1995), also found that the potential of trees to capture and 'pump up' subsoil nutrients is greatest when: 1) trees have deep rooting systems and high demand for nutrients; 2) water and/or nutrient stress occurs in the surface soil; and 3) considerable reserves of plant-available nutrients or weatherable minerals occur in the subsoil.

Hartemink *et al.,* (1996) found lower subsoil nitrate and water in a *S. sesban* fallow than unfertilised maize monoculture and suggested that fast-growing trees, such as *S. sesban,* grown in rotation with cultivated annual crops can capture and recycle subsoil nitrate otherwise unavailable to shallow-rooted crops. On the other hand Juo *et al.,* (1995) showed that chemical fertilizer alone on poorly buffered soils can not sustain crop yield under continuous cropping because of soil acidification, compaction and crusting. Nitrogen is one major nutrient that is easily recognized as a constraint and a quick indicator for decline in soil fertility in cereals, such as maize-based cropping systems, in the unimodal miombo eco-zone of Southern Africa (Kwesiga and Kamau, 1989).

Mafongoya *et al.,* (1998) found that leaves of *S. sesban*, *G. sepium* and pigeonpea with low lignin and concentrations of polyphenols can be used as green manures or mulch and can release nitrogen rapidly to meet nitrogen demands of annual crops. Tian *et al.*, (1992) reported that the rate of net nitrogen release from prunings of various leguminous trees was significantly related to the initial nitrogen, lignin and soluble polyphenol concentrations of the leaves. The net release of nitrogen increased with increasing N concentrations and decreased with higher concentrations of lignin and polyphenols. However, there have been few studies, which have looked at N mineralization in mixture of fresh leaves and litter (dry leaves).

Intensive cultivation and cropping may have deleterious effects on the chemical, physical, and biological properties of the soil due to the induction of changes in temperature, water, and aeration fluxes, decreasing organic matter content and increasing aggregate disruptions and soil erosion (Migliena *et al.,* 1988). Studies on tropical soils demonstrate a rapid decline in organic matter due to continuous cultivation (Allen, 1985; Brams, 1971; Brown and Lugo, 1990; Lugo and Brown, 1993). In order to avoid this, cropping systems that cause minimal distruption to soil properties while increasing soil organic matter (SOM) are preferred. However, Crop residues in the soil may exhibit short-term tendency of retarding the growth of the succeeding crop due to the inhibitory effect of phytotoxic substances, which occur during decomposition of the plant residues (Yakle and Cruse, 1984). Even then, Allison (1973) reported that soil organic matter has long been associated with soil fertility through its indirect effects on soil physical, chemical and biological properties. Similarly, Cassel and Lal (1992) showed that changes in some soil physical properties have a definite detrimental effect on plant growth and crop production. On the other hand Lal (1981) showed that organic matter is an important physical characteristic that plays a dominant role in the management of soils in the tropics. It governs soil-water relationships, aeration, crusting, infiltration, penetration, leaching losses of plant nutrients, and therefore, productive potential of a soil. Continuous cultivation on many strongly weathered, kaolinitic soils often decreases organic matter content, which consequently leads to declining soil productivity (Brams, 1971; Allen, 1985; Kang and Juo, 1986). Lal (1979a) reported that continuous cropping causes the breakdown of soil structure, while agroforestry-based systems reduce the risk of soil degradation. Young (1997) showed that trees can potentially improve soils through numerous processes including maintenance or increase of soil organic matter, biological N_2 fixation, uptake of nutrients from below the reach of crop roots, increased water infiltration and storage, reduced loss of nutrients by erosion and leaching, improved soil physical properties, reduced soil acidity and improved soil biological activity. Torquebiau and Kwesiga (1996) reported that there was a decrease in soil bulk density, decrease in resistance to penetration and increase in infiltration rate in the soil after 2 years of *S. sesban* fallow on Ferric lixisols at Msekera in eastern Zambia. Humbel (1975) showed that in undisturbed forest ecosystems, water movement under saturated conditions takes place in soils through macro-pores that dominate the pore space and therefore surface runoff is generally low, even in regions of intense rains with a high drop-size distribution. Trouse (1979) found that soils in good physical condition are loose, moist, and well aerated with well-connected macro pores that allow roots to grow unimpeded. Cassel and Lal (1992) and Taylor (1974) have shown that compaction, crusting, and pan formation are three physical processes that occur in many soils that have a weak structure, low organic matter, and high silt content. The work done by Trouse (1979) also indicated that machinery, or animals cause not all soil compaction in the tropics; people cause much of it as they till, harvest, and plant or otherwise manage the field. Unfortunately, most human-induced compaction is not even recognized as compaction, but has the same detrimental effects on crop emergence and root development as machinery compaction.

Over the last decade, improved planted fallow trials with *S. sesban* and pigeonpea at Msekera Research Station in eastern Zambia have increased maize yields without inorganic fertiliser application. Maize grain yield of 5.5 and 2.8 t ha^{-1} after 2 years of *S. sesban* and pigeonpea fallows, respectively, compared with 1.1 and 2.2 t ha^{-1} of continuous maize without fertiliser and 2 years natural grass fallow, respectively, have been reported (Kwesiga *et al.*, 1994). Similarly, in Malawi, Mac Coll (1989) showed that grain yield of the first crop of maize following pigeonpea averaged 2.8 t ha^{-1} higher than that following continuous maize supplied with 35 kg N ha^{-1} each year.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The experiment was conducted during the 1998/1999 season using an existing trial, which was established in November, 1996 at Msekera Research Station in the eastern province of Zambia. The station lies at an altitude of 1030 m above sea level, longitude of 32°34' E and latitude 13°38' S (Commissaris, 1975).

3.2 Climate

The station experiences a unimodal rainfall pattern with an annual rainfall of 1092 mm extending from November to April. Most of the rainfall occurs in December, January and February. The rain season is followed by a dry cool season from May to August and a hot spell with low humidity in September and October. The mean monthly temperature for 22 years record is 28°C (Commissaris, 1975).

The mean annual relative humidity is 69% with a range of 50 to 88%, and the average annual sunshine hours are 7.2, with a range of 4.4 to 9.5 (Commissaris, 1975). The station belongs to agro-ecological zone II characterised by a growing period of 130-140 days estimated with a 70% probability (Commissaris, 1975). The mean annual rainfall and temperature data during the 1996/97 to 1998/99 crop-growing season at the experimental site are shown in Table 1

Table 1. Mean annual rainfall and temperature at Msekera experimental site from 1996-1999

Season	Rainfall (mm)	Min. temp. (°C)	Max. temp. (°C)
1996/97	927	13.3	32.3
1997/98	1077	13.8	32.5
1998/99	1209	14.6	31.2

3.3 Soils

The soils at the experimental site are composed of upland soils developed over biotite-hornblende gneiss parent material (Commissaris, 1975). The dominant soils are strongly weathered, very deep to shallow and well to moderately well drained.

A stone line may be found from 40 –60 cm, with few gravels usually found on the surface and common iron and manganese-coated gravels occur below 80 cm (Commissaris, 1975). In general, the surface texture for the experimental site is sandy clay loam with reddish brown top and subsoils, classified as Typic kandiustalf (USDA, 1975) or Haplic luvisols (FAO, 1988). Some soil chemical and physical properties are presented in Tables 2 and 3, respectively.

Table 2. Chemical properties of the soils at Msekera experimental site, November 1998

Depth (cm)	pH ($CaCl_2$)	Org. C (%)	Total N (%)	Available P (Bray 1) (mg kg^{-1})	Ex. K	Ex. Mg	Ex Ca
					(cmols (+) kg^{-1})		
0 - 20	4.5	1.18	0.06	5.13	1.01	0.08	0.19
20 – 40	4.6	1.18	0.03	3.03	0.48	0.13	0.28
40 - 60	4.7	0.57	0.01	1.30	0.43	0.13	0.27

Table 3. Physical properties of the soils at Msekera experimental site, November 1998

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture class (USDA)	Soil bulk density (g cm^{-3})	Total pore space (%)
0 - 20	67.1	8.3	24.7	Sandy clay loam	1.38	47.9
20 – 40	59.8	6.9	33.3	Sandy clay loam	1.59	40.0
40 - 60	54.0	8.7	37.3	Sandy clay	1.75	34.0

3.4 Experimental design and plot layout

A randomised complete block design (RCBD) comprising of five land-use systems (LUSs) and three replications was used, with gross plots of 10 x 10 m and net plots of 6 x 6 m. The site was previously under maize monoculture without inorganic fertilizer for three years before the trees were established in November 1996. The land use systems are shown in Tables 4.

Table 4. Cropping systems during the experimental period.

Land-use system	Seasonal year		
	1996/97	1997/98	1998/99
2 years *S. Sesban*	Tree fallow	Tree fallow	Maize
2 years Pigeonpea	Tree fallow	Tree fallow	Maize
2 years natural fallow	[1]Nf	Nf	Maize
Maize + fertilizer	[2]M+f	M+f	M+f
Maize - fertilizer	[3]M-f	M-f	M-f

[1]M+f = continuous fertilized maize (112 kg N ha^{-1}, 18 kg P and 17 kg K)
[2]M-f = continuous unfertilised maize
[3]Nf = natural regrowth

3.5 Fallow species

3.5.1 *Sesbania sesban* (L.) Merr.

S. sesban is a semi-deciduous, multistemmed, shrub or small tree. *S. sesban is* fast growing and can grow up to a highet of 8 m. Its bark is reddish-brown or green, and the young shoots are hairy. The leaves are compound type and 12 cm long. Each leaflet is 2 cm in width with narrow notched tips (Kwesiga and Beniest, 1998).

S. sesban is widely distributed in Zambia, being conspicuous on the flood plains of the Kafue flats, Bangweulu and Chambeshi swamps and in most river valleys. It can live in shallow water and has a capacity to fix 542 kg N ha^{-1} yr^{-1} (Simute, 1992) It can grow between an altitude of 0 and 2000 m above sea level. In Eastern province, it grows naturally around dams and dambos.

S. sesban is found in acid and saline soils. It tolerates both seasonal and permanent water logging (Simute, 1992). *S. sesban* is a prolific seeder with a high germination rate. Beetles (*Mesoplatys ochroptera)* often attack the shoots and its roots suffer from root-knot nematode (*Meloidogyne* spp.) attack. In wet conditions, it may become a weed. On drier farmlands, this tree normally lives for 2-3 years. It drops much of its foliage in the dry season (June-November) while maintaining vital growth, which makes incorporating the leaf litter easy. It is easy to cut and roots decompose quickly after cutting. It is not very palatable to livestock as compared with other browse or fodder, such as *Leucaena leucocephala* (Kwesiga and Beniest, 1998).

3.5.2 *Cajanus cajan* (L.) Millsp (Pigeonpea)

Pigeonpea (var. ICP 9145) is a long-duration, fusarium wilt resistant, high yielding, and dual-purpose pigeonpea variety released in Malawi in 1987. It is the first wilt-resistant pigeonpea variety released in Africa. The plants of ICP 9145 are compared, intermediate, and tall (215 cm). The stem is green and leaves are large, broad, thick, and dark green. The flowers of ICP 9145 are ivory-coloured. Its pods are long, green with purple streaks, and are borne in clusters at the branch terminals. There are 4-5 seeds in a pod (ICRISAT, 1994). It is widely grown on a variety of soils, but does not do well under salinity or waterlogging. It grows at altitudes of between 0-3000 m above sea level (Simute, 1992). It has the capacity to fix between 168-280 kg N ha^{-1} yr^{-1} (Simute 1992). It is susceptible to macrophomina stem canker (*Macrophomina phaseolina*) and root knot nematode (*Meloidogyne* sp) (ICRISAT, 1994). It is direct seeded and the seeds are highly susceptible to insect attack (Simute, 1992).

3.6 Management practices

3.6.1 Trees

S. sesban (prov. Chipata dam) fallow trees were planted in November 1996 from nursery raised bare rooted seedlings at the age of 5 weeks at a spacing of 1.0 x 1.0 m (10 000 trees ha^{-1}). Pigeonpea was direct seeded in the plots at the same time the *S. sesban* seedlings were transplanted into the field in November 1996 at a spacing of 1.0 x 0.50 m (20 000 trees ha^{-1}).

Trees were clear felled on 5th November 1998 at collar (ground) level after 2 years of fallow when the present study was conducted, while stumps and root systems were left below ground. The tree mulch was incorporated in the soil by hand hoeing.

3.6.2 Natural vegetation fallow

Predominant vegetation in the natural fallow were grasses of *hyperrhenia* spp. Other weed species included herbs of *Galinsonga parviflora.* (less than 2 %). After 2 years of fallow, the vegetation in natural fallow was incorporated into the soil by hand hoeing in their respective plots.

3.6.3 Maize

MM 604 hybrid maize (three way cross) was sown by hand at 30 cm within-row and 75 cm between-row spacing (44 444 plant ha^{-1}) in both fertilised and unfertilised plots (controls) at the time of fallow establishment in 1996. The plots were managed following the recommended agronomic practices for fertiliser application, weeding and harvesting. Fertilizer was applied at the rate of 20 kg N ha^{-1}, 18 kg P $ha^{-1}$and 17 kg K $ha^{-1}$of Compound-D (basal dressing) at sowing and 92 kg N ha^{-1} as urea (top dressing) at 4 weeks after sowing (WAP). At the end of the fallow period (2 years of tree growth) all the plots were planted with a maize crop on 29th November 1999 to compare the effects of the fallow on the subsequent crop. Maize was sown on the flat after the land had been hand hoed. Ridging was done at 6 WAP, as is the practice in this area.

3.7 Data collection and observations

3.7.1 Soil chemical properties

Measurement of soil ammonium and nitrate nitrogen

Soil samples were collected at fallow clearing in November 1996 and subsequent samples were collected during the cropping phase at 4, 6, 8 and 24 WAP the maize crop. Soil samples were collected with a locally manufactured metal sampler (4.2 cm diameter galvanized iron pipe) from 0-20, 20-40, and 40-60 cm soil depths. The locally manufactured metal sampler was used because the soils at the site were too hard in the dry season to be sampled by a conventional auger The metal sampler was driven to each specific depth using a hammer and was then taken out of the ground to extract the soil samples. Samples were collected from 8 locations in the plot and composited (mixed). Samples were packed in plastic bags and transported to the laboratory immediately. For determination of ammonium and nitrate nitrogen, about 20 g of field moist soil was extracted with 100 ml of 2 *M* KCl. The samples were shaken on a horizontal shaker for 1 hour at 150 oscillations min^{-1}, followed by gravity filtering with pre-washed Whatman No. 5 filter paper. A second sub-sample of soil was dried at 105°C for 24 hours to determine the dry weight of the extracted soil. NH_4^+ was analysed by the modified calorimetric method of Dorich and Nelson (1984) and NO_3^- by the NH_4^+ calorimetric method, following cadmium reduction (Cataldo *et al.,* 1975). The sum of ammonium-N and nitrate-N constitutes the total inorganic-N. Soil bulk density values from the same profile depths were used to convert ammonium-N and nitrate-N data from mg N kg^{-1} to kg N ha^{-1}.

Laboratory incubation

Laboratory incubation was done to characterize the nutrient release patterns of *S. sesban* (fresh leaves + litter), *S. sesban* litter alone, pigeonpea (fresh leaves + litter), pigeonpea litter alone, and dry grass (litter). Fresh leaves collected from the two species were sun dried for 2-3 days and oven-dried at 65 °C for 48 hours to determine the dry matter (DM) content. The soil for incubation was taken from the top 20 cm of the mineral soil layer near the trial site and analysed for particle size distribution, pH, total exchangeable bases, organic carbon, NPK by the method described by Anderson and Ingram (1993). Soil was air-dried and sieved through a 2-mm mesh screen. The soil was first leached with deionised water at a water-to-soil ratio of 1 to 5 and left to drain until 50 % water holding capacity was achieved by constant weighing. The soil was mixed with the leaves and litter of the two fallow species that had been ground to pass through 1-mm mesh at the rate of 1.35 g per 270 g soil. This rate is equal to 5 t ha^{-1}, which is applied in the field. The treatments were 1) Soil mixed with *S. sesban* fresh leaves + *S. sesban* litter; 2) Soil mixed with *S. sesban* litter alone; 3) Soil mixed with pigeonpea fresh leaves + pigeonpea litter; 4) Soil mixed with pigeonpea litter alone; 5) Soil mixed with dry grass (litter) from the natural vegetation plots and 6) Soil alone (control). The soil, leaves and litter were thoroughly mixed and placed in 350 ml aluminium moisture cans. The moisture cans were covered with aluminium foil that was perforated to allow air movement and they were placed in the incubator at 28 ^{0}C throughout the experiment period. The soil moisture content was maintained at 50% water holding capacity by weight through periodic additions of deionised water using a syringe and constant weight adjustment. Each treatment was replicated three times in a completely randomised design. Nitrogen fractions (NH_4^+-N and NO_3^--N) were analysed immediately after addition of plant material (at week 0) and once every week for 10 weeks. by the method described above. The results were reported as cumulative net mineralizable total nitrogen (NO_3^- + NH_4^+) in mg N kg^{-1}.

Measurement of soil phosphorus, pH, organic carbon, calcium, magnesium, and potassium

Available phosphorus was extracted from the soil with a mixture of NH_4F and HCl (Bray 1 Method). The P was then determined colorimetrically by the ammonium molybdate procedure and ascorbic acid (Bray and Kurtz, 1945).

Soil pH was determined electrometrically in soil suspension prepared with solution of 0.01 M $CaCl_2$ at a soil to solution ratio of 1:2.5. The pH values were measured with a glass electrode and a pH meter (Mc Lean, 1982).

Soil organic carbon was determined by the dichromate method (Walkley-Black 1934). Exchangeable bases were extracted with a buffered neutral 1 N ammonium acetate solution. Potassium (K) was determined by flame photometry and calcium (Ca), magnesium (Mg) by atomic absorption (Chapman, 1965; Doll and Lucas, 1973).

3.7.2 Soil physical properties

Determination of particle size analysis (texture)

The hydrometer method (Gee and Bauder, 1986) was used to determine the particle size distribution (clay, silt and sand) in the sample after these were dispersed in a solution of Sodium hexametaphosphate (Calgon) at the beginning of the experiment. The soil texture was then read off from the standard textural triangle chart.

Determination of soil bulk density and porosity

Triplicate undisturbed core soil samples for soil bulk density and air-filled porosity were taken from three soil layers (0 - 20, 20 - 40 and 40 - 60 cm soil depth) using standard core rings 100 cm^3 (Blake and Hartge, 1986) at 4 weeks after planting (WAP) maize and crop harvest. Bulk density (ρ_b) and Total pore volume (porosity) (TPV) was calculated from Equation I and II, respectively. The particle density (ρ_s) of 2.65 g cm^{-3} was assumed to be for these soils.

$$\rho_b = \frac{Weight \quad of \quad oven \quad dry\, soil}{Volume \quad of \quad soil \quad (solids \quad + \; pores)}$$ Equation I

$$TPV \quad = \left(1 \; - \; \frac{\rho_b}{\rho_s} \right) \cdot 100$$ Equation II

Determination of aggregate stability and size distribution

Aggregate size distribution and stability was determined by the methods of De Leenheer and De Boodt (1958). Soil clods were dug at random from 0-20 cm depth at fallow clearing and at harvest using a hand hoe. The soil clods were hand broken and dried at room temperature. The sample was sieved through a 9.50 mm sieve and retained on the 0.30 mm opening sieve. A Yoder type of sieving machine (Yoder 1936), which raises and lowers a nest of sieves through water approximately 3.81 cm, 30 times per minute was used. A set of sieves with 4.75, 2.0, 1.0, 0.50 and 0.30 mm openings, with a receiver at the bottom, were used.

An air-dry sample of 500 g was placed gently in a sieve with 4.75 mm openings. The set of sieves were lowered up and down in water for five minutes. Fractions obtained on each sieve and retained was oven dried at 105°C for 48 hours and weighed. The oven-dry aggregates were expressed as mean weight diameter (MWD) of aggregates and percent of aggregates retained on each sieve. The MWD of soil aggregates was calculated using equation III

$$MWD = \frac{\sum_{i=1}^{i=n} \overline{\mathrm{x}}_{\mathrm{i}} . w_i}{\sum_{i=1}^{i=n} w_i}$$ Equation III

Where $\bar{x}_i$ is the mean diameter of fraction, i

w_i is the weight of the corresponding aggregate fraction, i.

Determination of soil Penetrometer resistance

Penetration resistance was measured with a hand penetrometer type "Bush soil penetrometer SP1000, version 1.0". The penetrometer probe of 12.83 mm diameter with a cone semi-angle of 60^0 was pushed to a depth of 50 cm, and the resistance offered by the soil was recorded at 2 cm interval by digital balance. Five insertions in the net plot were measured at 4 WAP and at crop harvest.

Determination of soil-water content

A calibrated neutron probe was used to measure volumetric soil-water content in 10 cm increments to a depth of 100 cm at fallow clearing and biweekly during the cropping phase, from all the plots. One aluminium access tube was installed in the center of the 10 x 10 m plot. Neutron probe calibration was based on simultaneous probe readings and gravimetric measurements. Soil water storage in the 100 cm soil profile was calculated based on equation IV:

$$S_{0-100} = \int_0^{100} \theta dz \qquad \text{Equation IV}$$

Where: S = Water storage in 100 cm soil profile

θ = Volumetric water content at depth z

Determination of water infiltration rate

Infiltration rates were monitored at fallow clearing and crop harvest during the dry season in all the plots. The Double Ring Infiltrometer method (Bouwer, 1986) was used to measure infiltration rates in the plots. Water measurements were recorded for three hours at 0, 5, 10, 15, 20, 30, 45, 60, 90, 120, 150 and 180 minutes intervals. The average readings were used to calculate infiltration and cumulative water intake per plot using Kostiakov (1932) model (Equation V and VI) and Philips (1957) model (Equation VII and VIII). Philips (1957) model was used to measure Sorptivity (S) and Transmissivity (A) of the soil. The capacity of a homogeneous soil to absorb or release water is known as sorptivity the parameter 'S' in the Philips equation.

$$i = akt^{a-1}$$ Equation V

Where: i = infiltration rate in cm hr^{-1}

t = time in minutes

a** and **k are constants determined empirically

$$z = kt^{a}$$ Equation VI

Where: z = cumulative depth infiltrated in mm

$$\mathrm{I} = \mathrm{St}^{0.5} + \mathrm{At}$$ Equation VII

Where: S = Sorptivity

A = Transmissivity

$$\mathrm{i} = \frac{\mathrm{dI}}{\mathrm{dt}} = {}_{0.5}\mathrm{St}^{-0.5} + \mathrm{A}$$ Equation VIII

3.7.3 Trees, natural vegetation and crop biomass

Total above ground biomass of natural vegetation and trees (leaves, twigs and litter) were measured at fallow clearing. Total-N in grass, leaves and litter was analysed by micro-kjeldahl digestion followed by distillation and titration (Anderson and Ingram, 1993).

Nitrogen uptake was assessed in the plant dry matter (DM) measured at 4, 6, 8 and 24 WAP (at harvest in grain and stover). Five plants were cut at ground level in each net plot at random using a pair of scateurs. The plants were weighed, chopped and taken to the laboratory in labelled paper bags. Samples were then oven-dried at 70^0C for 72 hours and the dry weights recorded as being the plant dry matter. The total DM per plant was calculated as the average for the five maize plants. Total-N uptake in the plant tissue was analysed by micro-kjeldahl digestion followed by distillation and titration (Anderson and Ingram, 1993). Maize grain and stover yields were measured at harvest (24 WAP). The total harvested area was 36 m^2. Moisture was determined from the sub-samples of 16 cobs, which were used to correct the weights to 13 % moisture content.

3.8 Data analysis

Data collected on soil physical and chemical properties, maize growth and yield were analysed using GENSTAT version 5 (Genstat 5 Committee, 1988). For all significant means at $P \leq 0.05$, Duncan's Multiple Range Test (Gomez and Gomez, 1984) was used to separate the means. Simple regression and correlation analysis, based on plot-wise data, were determined for linear relationship between maize grain yield and nitrate-N uptake; and dry matter and total-N uptake.

CHAPTER FOUR

RESULTS

4.1 Biomass production

Table 5 shows above ground biomass for natural fallow, *S. sesban* and pigeonpea LUS at 24 months (fallow clearing). Significant differences ($P \leq 0.05$) were observed in the survival rates, wood and litterfall & weeds at fallow clearing. At 24 months the highest survival rates were recorded in *S. sesban* (91.7%), while pigeonpea had only 31.0%. No significant differences were observed in leaf & twigs at fallow clearing. *S. sesban* produced the highest wood biomass as compared with pigeonpea planted fallow system (Table 5). High weed & litterfall biomass was recorded in natural fallow (Table 5). Similar to survival, high total biomass was recorded in *S. sesban* fallows (Table 5). The wood biomass, which was harvested from the S. sesban and pigeonpea fallows, were removed from the plots and used as fuel wood.

Table 5. Above ground biomass production of *S. sesban,* pigeonpea and natural fallow at 24 months after fallow establishment in Chipata, Zambia

Parameter	Land use system			Mean	*S.e.d*
	S. sesban	Pigeonpea	Natural fallow		
Survival (%)	91.7a	31.0b	+	61.3	10.7
Leaves + twigs (t ha^{-1})	0.19a	0.23a	+	0.2	0.2
Wood(t ha^{-1})	16.6a	8.3b	+	12.8	2.9
Litterfall + weeds(t ha^{-1})	3.9b	3.5c	6.8a	4.7	0.1
Total biomass(t ha^{-1})	20.7a	12.0b	6.8c	13.2	0.1

Means in the row followed by the same letter or letters are not significantly different at $P \leq 0.05$ based on the Duncan's Multiple Range Test
S.e.d = standard error of diffrence
+ = not quantified

4.2 Nitrogen dynamics

Nitrogen mineralization and immobilization

The organic materials used had C-to-N ratio ranging from 14.7 to 69 for *S. sesbania* fresh leaves and natural grass, respectively (Table 6). The N concentration ranged from 0.62 to 3.09 % for natural fallow and *S. sesban*, respectively (Table 6).

Table 6. Chemical compositions of organic materials used for incubation study at Msekera, Chipata-Zambia

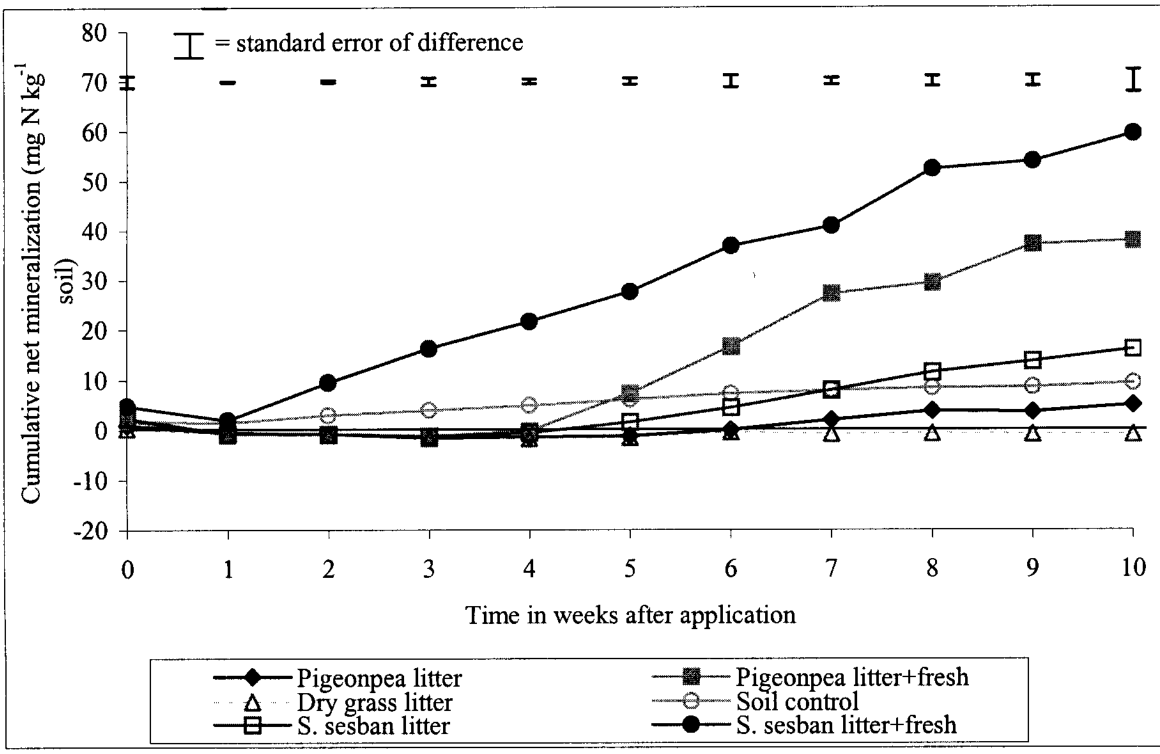
Land-use system	Carbon %	Nitrogen %	Carbon to Nitrogen ratio
Pigeonpea fresh alone	45	2.98	15.1
Pigeonpea litter alone	45	1.36	33.1
Pigeonpea (fresh leaves + litter) mixture	45	2.10	21.4
S. sesban fresh leaves alone	45	3.09	14.7
S. sesban litter alone	45	1.28	35
S. sesban (fresh leaves + litter) mixture	45	2.4	18
Natural fallow litter alone	43	0.62	69

Litter = dry leaves or senesced leaves

The quality of leaves and litter significantly affected the N release pattern throughout the 10-week incubation period. After 10 weeks of incubation, the cumulative net N mineralization ranged from 5.1 to 59.4 mg N kg^{-1} soil for pigeonpea litter only and *S. sesban* (fresh leaves + litter) mixture, respectively (Figure 1).

Cumulative net immobilization of 0.8 mg N kg^{-1} soil was observed at end of the incubation period in natural grass litter (Figure 1). Between week 1 and 4 there was net immobilization in pigeonpea (fresh leaves + litter) mixture and *S. sesban* litter alone. Pigeonpea litter alone had a cumulative net immobilization from week 1 to 5.

Figure 1. Cumulative amount of net N mineralised as affected by quality of multipurpose tree leaves and litter during 10-week incubation period at Msekera, Chipata-Zambia.



Nitrogen inputs and pre-season soil mineralizable nitrogen as affected by land-use systems and soil depth at fallow clearing, (November 1998)

At fallow clearing the litterfall, twigs and leaves were incorporated in the soil and contributed 56 kg of N and 54 kg of N per ha to the *S. sesban* and pigeonpea fallow systems, respectively (Table 7). On the other hand natural fallow system only contributed 42 kg of N per ha to the fallow effect (Table 7). There were significant differences in inorganic nitrate-N between treatments at each depth (Table 7). Continuous fertilized maize had the highest pre-season soil inorganic nitrate-N at all soil depths. At 0-20 cm soil depth, pre-season soil inorganic nitrate-N was in the order of: fertilized maize (M+f) ≥ pigeonpea = *S. sesban* ≥ unfertilised maize (M-f) = natural fallow (Nf). In the 20-40 cm soil layer the order was: M+f ≥ pigeonpea = M-f = *S. sesban* ≥ Nf. While at 40-60 cm soil depth pre-season soil inorganic nitrate-N had the following trend: M+f > *S. sesban* ≥ M-f =

pigeonpea ≥ Nf. Higher amounts of pre-season soil inorganic nitrate-N were found at 40-60 cm soil depth than 20-40 cm depth in M+f (4.74 mg N kg^{-1}), *S. sesban* (2.07 mg N kg^{-1}) and M-f (1.81 mg N kg^{-1}) as compared with the 20-40 cm soil depth (Table 7).

Regression analysis showed that pre-season soil inorganic nitrate-N in 0-20 cm, 0-40 cm and 0-60 cm soil layer was significantly correlated ($p \leq 0.001$) to grain yield (R^2 = 0.70, 0.67 and 0.69, respectively) (Figure 2a, b and c).

Inorganic total-N in the top 0-20 cm and 20-40 cm soil layers was not significantly affected by the LUS, but fertilized maize was significantly different from other LUS at 40 –60 cm soil depth (Table 7).

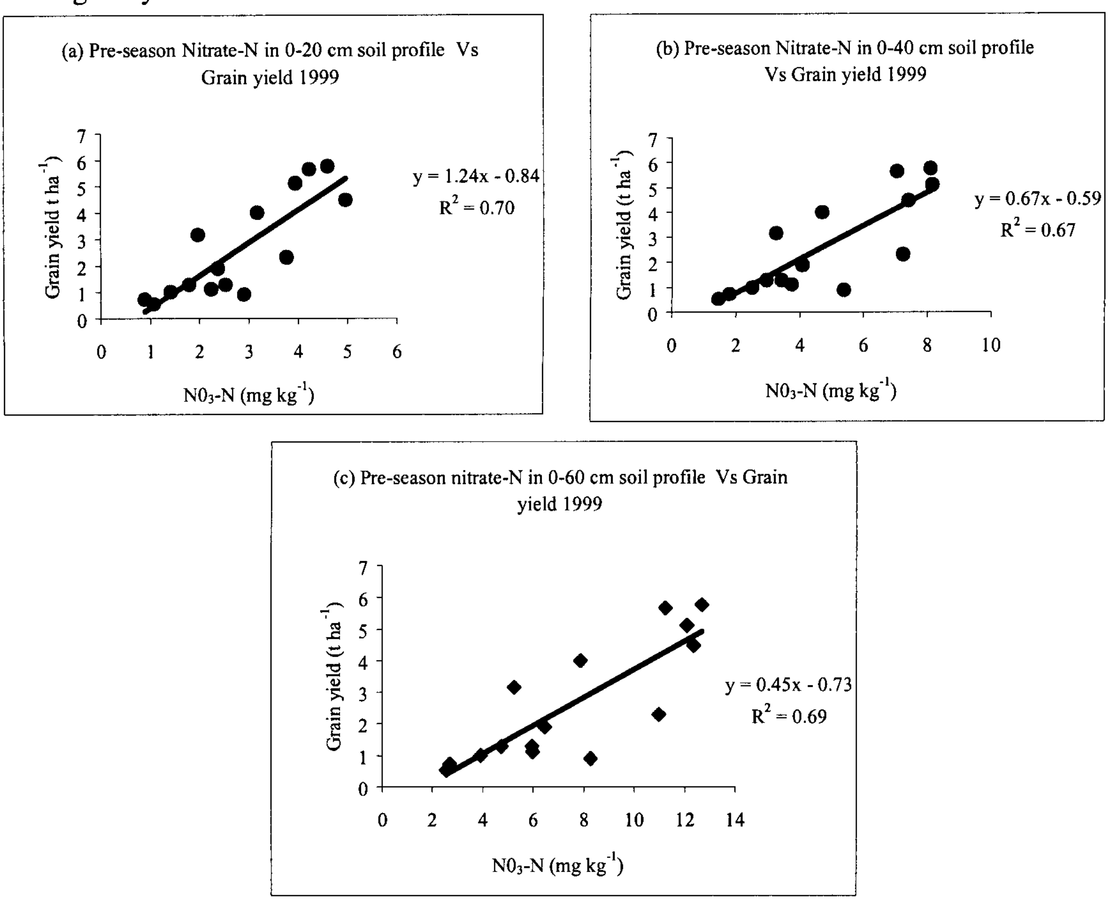
Table 7. Nitrogen inputs and pre-season soil mineralizable inorganic nitrogen as affected by land-use system and soil depth.

Treatment	Nitrogen inputs kg ha^{-1}	Nitrate (mg kg^{-1})			Total-N (mg kg^{-1})		
		0-20	20-40	40-60	0-20	20-40	40-60
*Pigeonpea	54.5	3.49ab	2.37ab	1.25bc	7.14ab	4.88ab	3.36b
*Natural fallow	42.2	1.49b	0.74c	0.59c	4.58b	2.88b	2.23b
Cont. Maize +fert	112	4.24a	3.52a	4.74a	8.32a	5.52a	7.73a
Cont. Maize – fert	0	2.18b	1.70bc	1.81bc	5.29ab	4.23ab	3.41b
**S. Sesban*	55.8	2.49ab	1.52bc	2.07b	6.70ab	3.37ab	4.04b
Mean	-	2.78	1.97	2.09	6.40	4.18	4.15
SED	-	0.84	0.58	0.56	1.29	0.94	0.98
CV%	-	36.9	36.2	32.5	24.7	27.6	29.0

Means in a column followed by the same letter or letters are not significantly different at P≤0.05 based on the Duncan's Multiple Range Test
*Nitrogen inputs = Biomass added at fallow clearing (litter, fresh leaves and twigs only)
SED = Standard error of difference
CV% = Coefficient of variation percent

Similar to pre-season soil inorganic nitrate-N regression analysis, inorganic total N regression analysis also showed that inorganic total N in 0-20 cm, 0-40 cm and 0-60 cm soil layers was significantly correlated ($p \leq 0.05$) with grain yield (R^2 = 0.70, 0.66 and 0.70), respectively.

Figure 2. Relationship between pre-season soil mineralizable inorganic nitrogen and maize grain yield.

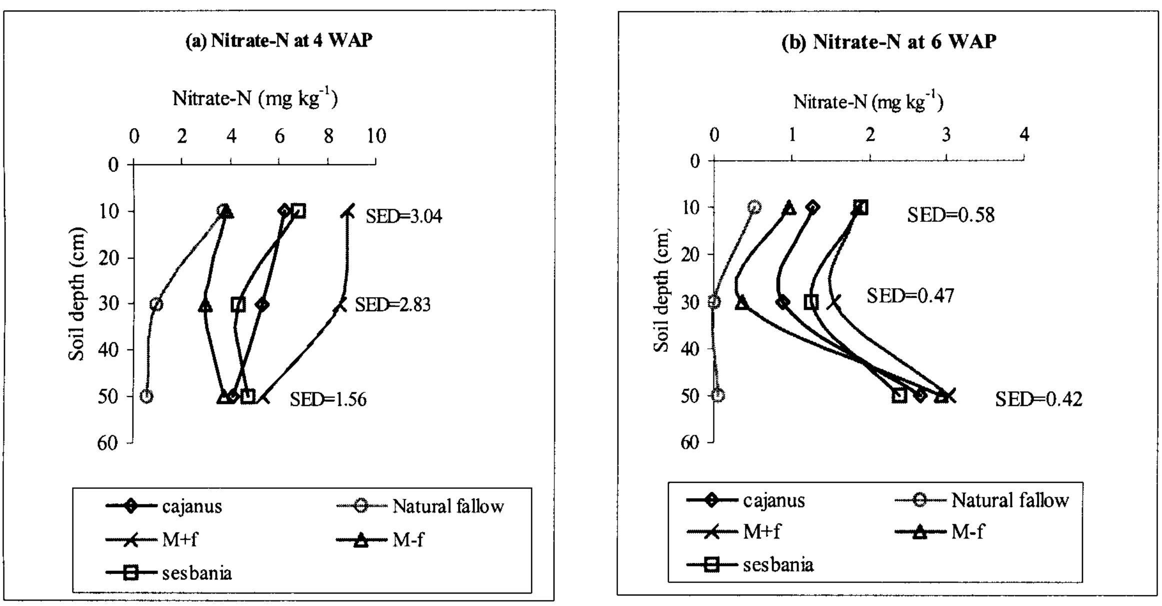


Soil mineralizable inorganic nitrogen at 4 and 6 WAP as affected by LUS and soil depth

Inorganic nitrate-N and inorganic total-N at 4 WAP was not affected by the LUS ($p \geq 0.05$). Inorganic nitrate-N at different depths was significantly different ($p \leq 0.05$) in all LUS. In all the LUS, except unfertilised maize and *S. sesban*, showed a decreased inorganic nitrate-N with increasing depth (Figure 3a).

Inorganic nitrate-N at 6 WAP was only significantly different (P≤0.05) at 40-60 cm soil depth. High concentrations of inorganic nitrate-N were found in the 40-60 cm soil depth in all LUS as compared with the 20-40 cm soil depth (Figure 3b). On the other hand, inorganic total N at 6 WAP was only significantly affected by the LUS in the 0-20 cm and 40-60 cm soil depths (p≥0.05). Inorganic total N in the top 20 cm soil layer had the following trend: M+F > *S. sesban* > pigeonpea > NF > M-F.

Figure 3. Soil mineralizable inorganic nitrogen at 4 and 6 WAP as affected by land-use systems and soil depth

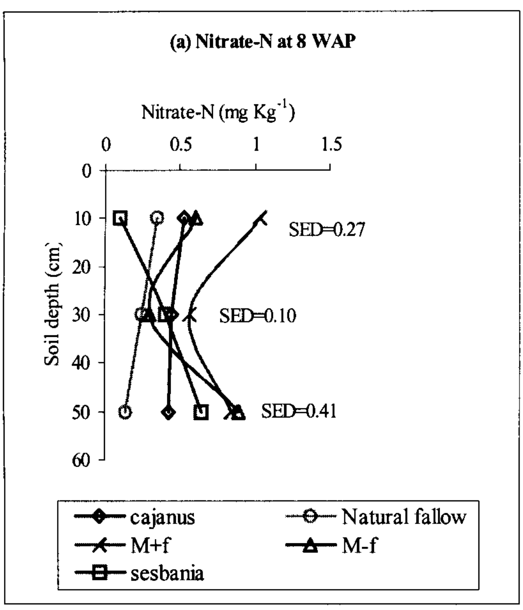


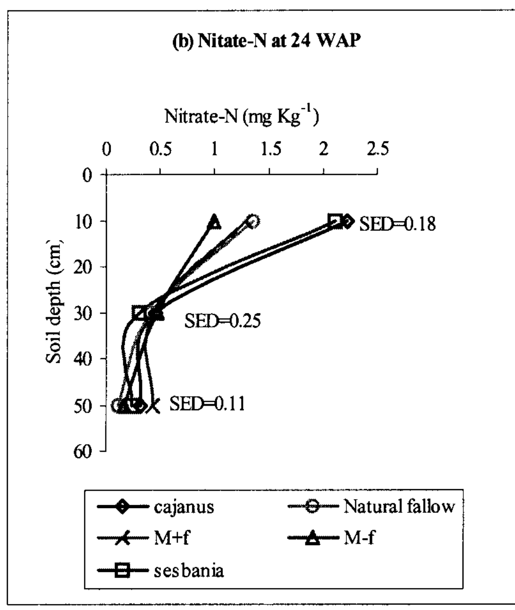
Soil mineralizable inorganic nitrogen at 8 and 24 WAP as affected by land-use system and soil depth

At 8 WAP soil inorganic nitrate-N were significantly affected by the LUSs (Figure 4a). Soil inorganic nitrate-N in the 0-20 cm soil layer was in the order: M+f > M-f ≥ pigeonpea >Nf > *S. sesban* (Figure 4a). On the other hand in the 40-60 cm soil depth the order was: M+f ≥ M-f > *S. sesban* > pigeonpea >Nf (Figure 4a).

Inorganic nitrate-N at 24 WAP in the top 20 cm soil depth was significantly different ($P \leq 0.05$) in the different LUS. Pigeonpea had the highest amounts of 2.22 mg N kg^{-1}, which was not significantly different from the *S. sesban* (2.11 mg N kg^{-1}) LUS. The lowest concentration of inorganic nitrate-N was in the unfertilised maize LUS (0.99 mg N kg^{-1}), but was not significantly different from the M+f and Nf LUS. Inorganic nitrate-N at 24 WAP in 0-20 cm soil depth was highly significantly different ($p<0.01$) in all LUS. Soil inorganic nitrate-N was higher in the 0-20 cm soil depth as compared with the subsequent soil depths.

Figure 4. Soil mineralizable inorganic nitrogen at 8 and 24 WAP as affected by land-use systems and soil depth

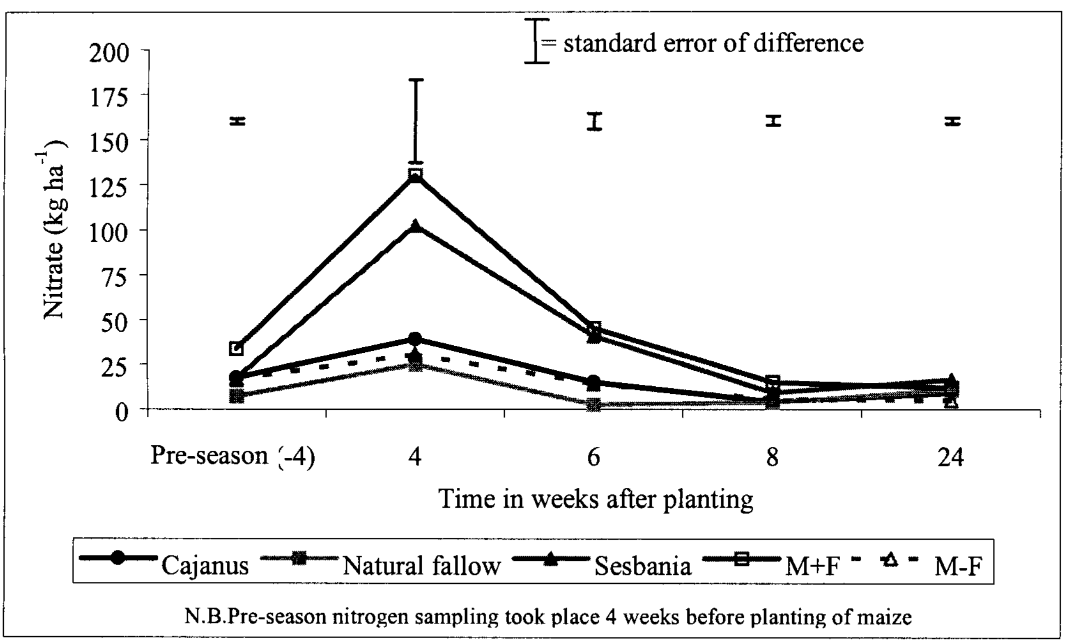




Seasonal soil inorganic nitrate nitrogen in 0-60 cm soil profile as affected by land-use system during the growing season

Figure 5 shows the sum of soil inorganic nitrate in the 0-60 cm soil profile at the 5 sampling times during the season for the different LUSs. There were high amounts of inorganic nitrate nitrogen in the fertilized control (33.8 kg ha^{-1}), followed by the pigeonpea fallow (17.5 kg ha^{-1}) at fallow clearing. The least amounts of inorganic nitrate-N were in the natural fallow control (7.3 kg ha^{-1}). After a period of 8 weeks, the inorganic nitrate nitrogen in all LUS accumulated rapidly with the highest being recorded in the fertilized control (130 kg ha^{-1}). The seasonal inorganic nitrogen pattern at 4 WAP followed the following order: M+f > *S. sesban* >pigeonpea > M-f > Nf. After a period of 6 WAP, the inorganic nitrate-nitrogen steadily declined in all LUS, with the highest being recorded in the fertilized control (45.0 kg ha^{-1}). At 6 WAP and 8 WAP, the inorganic nitrate-nitrogen followed the same pattern as that recorded at 4 WAP. At crop harvest, the inorganic nitrate-nitrogen was not significantly different among the LUS.

Figure 5. Seasonal soil mineralizable inorganic nitrate nitrogen in 0-60 cm soil profile as affected by land-use systems during the growing season

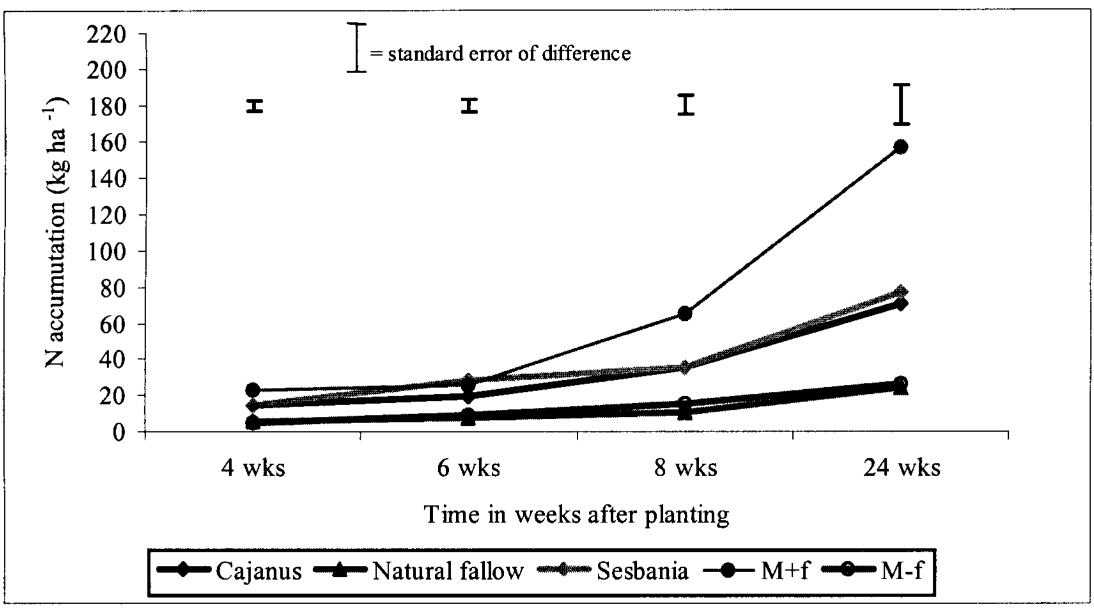


4.3 Dry matter and seasonal nitrogen accumulation in maize plants

Figure 6 shows seasonal N accumulation in maize above ground biomass during the growing season. High N accumulation was observed from 4 to 6 WAP in the *S. sesban*

LUS (13.9 kg N ha^{-1}), as compared with fertilized plot that only accumulated 2.4 kg N ha^{-1}. Between 6 WAP to 8 WAP, there was a sharp rise of N accumulation in fertilized maize. Fertilized maize accumulated the highest amount of N (39 kg N ha^{-1}). On the other hand, *S. sesban* and pigeonpea had only 7.0 kg N ha^{-1} and 15.8 kg N ha^{-1}, respectively (Figure 6). The maximum N accumulation in maize aboveground biomass at 24 WAP averaged 156.9 kg N ha^{-1} and 77.0 kg N ha^{-1} for continuous fertilized maize and *the S. sesban* LUS, respectively, with corresponding grain yields of 5.51 and 3.02 t ha^{-1}.

Figure 6. Seasonal nitrogen accumulation in maize above ground biomass during the growing season under different land-use systems



Maize dry matter (DM) was not significantly affected by the different LUS during the growing season at 4, 6, 8 and 24 WAP (Table 8). At 4 WAP the DM ranged from 0.25 t ha^{-1} to 0.73 t ha^{-1} for the M-f and M+f, respectively (Table 8). At 8 WAP the DM ranged from 0.79 t ha^{-1} to 4.26 t ha^{-1} for the Nf and M+f, respectively (Table 8). On the other hand, at 24 WAP the DM was in the order of: M+f > *S. sesban* ≥ pigeonpea ≥ M-f = Nf (Table 8).

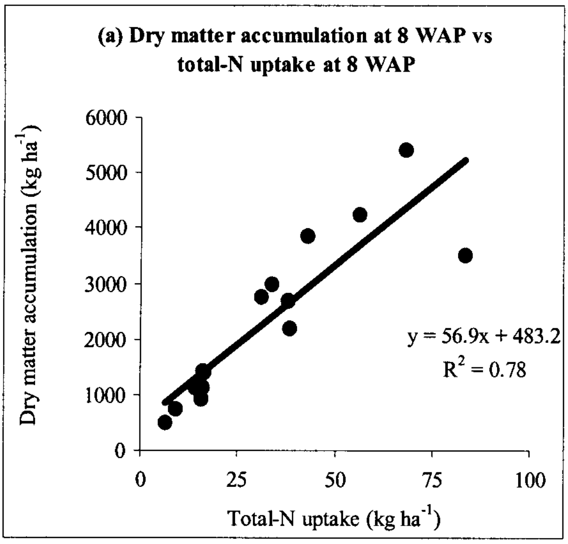
Regression analysis showed that dry matter accumulation at 8 WAP and 24 WAP was significantly correlated ($p \leq 0.001$) to nitrogen uptake at 8 WAP ($R^2=0.78$) and 24 WAP ($R^2=0.98$), respectively (Figure 7a and b).

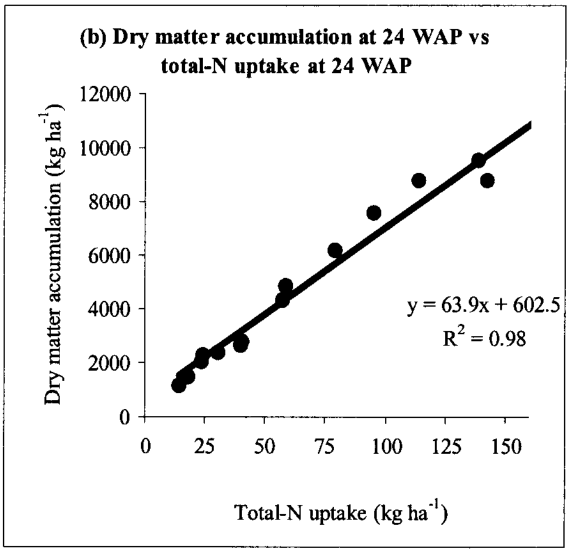
Table 8. Maize dry matter (DM) at different times during the growing season under different land-use systems

Land use system	Dry matter at different times (t ha^{-1})			
	4 WAP	6 WAP	8 WAP	24 WAP
Pigeopea	0.56ab	1.19ab	2.72ab	5.48bc
Natural fallow	0.25b	0.48b	0.79c	1.78c
Maize with fertilizer	0.73a	1.54a	4.26a	9.52a
Maize without fertilizer	0.19b	0.63b	1.32bc	2.26c
S. sesban	0.57ab	1.55a	2.55ab	6.02b
Mean	0.48	1.08	2.33	5.02
SED	0.23	0.44	0.84	1.53
CV%	46.2	47.4	42.6	35.8

Means in a column followed by the same letter or letters are not significantly different at $P \leq 0.05$ based on the Duncan's Multiple Range Test
SED = Standard error of difference
CV% = Coefficient of variation percent

Figure 7. Relationship between dry matter and nitrogen uptake by maize plants at 8 and 24 WAP during the growing season

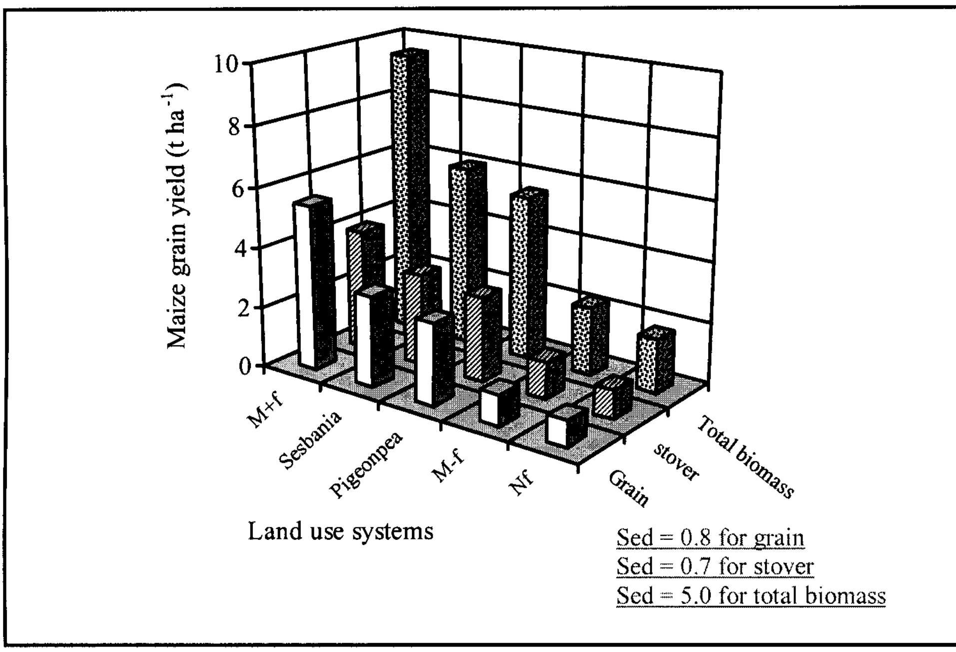




4.4 Maize yields

There were significant differences (P≤0.05) between the treatments and maize grain yield. The highest grain yield of 5.51 t ha^{-1} was recorded in continuous maize with fertilizer followed by *S. sesban* (3.02 t ha^{-1}) and the least was in natural fallow (0.85 t ha^{-1}) (Figure 8).

Figure 8. Maize yields as affected by different land-use systems



4.5 Soil bulk density and porosity

Soil bulk density and porosity in all soil layers, measured at both fallow clearing and at crop harvest were not significantly different (P≤0.05) among the LUS (Table 9). However, the tendency was that there was low soil bulk density in the *S. sesban* LUS. During the cropping phase, the soil bulk density in the top 20 cm soil layer increased by 37.7% and 17.6% in natural fallow and *S. sesban* LUS, respectively, while pigeonpea and unfertilized maize increased by 20.5% and 17.5%, respectively. The increase in soil bulk density with duration of cultivation (from fallow clearing to crop harvest) for 0-20 cm soil depth ranged from 0.23 g cm^{-3} for M-f to 0.43 g cm^{-3} for the natural fallow LUS.

As was the case with soil bulk density, porosity was not significantly affected by the different LUS at both fallow clearing and crop harvest (Table 9). Even then, there were reductions in the porosity with duration of cultivation in the natural fallow LUS. The decrease in porosity with the duration of cultivation (from fallow clearing to crop harvest) in the 0-20 cm soil layer ranged from 8.4% in fertilized maize to 16.3% in the natural fallow.

Table 9. Effects of land-use systems on soil bulk density and porosity at fallow clearing and crop harvest.

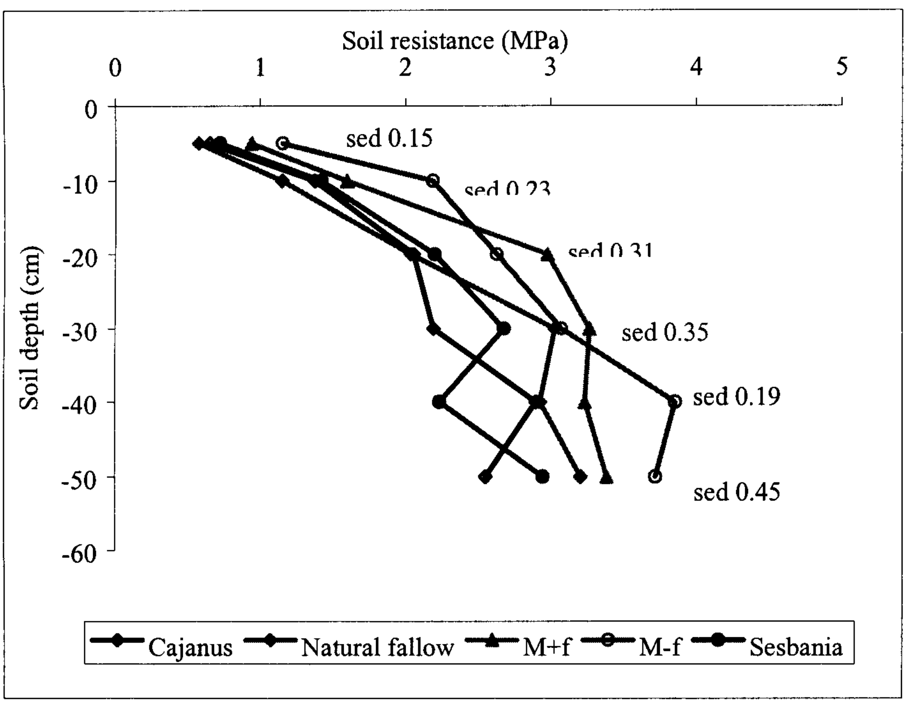
Land-use system	Bulk density (g cm^{-3})		Porosity (%)	
	At fallow clearing	At crop harvest	At fallow clearing	At crop harvest
S. sesban	1.25a	1.47a	52.7a	44.7a
Pigeonpea	1.22a	1.47a	53.9a	44.6a
Natural fallow	1.14a	1.57a	57.1a	40.8a
Continuous M+F	1.31a	1.54a	50.4a	42.0a
Continuous M-F	1.32a	1.55a	50.0a	41.5a
Mean	1.25	1.52	52.8	42.7
SED	0.10	0.05	3.84	1.97
CV%	10.0	4.2	8.9	5.7

Means in a column followed by the same letter or letters are not significantly different at $P \leq 0.05$ based on the Duncan's Multiple Range Test
SED = Standard error of difference
CV% = Coefficient of variation percent

4.6 Penetration resistance

The cone penetration resistance measurements at 4 WAP increased with depth and were significantly different ($P \leq 0.05$) at 5 cm, 10 cm and 40 cm soil depths. The lowest resistance at 5 cm soil depth was recorded in the pigeonpea LUS (0.65 MPa) followed by natural fallow (0.58 MPa). The highest resistance was in continuous M-f LUS (1.15 MPa) (Figure 9). At 10 cm soil depth, cone penetration resistance was in the order of M-F > M+F > *S. sesban* > pigeonpea > NF. At 40 cm soil depth the order was M-F > M+F > NF > pigeonpea > *S. sesban*. Similar to soil bulk density, the penetration resistance also increased with increase in soil depth and duration of cultivation. On the other hand, the cone penetration resistance measured at 24 WAP increased with depth and was only significantly different ($P \leq 0.05$) at 10 cm soil depths.

Figure 9. Effects of land-use systems on soil penetration resistance measured at 4 WAP



4.7 Soil organic carbon

There were no significant differences in soil organic carbon (SOC) among the LUS at all soil depths, measured both at fallow clearing and end of crop harvest (Table 10). However, at fallow clearing the SOC to a depth of 0-20 cm ranged between 35.7 t C ha^{-1} with continuous maize without fertilizer to 46.9 t C ha^{-1} with *S. sesban* fallow. On the other hand, the SOC at crop harvest to a depth of 0-20 cm ranged between 31.4 t C ha^{-1} with continuous maize without fertilizer to 42.5 t C ha^{-1} with pigeonpea LUS. All land-use systems resulted in a decline in SOC over a period of 8 months. Similar to porosity, the SOC also decreased with increasing soil depth and the duration of the cultivation period.

Table 10. Soil organic carbon at fallow clearing and at maize harvest as affected by land-use systems and soil depth

Treatment	SOC (t C ha^{-1}), Nov 1998			SOC(t C ha^{-1}), June 1999		
	0-20	20-40	40-60	0-20	20-40	40-60
Pigeonpea	46.6a	41.0a	29.6a	42.5a	32.7a	17.6a
Natural fallow	44.3a	42.0a	38.7a	41.6a	39.3a	21.7a
Cont. Maize +fert	44.7a	40.6a	34.0a	38.6a	32.9a	30.5a
Cont. Maize – fert	35.7a	35.2a	32.8a	31.4a	33.2a	25.3a
S. sesban	46.9a	42.1a	40.6a	40.8a	40.2a	32.9a
Mean	43.6	40.2	35.1	39.0	35.7	25.6
SED	4.92	4.29	4.15	5.74	3.98	7.64
CV%	13.8	13.1	14.5	18.0	13.7	36.5

Means in a column followed by the same letter or letters are not significantly different at $P \leq 0.05$ based on the Duncan's Multiple Range Test
SOC = soil organic carbon
SED = Standard error of difference
CV% = Coefficient of variation percent

4.8 Aggregate stability and size distribution

The wet mean weight diameter (WMWD) was significantly affected by the LUS at fallow clearing and at crop harvest ($p \leq 0.01$). The highest mean WMWD's were recorded in the pigeonpea LUS at both fallow clearing and crop harvest, respectively. The least were recorded in continuous unfertilised maize (Table 11).

Table 11. Effect of land-use system on wet mean weight diameter

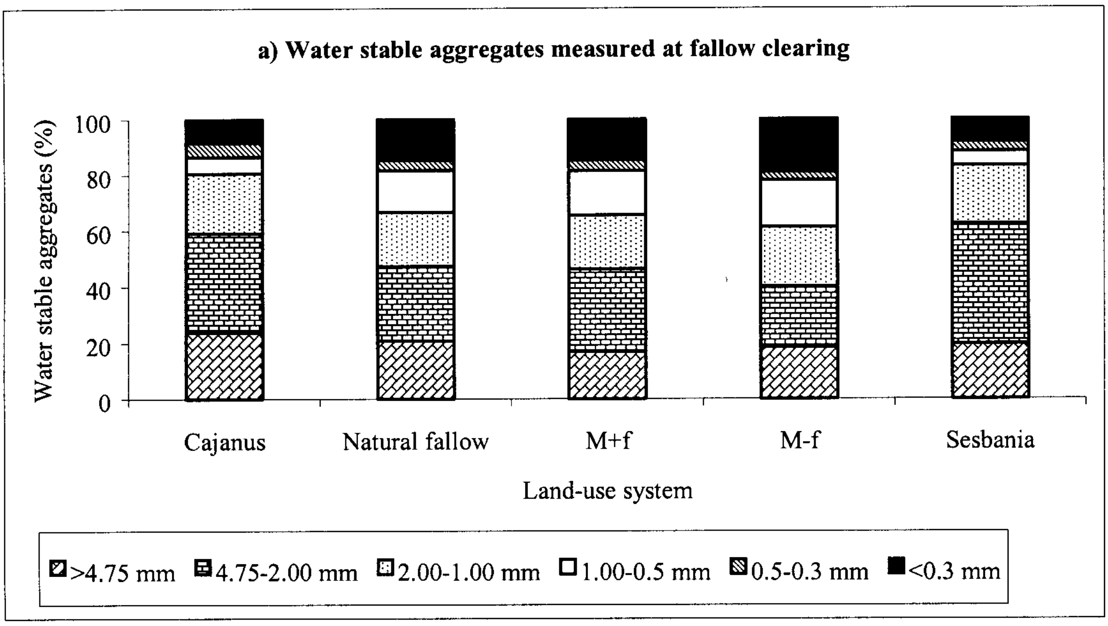
Land-use system	Mean Weight Diameter	
	At fallow clearing	At crop harvest
Pigeonpea	3.3a	3.0a
Natural fallow	2.8ab	2.6b
Cont. Maize +fertilizer	2.6b	2.3b
Cont. Maize – fertilizer	2.5b	1.7c
S. sesban	3.2a	2.6b
Mean	2.9	2.4
SED	0.18	0.14
CV%	7.7	6.9

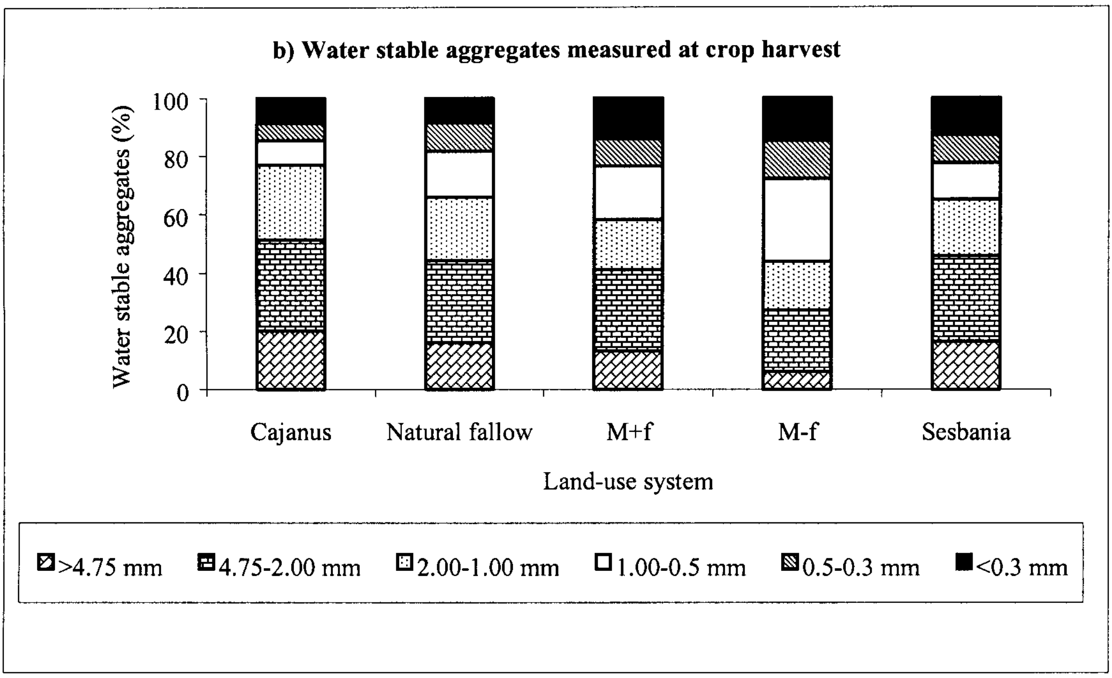
Means in a column followed by the same letter or letters are not significantly different at $P \leq 0.05$ based on the Duncan's Multiple Range Test
SED = Standard error of difference
CV% = Coefficient of variation percent

The percentages of aggregates larger than 2.00 mm (> 2.00 mm) were significantly affected by the LUS at fallow clearing and at crop harvest ($p \leq 0.01$). The distributions of water stable aggregates at fallow clearing for the different LUS are shown in Figure 10a. Water stable aggregates were only significantly different ($p \leq 0.01$) for those between 4.75 - 2.00 mm, 1.00-0.50 mm and less than 0.30 mm. The highest percentage of water stable aggregates greater than 2.00 mm at fallow clearing was recorded in the *S. sesban* LUS (83 %) followed by pigeonpea LUS (81 %). The least was recorded in continuous unfertilised maize (61 %) (Figure 10a).

Significant differences ($p<0.01$) were observed at crop harvest for the water stable aggregates greater than 2.00 mm among the LUS. The distributions of water stable aggregates at crop harvest for the different LUS are shown in Figure 10b. The highest percentage of aggregates (> 2.00 mm) was recorded in pigeonpea LUS (77 %) followed by natural fallow LUS (66 %). The least was recorded in unfertilised maize (44.0 %).

Figure 10. Effect of land-use system on water stable aggregates





4.9 Water dynamics

4.9.1 Infiltration

Significantly different ($P \leq 0.05$) infiltration rates were observed among the LUSs at both fallow clearing and crop harvest. At fallow clearing, the highest average infiltration rate at the end of 3 hours was recorded in natural fallow (31.6 cm hr^{-1}), while continuous maize without fertilizer had the least with 12.9 cm hr^{-1} (Table 12). On the other hand, at crop harvest, the highest average infiltration rate at the end of 3 hours was recorded in *S. sesban* (23.4 cm hr^{-1}) and the least was continuous maize without fertilizer (10.4 cm hr^{-1}) (Table 12).

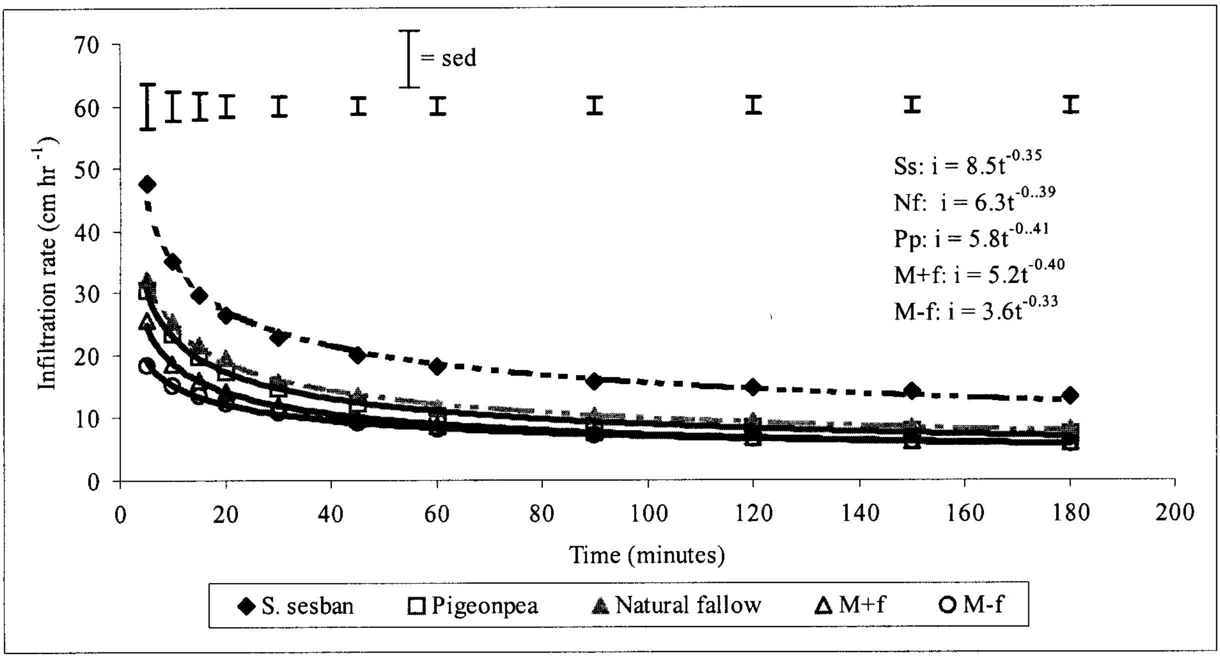
Table 12. Comparison of the average infiltration rate at fallow clearing and crop harvest in different land-use systems.

Land-use system	Average infiltration rate (cm hr^{-1})	
	At fallow clearing	At crop harvest
S. sesban	26.5a	23.4a
Pigeonpea	31.4a	14.7bc
Natural fallow	31.6a	16.0b
Continuous M+F	18.6b	12.0bc
Continuous M-F	12.9c	10.4c
Mean	24.2	15.3
SED	4.8	3.2
CV%	13.8	14.8

Means in a column followed by the same letter or letters are not significantly different at $P \leq 0.05$ based on the Duncan's Multiple Range Test
SED = Standard error of difference
CV% = Coefficient of variation percent

At crop harvest, the basic infiltration equilibrium rates at crop harvest were in the order of *S. sesban* > natural fallow > pigeonpea > M+f > M-f (Figure 11).

Figure 11. Effects of land-use system on infiltration rate of the soil at crop harvest



i = infiltration rate, t = time, Ss = *S.sesban*, Nf = natural fallow, Pp = pigeonpea, M+f = Maize with fertilizer, M-f = maize without fertilizer, sed = standard error of difference

Table 13 shows regression equations relating to infiltration rate based on Kostiakov's model and sorptivity and transmissivity characteristics computed on the basis of Philip's model, at fallow clearing and crop harvest. At fallow clearing the Kostiakov K values were in the order pigeonpea > Nf > *S. sesban* > M+f > M-f. On the other hand, Philips soil water sorptivity (S) values at fallow clearing were in the order pigeopea > Nf > *S. sesban* > M+f > unfertilized maize (Table 13). At crop harvest the Kostiakov K values were in the order *S. sesban* > Nf > pigeonpea > M+f > M-f (Table 13). On the other hand, Philips soil water sorptivity (S) values at crop harvest were in the order *S. sesban* > Nf > pigeonpea > M+f > M-f. (Table 13).

Table 13. Prediction equations and correlation coefficients (R^2) relating to equilibrium cumulative depth (z) to time (t).

Land-use system	Kostiakov's model of cumulative depth (mm) $z = kt^a$			Philip's model of cumulative depth (mm) $z = St^{-1/2} + At$		
	a	k	R^2	S	A	R^2
S. sesban (Nov 1998)	0.67	13.52	0.99	15.92	1.44	0.98
S. sesban (May 1999)	0.65	13.02	0.99	14.97	1.09	0.99
Pigeonpea *(Nov 1998)*	0.63	18.50	0.99	22.30	1.12	0.88
Pigeonpea *(May 1999)*	0.59	9.76	0.99	10.92	0.40	0.95
Natural fallow *(Nov 1998)*	0.66	16.89	0.99	19.05	1.66	0.98
Natural fallow *(May 1999)*	0.61	10.26	0.99	11.68	0.49	0.95
M+F *(Nov 1998)*	0.63	10.97	0.99	12.41	0.79	0.96
M+F *(May 1999)*	0.66	7.98	0.99	8.82	0.34	0.98
M-F *(Novy 1998)*	0.69	6.25	0.99	7.74	0.72	0.94
M-F *(May 1999)*	0.67	5.42	0.99	6.64	0.50	0.96

S= Sorptivity, A= Transmissivity, Nov. 1998 = Fallow clearing, May 1999 = crop harvest, a and k are constants

4.9.2 Cumulative water intake

There were significant differences ($P \leq 0.05$) in cumulative water intake at both fallow clearing and crop harvest.. At fallow clearing, the highest average cumulative water intake was 247.9 mm in natural fallow followed by pigeonpea (235.8 mm). The lowest cumulative water intake was recorded in continuous maize without fertilizer (103.4 mm) (Table 14). Cumulative water intake after 3 hours was in the order natural fallow > pigeonpea > *S. sesban* > M+f > M-f (Table 14). At crop harvest, the maximum (180.6 mm) and least (81.1 mm) average cumulative water intake were recorded in *S. sesban* and continuous maize without fertilizer, respectively (Table 14).

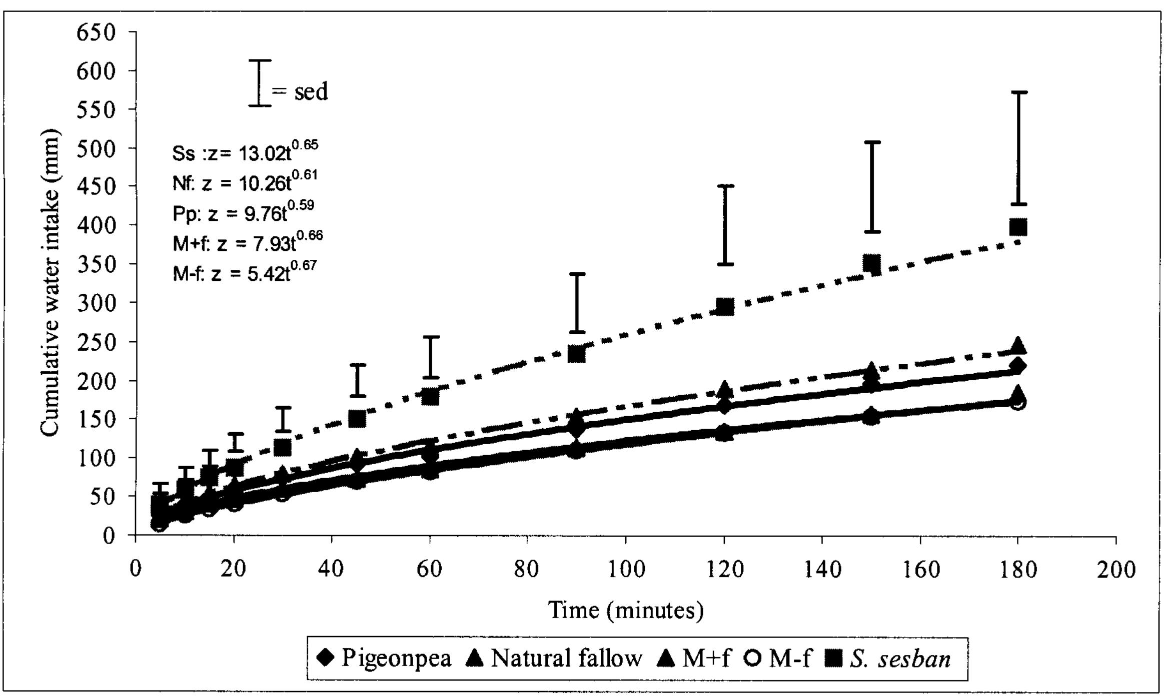
Table 14. Comparison of the average cumulative water intake at fallow clearing and at crop harvest in different land-use systems.

Land-use system	Average cumulative water intake (mm)	
	At fallow clearing	At crop harvest
S. sesban	210.6ab	180.6a
Pigeopea	235.8a	105.7b
Natural fallow	247.9a	117.1b
Continuous M+F	142.0bc	86.4b
Continuous M-F	103.4c	81.1b
Mean	187.9	114.2
SED	36.0	31.0
CV%	23.4	33.2

Means in a column followed by the same letter or letters are not significantly different at P≤0.05 based on the Duncan's Multiple Range Test
SED = Standard error of difference
CV% = Coefficient of variation percent

At crop harvest, the cumulative water intake at the end of 3 hours was in the order *S. sesban* > Nf > pigeonpea > M+f > M-f (Figure 12).

Figure 12. Effects of land-use system on cumulative water intake of the soil at crop harvest



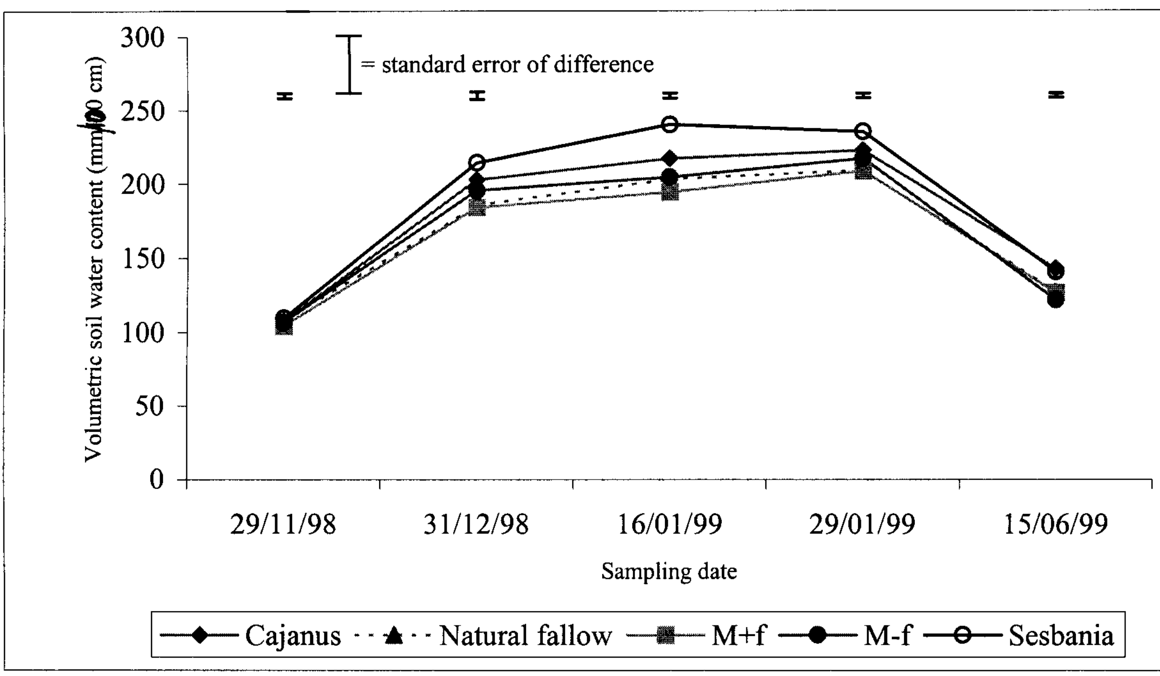
z = cumulative water intake, t = time, M+f = Maize with fertilizer, M-f = maize without fertilizer, Ss = *S.sesban*, Nf = natural fallow, Pp = pigeonpea, sed = standard error of difference

4.9.3 Soil-water content

Soil-water storage

No significant differences were observed in soil-water storage (0–100 cm depth) between sampling dates, except at 8 WAP (Figure 13). Soil-water content ranking at 8 WAP was in the order *S. sesban* > pigeonpea > M-F > Nf > M+F.

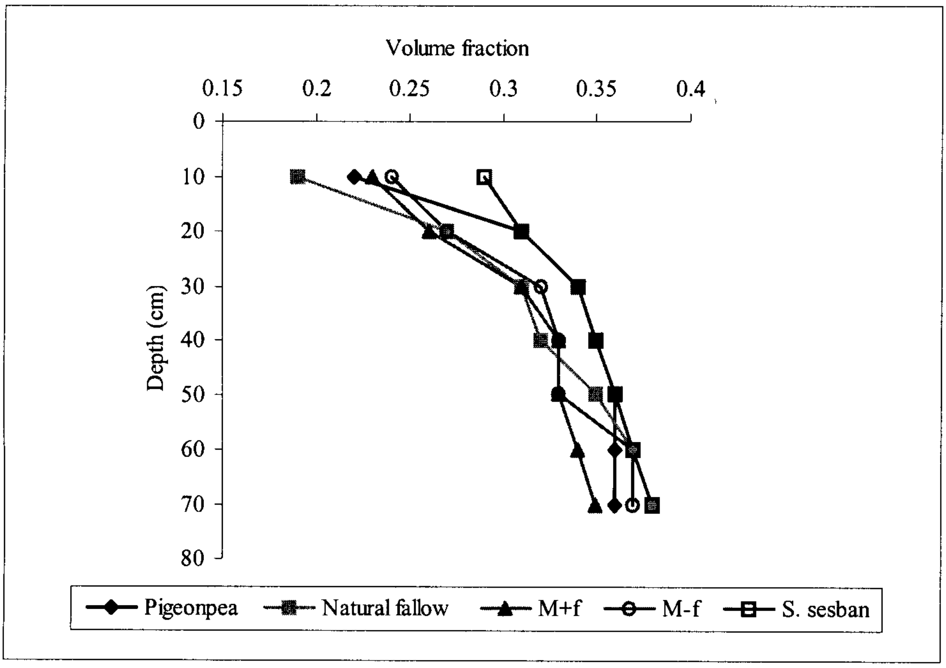
Figure 13. Amount of water stored in the root zone (0–100 cm) as affected by land-use system during the cropping phase.



Volumetric soil-water content

Significant differences (P≤0.05) were recorded in volumetric soil water content among the LUS at 8 WAP. High volumetric soil-water content was recorded in the *S. sesban* LUS at 10 cm soil depth. The order was: *S. sesban* > M-F > M+F > pigeonpea > Nf. Soil-water content increased with increasing soil depth across all LUS. The soil-water content at 70 cm soil depth was in the order *S. sesban* = natural fallow > M- F > pigeonpea > M+F (Figure 14).

Figure 14. Volumetric soil-water content profiles at 8 WAP as affected by land-use systems.



CHAPTER FIVE

DISCUSSION

5.1 Biomass production

The growth performance of pigeonpea fallows showed that survival was very poor and this can be attributed to the method of tree establishment and the ensuing drought. Pigeonpea was directly seeded as compared with *S. sesban* that was raised from nursery seedlings. Soon after the sowing of pigeonpea, there was a drought that contributed to high mortality. Kwesiga *et al.* (1993) reported similar results of poor establishment and high mortality in pigeonpea fallows under similar environmental conditions.

5.2 Nitrogen dynamics

Nitrogen mineralization and immobilization

The large C-to-N ratio (69) and low N (0.62%) in grass litter resulted in immediate immobilization of all N available in the soil. All the treatments, which had litter, showed some form of immobilization except for *S. sesban* (fresh leaves + litter) mixture. This was because of the low C-to N ratio of 18. Leaves with higher N concentration and low C-to-N ratios would be expected to decompose faster than those with high C-to-N ratios (Palm *et al.* 1997). *S. sesban* fresh leaves which have 3-4 % N decomposed faster than the other species with high C-to-N ratio. The higher growth and grain yield in the *S. sesban* LUS can be attributed to the high concentrations of N, fast nutrient release and the decomposition of the fresh leaves and litter. The 4 weeks of N immobilization in the pigeonpea (fresh leaves + litter) delayed the release of N to the maize crop. Sakala *et al.* (2000) also reported that senesced pigeonpea leaves have a short period of N immobilization despite having a narrow C-to-N ratio. Similarly, Mafongoya *et al.* (2000) reported that low quality materials may initially immobilize nutrients, but later mineralise them and make them available for crop uptake. Therefore the mixture pigeonpea fresh leaves and litter in the study probably only started adding N to the maize crop after a period of 4 weeks compared with mixture *S. sesban* fresh leaves and litter. The other reason of high N mineralization for sesbania fresh leaves + litter could be ascribed to low lignin content as compared to other materials used in this study (Mafongoya *et al.* (1998).

The low release of nitrogen in the natural grass fallow litter or pigeonpea litter could be as a result of high lignin and low N contents in these materials. While Mafongoya *et al.* (2000) reported that nutrient release from these organic inputs depends on their chemical composition and soil properties. Mafongoya *et al.,* (1998), Handayanto *et al.*, (1995) and Constantinides and Fownes (1994) observed that nitrogen release patterns of MPT leaves were related to the ratios of NDF-N:N, Soluble polyphenols:N, and (Lignin + polyphenol):N are a good predictor of net N release patterns on MPT leaves. Our results indicate that mixing of litter of low quality with fresh leaves at fallow clearing will cause the nitrogen to immobilize for a few weeks except for those species, which have low C-to-N ratio. Under field conditions there is either more of the litter or fresh leaves depending at what time you terminate the fallow. In most cases fallows are terminated in November or December at that time there is less fresh leaves on the trees. Therefore, the N mineralization patterns will depend on the ratios of these organic materials (fresh leaves to litter). Athough no data is available on the polyphenols and lignin composition of these organic inputs used, our results suggest that not only the C-to-N ratio played a major role in the N mineralization pattern, but also other chemical characteristics of these materials as reported by many workers (Mafongoya *et al.,* 1998; Handayanto *et al.,* 1995; Constantinides and Fownes 1994)

Higher nitrate-N in the topsoil was observed in the pigeonpea and *S. sesban* fallows than in the natural grass fallow. The higher topsoil-nitrate in pigeonpea and *S. sesban* could be attributed to faster mineralization under N-fixing trees than under natural grass fallow (Mekonnen *et al.*, 1997; Onim *et al.*, 1990). The pre-season soil inorganic nitrate-N and inorganic total N at lower depths was higher in fertilized plots than in the tree or natural fallow plots.

The sharp rise in nitrogen content at 4 WAP could be attributed to rainfall that wetted the soil profile to increase the amount of available nitrogen (nitrogen flush). Warren *et al.*, (1997) reported that wetting of soil after a dry season resulted in an increase in available N a phenomenon well known as the "Birch effect". This high N flush potential in *S. sesban* can be equated to the mineralization potentials in the laboratory incubation, which showed that *S. sesban* was superior in terms of nitrogen release pattern. The LUS did not have any effect on total N in all soil depths. These results are consistent with the findings of Barrios *et al.*, (1997) and Maroko *et al.*, (1998).

The decline of nitrate-N in the profile during the maize growing season can be attributed to vigorous maize N uptake and high leaching of nutrients because of unfavourable high rainfall and water logging condition. Mafongoya *et al.* (1999) found high concentrations of nitrate-N in the subsoil profiles beyond the rooting depth of most annual crops on an Acrisol at Msekera, eastern province of Zambia.

5.3 Dry matter and seasonal nitrogen accumulation in maize plants

The high N accumulation in maize with fertilizer above ground biomass was probably due to the addition of mineral fertilizer and rapid assimilation of nutrients by the maize plants, which resulted in high DM weights. Low N accumulation in the *S. sesban*, pigeonpea, natural fallow and maize without fertilizer can be attributed to the low rate of inorganic-N mineralization and lack of synchrony between N release and N demand by the maize crop resulting in low DM weights. On the other hand, Mafongoya *et al.,* (2000) attributed the synchrony mechanism to the action of chemical constituents in organic inputs, which slow or delay the release of nutrients, thus reducing leaching and asynchrony between nutrient release and crop uptake. The other reasons for low N accumulation in maize without fertiliser and natural fallow LUS is perhaps due to: 1) low levels of soil nutrients to influence plant uptake and growth, and 2) the limited utilization of soil nitrate from the subsoil by maize due to poorly developed root system resulting from the rapid deterioration of soil physical properties as reflected by high penetration resistance, high soil bulk densities, low infiltration rate, and low aggregate stability. A polynomial regression model between maize dry matter accumulation and nitrogen uptake at 8 WAP and 24 WAP showed that the amount of nitrogen uptake accounted for 93% and 98%, respectively of the dry matter accumulation in maize plant

5.4 Maize yields

The grain yield increase in the *S. sesban* and pigeonpea fallow systems can be attributed to plant-available N from above ground decomposing biomass (fresh leaves and litter). Other sources of nitrogen can be attributed to the decomposition of *S. sesban* and pigeonpea of root biomass. Work done by Maroko *et al.*, (1998) attributed the increase in crop yield after a *S. sesban* fallow to rapid release of plant-available N from *S. sesban* litter and leaves, and increased soil-N mineralization rates. Similar results of increased maize yields after 2 years of *S. sesban* and pigeonpea fallows have been reported by Kwesiga and Coe (1994). On the other hand, the decline in maize yields in unfertilised and natural fallow plots is due to soil fertility depletion and the deterioration of soil physical properties, such as high soil bulk density, reduced pore spaces leading to low infiltration rates. Sanchez (1976) reported that the main reason for the decline in yield is soil fertility depletion, increased weed infestation, deterioration of soil physical properties, and increased insect and disease attacks. Similarly, the data from this experiment confirms the decline in yield of continuously cropped maize without fertilizer as being due to soil fertility depletion and deterioration of soil physical properties.

5.5 Soil bulk density and porosity

Soil bulk density and porosity at fallow clearing and at crop harvest were not significantly affected by the different LUS. However, natural fallow, *S. sesban* and pigeonpea LUS had lower soil bulk density and high porosity values at fallow clearing. This may be due to the amount of above ground biomass added as well as lack of soil disturbance during the fallow phase. Similarly, decrease and increase in bulk density under agroforestry systems and continuously cultivated soils, respectively, have also been reported on Ferric lixisols at Msekera in eastern Zambia (Torquebiau and Kwesiga, 1996) and on a tropical Alfisol in western Nigeria (Lal, 1989). On the other hand, the increase in bulk density and decrease in porosity under continuous cultivated controls of fertilized and unfertilised maize plots could be due to high compaction especially in the plough layer of 0-20 cm soil depth.

5.6 Penetration resistance

Low penetration resistance was observed in the natural fallow, *S. sesban* and pigeonpea LUSs at fallow clearing. This can be ascribed to increased organic matter content, improved soil aggregation, reduced soil bulk density, improved soil porosity, reduced surface sealing, increased water infiltration, and hence, better water holding capacity. This is in agreement with the results of Harris, *et al.*, (1996) who concluded that the addition of soil organic matter increased soil microbial activity and together with the decomposed soil organic matter, the microbial activity promoted aggregation, hence the soil was more porous and as a result soil penetration resistance decreased. The other reason is perhaps due to the amount of above ground biomass added during the fallow phase. Low penetration resistance values under agroforestry systems have also been reported for Ferric lixisols at Msekera in eastern Zambia (Torquebiau and Kwesiga, 1996), on a tropical Alfisol in western Nigeria (Lal, 1985 and 1989), and on Ultisol at Misamfu in northern Zambia (Dalland *et al.*, 1993).

5.7 Soil organic carbon

The increase of soil organic carbon in the pigeonpea, *S. sesban* and natural fallow LUSs at fallow clearing can be attributed to soil organic matter addition from decomposing fresh leaves and litter. Gichuru (1991) reported an increase of soil organic carbon of pigeonpea fallows over natural bush in the surface 0-5 cm.

Soil organic carbonr under all LUSs (natural fallow, *S. sesban*, pigeonpea, fertilized maize and unfertilised maize) decreased after cropping. This is in agreement with the results of Juo *et al.* (1995) who concluded that the soil organic carbon content under bush fallow, planted fallows and continuous cropped maize fields decreased during the first 7 years of forest clearing. Similarly, Elliot (1986) and Beare *et al.,* (1994) reported that conventional tillage practices are largely responsible for soil organic carbon decline due to exposure of aggregate protected organic matter to microbial decomposition.

On the other hand, Jenny (1980) and Mann (1986), suggested that changes in microclimate due to cultivation might result in more rapid mineralization in soils initially high in carbon content. Intensive agricultural use, with no regard to organic matter management, reduces soil organic matter and has also been reported on a temperate humic loamy soil in France (Arrouays and Pelissier, 1994).

5.8 Aggregate stability and size distribution

The high wet mean weight diameter (WMWD) and percent of water stable aggregates (>2.00 mm) in pigeonpea, *S. sesban* and natural fallow at both fallow clearing and at crop harvest is due to high organic matter content when compared with the unfertilised and fertilized LUS. Mapa and Gunasena (1995); Yamoah *et al.*, (1986) in hedgerow intercropping reported similar results. The importance of soil organic matter in stabilizing the soil has been well documented in the literature (Allison, 1973; Tisdall and Oades, 1984; Chaney and Swift, 1984; Brown and Lug, 1990)

Continuous cultivation causes greater breakdown of large aggregates into smaller aggregates than fallows as evidenced at crop harvest in this study. There was a decrease in both WMWD and water stable aggregates (>2.00 mm) at crop harvest. The increased size aggregation in *S. sesban,* pigeonpea and natural fallow LUSs has an effect on increased water infiltration and water holding capacity, which reduces surface water runoff, and hence decreased erosion compared with maize monocropping system. This is in agreement with the results of Mapa and Gunasena (1995) who concluded that the increase in aggregate size, stability and porosity of the soil in alley cropped plots enhance infiltration, decrease runoff and associated erosion making such systems more sustainable than shifting cultivation.

5.9 Water dynamics

Infiltration rate

The high infiltration rate and cumulative intake in the natural, *S. sesban* and pigeonpea fallows can be ascribed to the improvement in soil physical properties, such as aggregate stability, reduced soil bulk density and increased pore space. Similar results in hedgerow intercropping have been reported (Lal 1989; Hulugalle and Ndi 1993; Mapa and Gunasena 1995). On the other hand, the decline of infiltration rate in continuous maize with fertilizer could be due to the high soil bulk density and penetrometer resistance. Decline in infiltration rate of a no-till treatment is associated with high soil bulk density and penetrometer resistance (Lal 1989).

Van Noordwijk *et al.*, (1991) showed that channels from decaying roots, soil aeration and macrostructures (e.g., earthworm channels) are classically known to be positive factors for infiltration, crop root growth and nutrient capture, especially at low water potential. The high cumulative water intake in the natural fallow can be ascribed to less runoff, high root mass, less compaction (since no human traffic or management practice took place in this LUS as compared with the tree and crop LUSs), low bulk density, high soil aggregation, hence high water infiltration rate. Fallowing with various legumes and grass cover crops is known to improve soil infiltrability (Pereira *et al.*, 1958; Lal *et al.*, 1978, 1979b).

The benefits accrued during fallowing are, easily lost by cultivation (Lal, 1985; Wilkinson and Aina, 1976). In this study, the benefits were lost much more in continuously cropped maize and natural fallow system. The low infiltration and cumulative water intake in unfertilised and fertilized LUSs can be ascribed to rapid soil structural degradation. Continuous cultivation has been reported by several researchers (Lal, 1985; Wilkinson,

1975) as being responsible for structural degradation, decrease in soil organic matter content. Lal (1989) also showed that the decline in equilibrium infiltration rate was due to structural degradation, decrease in soil organic matter content, and reduction in activity of earthworms and other soil fauna.

Water storage dynamics

There was above-normal rainfall during the maize growing period. As such, plant-available water in the root zone was adequate throughout the season to support crop growth. However, there were significant differences in volumetric soil water content measured at 8 WAP. The high water storage in the *S. sesban* and pigeonpea LUSs can be ascribed to numerous channels created by decaying roots and high infiltration rates. Yamoah *et al.*, (1986); Lal (1989); Juo *et al.*, (1996) reported similar high water holding capacity values under hedgerow intercropping and improved fallow systems, respectively, as compared with the maize monocropping controls.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to quantify some changes in soil properties that are responsible for crop productivity improvement under fallow cultivation systems compared with the continuously cropped maize system. The study was also intended to show nitrogen mineralization patterns of mixing litter and fresh leaves of fallow species. The data presented supports the following conclusions:

1. Soil physical properties, such as lower soil bulk density, greater water infiltration, higher water storage capacity, and reduced resistance to penetration played an important positive role in the improvement of maize grain yields under fallow cultivation systems, compared with the maize monocropping system
2. The nitrogen contribution from above ground decomposing materials (litter plus fresh leaves) and below ground biomass (roots) of *S. sesban* and pigeonpea fallows to subsequent crop was evidenced in the increased maize yields after these fallows, compared with the no tree treatments.
3. Leguminous materials, high in initial nitrogen content can mineralise rapidly at the start of the season. However, synchrony or asynchrony of N demand by the crop will depend on the rate of mineralization and availability of organic materials to maintain adequate crop growth and subsequent crop yield.
4. The high correlation between maize grain yield and pre-season nitrate-N and total-N at all soil depths could provide a good estimate of expected yield given the nitrogen levels in the soil under inorganic or organic inputs.
5. The results from the incubation study under laboratory condition are a useful estimate of N mineralization from mixing litter and fresh leaves of fallow species in the initial

screening of organic inputs. However, there is need to carryout the incubation study under field conditions to support the results found under laboratory conditions.

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