Changes in Soil Properties and their Effects on Maize Productivity Following *Sesbania Sesban* and *Cajanus Cajan* Improved Fallow Systems in Eastern Zambia

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Abstract

Changes in soil properties and their effects on maize productivity following *Sesbania sesban* and *Cajanus cajan* improved fallow system were measured on a Typic kandiustalf in eastern Zambia. The treatments used in the study were two-year planted improved fallows of *Sesbania sesban* (L.)

Merr. (sesbania) and *Cajanus cajan (L.)* Millsp (pigeonpea); natural fallow and continuous fertilized (m+f) and unfertilized maize (m-f) (*Zea mays* L.) mono culture. At the end of 10-week incubation period, the cumulative N mineralization of sesbania (fresh leaves + litter), reached 59.4 mg N kg^{-1} soil as compared to 5.1 mg N kg^{-1} soil for pigeonpea litter. Grass fallow litter had a cumulative net immobilization of 0.8 mg N kg^{-1} soil. Maize with fertilizer had the highest pre-season soil nitrate-N at all soil depths. A polynomial regression model between maize grain yield and pre-season 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 for 71%, 68% and 71%, respectively of the maize yield. Total inorganic N in the top 0-20 cm soil depths was in the order of: m+f > cajanus > sesbania > m-f > natural fallow. 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 was significantly correlated to grain yield (R^2 = 0.70, 0.67 and 0.71). DM accumulation ranged from 0.2 t ha^{-1} to 9.5 t ha^{-1} for m-f (at 4 WAP) and m+f (at 24 WAP), respectively. The maximum N accumulation in maize tops at 24 weeks after planting (WAP) averaged 156.9 kg N ha^{-1} and 77.0 kg N ha^{-1} for m+f and sesbania land use system (LUS), respectively, with grain yields of 5.51 and 3.02 t ha^{-1}, correspondingly. The lowest penetrometer resistance measured at 4 WAP for 0 -40 cm soil depth was recorded in sesbania LUS (2.2 Mpa). On the other hand fertilized maize had the highest resistance of 3.9 Mpa. The highest percentage of water stable aggregates > 2.00 mm at fallow termination was recorded in sesbania LUS (83.3 %), followed by pigeonpea LUS (80.8 %). At crop harvest the highest percentage of water stable aggregates > 2.00 mm was recorded in pigeonpea LUS (76.9 %), followed by natural fallow LUS (65.8 %). At fallow termination, the average cumulative water intake after 3 hours was 233, 315, 465, 485 and 572 mm for continuous maize without fertilizer, continuous maize with fertilizer, sesbania, pigeonpea and natural fallow, respectively. Soil water sorptivity at fallow termination was in the order of pigeonpea > natural fallow > sesbania > m+f > m-f. On the other hand soil water sorptivity at crop harvest was in the order of sesbania > natural fallow > pigeonpea > m+f > m-f. At crop harvest the average cumulative water intake at 3 hours was 173, 184, 221, 246 and 399 mm for unfertilized maize, fertilized maize, pigeonpea, natural fallow and sesbania, respectively. The improved soil condition and nitrogen contribution of sesbania and pigeon pea fallows to subsequent crop was evidenced by increased maize yields after these fallows as compared with no tree treatments. Mixing of litter (low quality) with fresh leaves (high quality) from the same tree species at fallow termination had an effect on maize N uptake. Therefore there is need to carefully manipulate the quantities of materials (fresh leaves and litter) at fallow termination so as to get the maximum N utilization by maize plants in improved planted fallow systems.

Key words: Mineralization, immobilization, stable aggregates, penetration resistance, cumulative water intake

Introduction

Under traditional farming methods, farmers have relied on short natural or shrub fallows to grow maize and other crops. In eastern part of Zambia this fallow system is known locally as 'cisala' (Kwesiga *et al.* 1997). 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 bush short duration fallows of between 1-5 years and this has necessitated the need for improved fallows.

Intensive cultivation and cropping may have negative 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). Nitrogen limits crop production over large areas of Zambia and the main sources of plant-available N are mineralization of soil organic matter (SOM), biological N_2 fixation, fertilizers and organic inputs (e.g., plant residues, composts and manures (Giller *et al.* 1997). The improvement in soil physical properties could be another reason for yield improvement but little quantitative data exist on these changes. Recent reviews (Rhoades, 1997 and 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. Studies by Mafongoya and Nair (1997) under field conditions showed that lignin, polyphenols and nitrogen content had a significant effect on N release and maize yield. Research on mixing of legume tree prunings from different species of high quality with low quality has been done by many researchers

(Handayanto *et al.* 1995 and Mafongoya *et al.* 1997). The residual effect on nutrient release and long-term changes in soil fertility resulting from mixing of prunings of different quality from the same tree legume species is a subject, which has received little attention to date.

Soil physical properties, such as aggregate stability and infiltration, are difficult, time consuming, and expensive to measure, hence their importance often receives insufficient research attention. Whilst the response of maize growth and yield in improved fallow systems has received much attention, the processes in tree and post fallow phase have not been understood. Therefore, the objectives of the study were: 1) To quantify some changes in soil properties that are responsible for improvement in crop productivity under fallow cultivation systems compared to the continuously cropped maize system. 2) To quantify the nitrogen mineralization patterns of mixing litter and fresh leaves from the same tree species.

Materials and Methods

The study was conducted in Eastern province of Zambia at Msekera research station during 1996/97 to 1998/99 season. Msekera research station is situated between latitudes 13^{0}38' S and longitudes 32^{0}34' E. The soils at experimental site in 0-20 cm soil layer are composed of 1.2% carbon content, pH ($CaCl_2$) of 4.5, 25% clay, 67% sand and receives an average rainfall of 1092 mm per annum. 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).

A randomised complete block design (RCBD) comprising of five land-use systems (LUS) replicated three times was used, with gross plots of 10 m x 10 m. The LUS were *Sesbania sesban* (L.) Merr. (sesbania) and *Cajanus cajan* (L.) Millsp (pigeonpea); natural fallow and maize (*Zea mays* L.) monoculture with and without fertilizer. *Sesbania sesban* (prov. Chipata dam) fallow trees were planted from nursery raised bare rooted seedlings at the age of 5 weeks at a spacing of 1.0 m x 1.0 m (10 000 plants ha^{-1}). While *Cajanus cajan* (cv. ICP 9145) was direct seeded in the plots at the same time the *Sesbania sesban* seedlings were transplanted into the field in November 1996 at a spacing of 1.0 m x 0.50 m (20 000 plants ha^{-1}). Trees were clear felled at collar (ground) level in November 1998 after 2 years of fallow, while stumps and root system were left below ground.

Data collection and observations

Total above ground biomass of trees (leaves, twigs and wood) was measured at fallow clearing by separating the biomass components into foliage (leaves and twigs), branches and stems. These components were then weighed as green after which samples of each component were collected on plot basis and oven dried at 70°C to equilibrium moisture content. This data was used to estimate dry weight on plot basis and extrapolated to a hectare basis. The tree biomass (leaf + twig) and natural grass fallow of *hyparrhenia* sp. was incorporated in the soil by hand hoeing. After land preparation, hybrid maize (*Zea mays* L.) (variety MM 604) was sown by hand at 30 cm within-row and 75 cm between-row spacing (44 444 plant ha^{-1}). Fertilizer was applied to the fertilized control plots at the recommended rates of 20 kg N ha^{-1}, 40 kg P_2O5 ha^{-1}, and 20 kg K_2O ha^{-1} of Compound-D at sowing and 92 kg N ha^{-1} as urea at 4 weeks after sowing (WAS). All the plots were managed following the recommended agronomic practices for weeding and harvesting.

Soil ammonium and nitrate nitrogen

Soil sampling for soil ammonium and nitrate was done at fallow clearing (pre-season, November 1998) using a metal sampler (4.2 cm diameter G. I. Pipe) from 0-20, 20-40 and 40-60 cm soil depths. 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. Ammonium was determined by colorimetric method (Anderson and Ingram, 1993). Nitrate and nitrite concentrations were determined by cadmium reduction (Dorich and Nelson, 1984). The sum of inorganic ammonium-N and inorganic nitrate-N constituted the total inorganic nitrogen.

Laboratory incubation

Laboratory incubation was done to characterize the nutrient release patterns of sesbania (fresh leaves + litter), sesbania litter alone, pigeonpea (fresh leaves + litter), pigeonpea litter alone and dry grass littter. Chemical compositions of the organic materials used are shown in Table 6.2. Fresh leaves collected from the two species were sun dried for 2-3 days and oven-dried at 65 ^{0}C for 48 hours to determine the dry matter (DM) content. 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 3 and left to drain until 50 % water holding capacity was achieved by constant weighing. 1.35g of ground organic material was mixed with 270g of soil in 350 ml aluminium moisture cans. This rate is equal to 5 t ha^{-1}, which is applied in the field. The treatments were 1) Soil + sesbania (fresh leaves + litter). 2) Soil + sesbania litter alone. 3) Pigeonpea (fresh leaves + litter). 4) Pigeonpea litter alone. 5) Soil + dry grass. 6) Soil alone (control). Fresh leaves and litter were mixed in a 1:1 w/w basis. Moisture cans were covered with aluminium foil that was perforated to allow air movement and put in the incubator at 28 ^{0}C throughout the experiment period. Soil moisture content in the cans was maintained at 50% water holding capacity throughout the experimental period by periodic additions of deionised water using a syringe and constant weight adjustment. Each treatment was replicated three times in a completely randomised design. Sub samples (20g) were analyzed for exchangeable NH_4^-N and NO_3^-N immediately after addition of plant material (at week 0) and once every week for 10 weeks. Ammonium was analysed by the modified calorimetric method of Dorich and Nelson (1984) and nitrate by the method of Cataldo *et al.* (1975). Results were reported as cumulative net mineralizable total inorganic nitrogen (ammonium-N + nitrate-N).

Soil penetration resistance

Penetration resistance was measured with a hand penetrometer, Bush soil penetrometer SP1000, version 1.0, supplied by ELE International, England. 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 a digital balance. Five insertions in the net plot were measured at 4 WAP and 24 WAP.

Cumulative water intake

Cumulative water intakes were monitored at fallow clearing and at crop harvest during the dry season. Two standard infiltrometer rings (double ring) per plot were used according to the procedure described by Bouwer (1986). Water measurements were recorded for three hours at 0, 5, 10, 15, 20, 30, 45, 60, 90, 120, 150 and 180-minute intervals. The average readings were used to calculate cumulative water intake per plot using Kostiakov (1932) and Philip (1957) models.

The Kostiakov (1932) model is described by equations 1 and 2:
1) Equation for cumulative depth is described by:
$z = kt^a$
2) Equation for infiltration rate is described by:
$i = akt^{a-1}$

Where: z = cumulative depth infiltrated
t = time
i = infiltration rate
a and k are constants determined empirically.
The Philip's model is described by equations 3 and 4:
3) Equation for cumulative depth is described by:
$z = St^{1/2}+At$
4) Equation for infiltration rate is described by:
$i = {}_{1/2}St^{-1/2}+ A$
Where: z = cumulative depth infiltrated
t = time
i = infiltration rate
S =sorptivity which indicates the capacity of a soil to absorb water.
A = transmissivity

Aggregate 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 crop harvest using a hand hoe. Soil clods were hand broken to a maximum aggregate size of 50 mm then each soil sample was air dried at room temperature to stimulate some forces involved in aggregation. These forces are those related to cultivation, erosion (wind and water), and wetting of soils, respectively. The sample was allowed to pass through 9.50 mm and retained on the 0.30 mm opening sieve. A Yoder (1936) type-sieving machine, which raises and lowers the nests of sieves, through water with a stroke length of 1.5 inches approximately 30 cycles per minute was used with a set of 4.75, 2.0, 1.0, 0.50 and 0.30 mm openings sieves with a receiver at the bottom. An air-dry sample of 500g was placed gently in the sieve with 4.75 mm opening. The set of sieves were lowered in water of sieving machine and the machine was made to run for five minutes. Fractions obtained on each sieve and retainer 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.

Trees, natural grass and crop biomass

Total above ground biomass of natural grass and tree components including leaves, twigs and litter were measured at fallow clearing. Total inorganic 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 and oven-dried at 70°C for 72 hours for DM determination. N 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).

Data analysis

The data were subjected to analysis of variance using GENSTAT version 5 (Genstat 5 committee, 1988). For all mean comparisons significance was tested at $P \leq 0.05$, using Duncan's Multiple Range Test (Gomez and Gomez, 1984). Simple linear and curvilinear regressions were used to determine the relationship between maize grain yield and pre-season soil inorganic nitrate-N and total inorganic N.

Results

Tree growth

Significant differences ($P \leq 0.05$) were observed in the survival rates. The highest survival rates were recorded in sesbania (91.7%), while pigeonpea had only 31.0%. As was the case with survival, high total biomass was recorded in sesbania fallows (Table 6.2).

Table 6.1: Growth performance of *Sesbania sesban* and *Cajanus cajan* fallow species at 24 months after fallow establishment at Msekera, Chipata-Zambia (November 1998)

Land-use system	Survival (%)	Leaf + Twig (t ha^{-1})	Total biomass (t ha^{-1})
Pigeonpea	31.0b	0.19a	8.50
Sesbania sesban	91.7a	0.23a	16.8
Mean	61.30	0.21	12.6
SED	10.68	0.18	2.94

Nitrogen mineralization and immobilization

The organic materials used had C-to-N ratio ranging from 14.7 to 69 for sesbania fresh leaves and natural grass, respectively (Table 6.1). The N concentration ranged from 0.62 to 3.09% for natural grass and sesbania, respectively (Table 6.1). 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 sesbania (fresh leaves + litter) mixture, respectively (Figure 6.1). Cumulative net immobilization of 0.8 mg N kg^{-1} soil was observed at end of the incubation period in natural grass litter (Figure 6.1). Between week 1 and 4 there was net immobilization in pigeonpea (fresh leaves + litter) mixture and sesbania litter alone. Pigeonpea litter alone had a cumulative net immobilization from week 1 to 5.

Table 6.2: 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
Sesbania fresh leaves alone	45	3.09	14.7
Sesbania litter alone	45	1.28	35
Sesbania (fresh leaves + litter) mixture	45	2.4	18
Natural grass litter alone	43	0.62	69

Pre-season soil mineralizable nitrogen

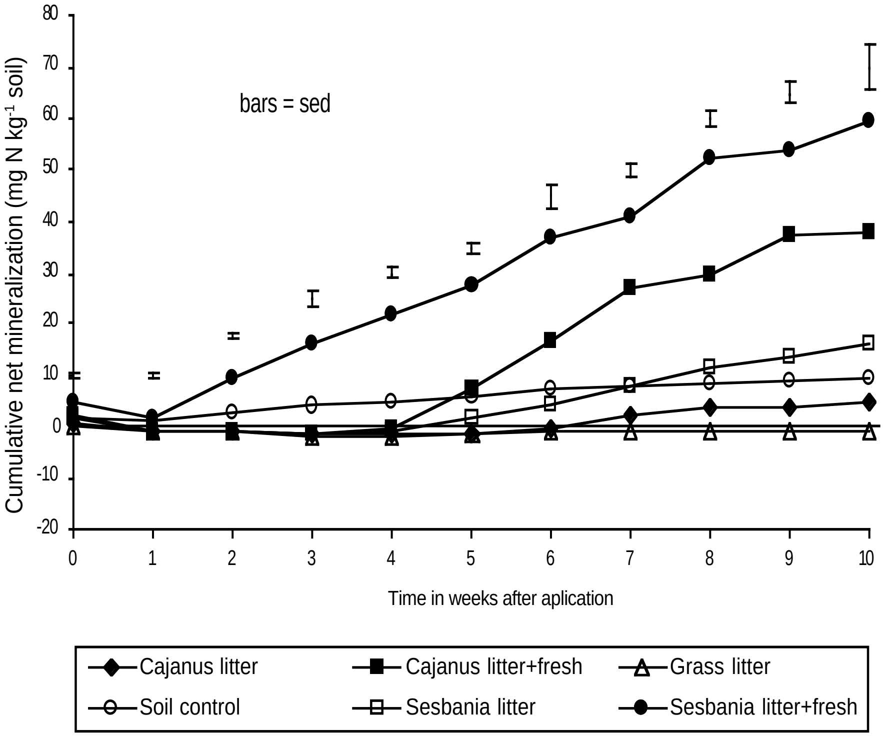
Pre-season nitrate-N and total inorganic N was significantly ($P \leq 0.05$) affected by soil depth and LUS (Table 6.3). Ammonium-N was not significantly affected by either soil depth or LUS (Table 6.3). Maize with fertilizer had the highest soil nitrate-N in all soil depths, which was not significantly different from pigeonpea and sesbania LUS. At 40-60 cm soil depth soil nitrate-N had the following trend: m+f > sesbania > m-f > pigeonpea > natural fallow (Table 6.3). A polynomial regression model between maize grain yield and pre-season 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 for 71%, 68% and 71%, respectively of the maize yield. Total mineral N in the top 0-20 cm soil depths was in the order of: m+f > pigeonpea > sesbania > m-f > natural fallow (Table 6.3). As was the case with pre-season soil nitrate-N, total mineral N in 0-20 cm, 0-40 cm and 0-60 cm soil depths was significantly correlated to grain yield (R^2 = 0.70, 0.67 and 0.71).

Table 6.3: Pre-season soil mineralizable nitrogen as affected by Land-use system and soil depth at Msekera, Chipata-Zambia (November 1998)

Treatment	Ammonium (mg N kg^{-1})			Nitrate (mg N kg^{-1})			Total N (mg N kg^{-1})		
	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60
Pigeonpea	3.65^{a}	2.52^{a}	2.10^{a}	3.49^{ab}	2.37^{ab}	1.25^{bc}	7.14^{ab}	4.88^{ab}	3.36^{b}
Natural fallow	3.09^{a}	2.14^{a}	1.64^{a}	1.49^{b}	0.74^{c}	0.59^{c}	4.58^{b}	2.88^{b}	2.23^{b}
Maize +fert	3.11^{a}	2.53^{a}	1.59^{a}	4.24^{a}	3.52^{a}	4.74^{a}	8.32^{a}	5.52^{a}	7.73^{a}
Maize – fert	4.07^{a}	2.00^{a}	2.99^{a}	2.18^{b}	1.70^{bc}	1.81^{bc}	5.29^{ab}	4.23^{ab}	3.41^{b}
Sesbania	4.21^{a}	1.85^{a}	1.97^{a}	2.49^{ab}	1.52^{bc}	2.07^{b}	6.70^{ab}	3.37^{ab}	4.04^{b}
Mean	3.36	2.21	2.06	2.78	1.97	2.09	6.40	4.18	4.15
SED	0.83	0.71	0.62	0.84	0.58	0.56	1.29	0.94	0.98

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

Figure 6.1: 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



Dry matter and seasonal nitrogen accumulation in maize topmass

DM accumulation during the growing season ranged from 0.2 t ha^{-1} to 9.5 t ha^{-1} for maize without fertilizer (at 4 WAP) and with fertilizer (at 24 WAP), respectively (Figure 6.2). High N accumulation in maize above ground biomass was observed from 4 to 6 WAP in sesbania LUS (13.9 kg N ha^{-1}), as compared to fertilized plot that only accumulated 2.4 kg N ha^{-1} (Figure 6.3). 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, sesbania and pigeonpea had only 7.0 kg N ha^{-1} and 15.8 kg N ha^{-1}, respectively (Figure 6.4). 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 maize with fertilizer and sesbania LUS, respectively. 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.

Figure 6.2: Maize dry matter (DM) accumulation during the growing season under different land-use systems at Msekera, Chipata-Zambia (1998/99 season)

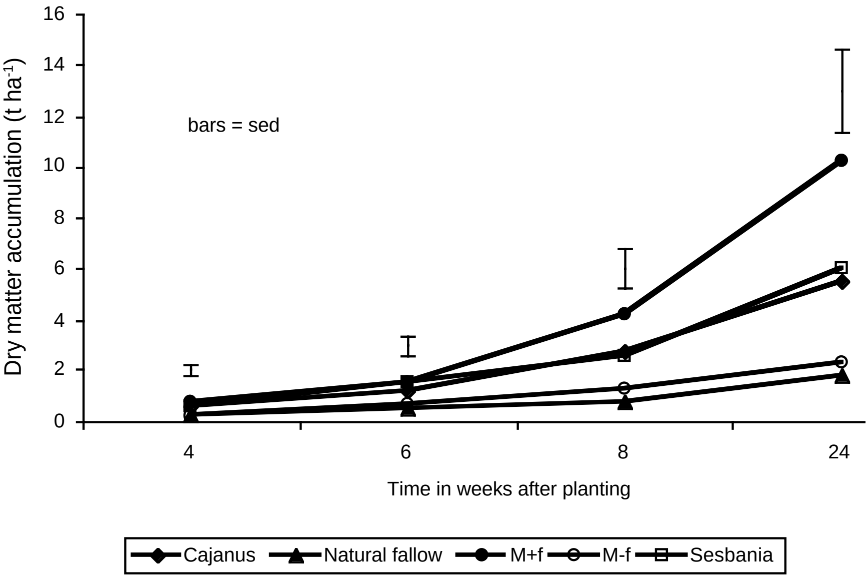


Figure 6.3: Seasonal Nitrogen accumulation in maize above ground biomass during the growing season under different land-use systems

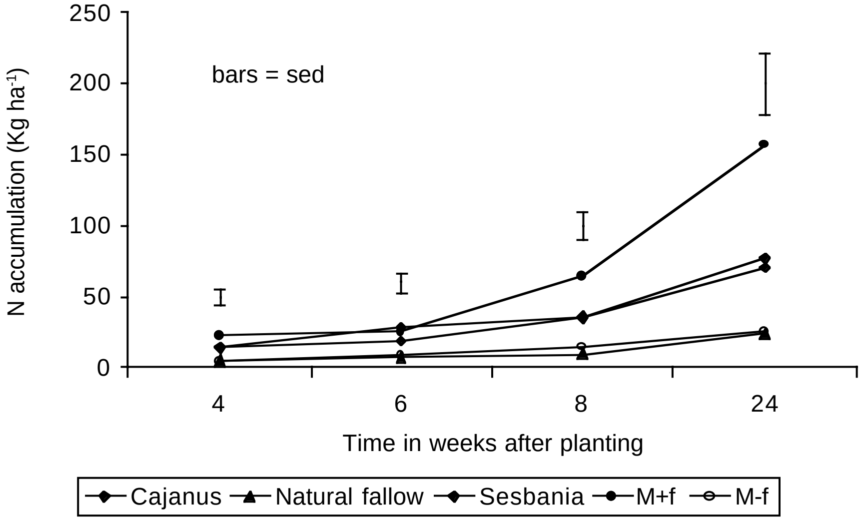
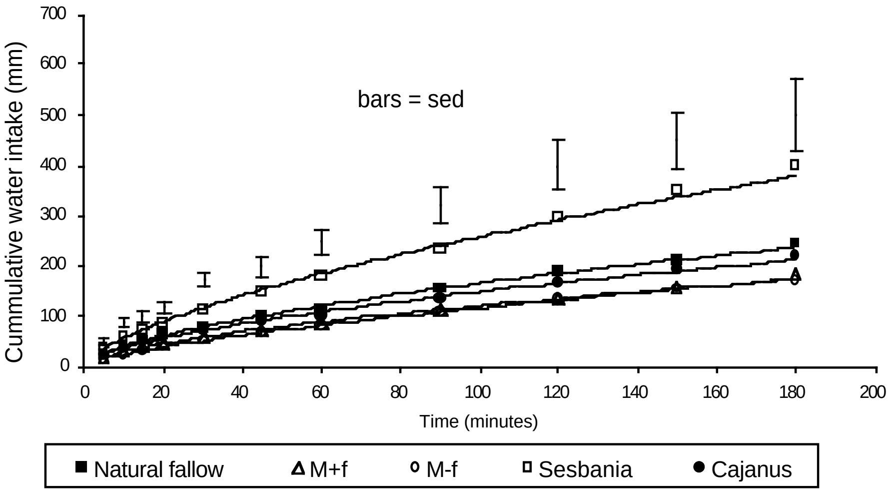


Figure 6.4: Effects of Land-use system on cumulative water intake (mm) of the soil at Msekera, Chipata-Zambia (at crop harvest May 1999)



Maize yields

Analysis of variance of maize stover, grain yield and total biomass showed significant differences (P≤0.05) due to land-use systems. The highest stover yield of 4.01 t ha^{-1} was in continuous maize with fertilizer followed by sesbania (3.01 t ha^{-1}) and the least was in natural fallow (0.93 t ha^{-1}). As was the case with stover, the highest grain yield of 5.51 t ha^{-1} was recorded in maize with fertilizer followed by sesbania (3.02 t ha^{-1}) and the least was in natural fallow (0.85 t ha^{-1})(Table 6.4).

Table 6.4: Maize yields as affected by different land-use system at Msekera, Chipata-Zambia (May 1999)

Land-use system	Stover yield (t ha^{-1})	Grain yield (t ha^{-1})	Total biomass (t ha^{-1})
Sesbania sesban	3.01^{a}	3.02^{a}	6.02^{b}
Cajanus cajan	2.79^{a}	2.69^{bc}	5.48^{bc}
Natural fallow	0.93^{a}	0.85^{c}	1.78^{d}
Cont. M+F	4.01^{a}	5.51^{a}	9.52^{a}
Cont. M-F	1.25^{b}	1.01^{c}	2.26^{cd}
Mean	2.40	2.61	5.01
SED	0.67	0.82	1.46

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

Penetration resistance

Average cone penetrometer resistance measured at both 4 WAP (November 1998) and 24 WAP (May 1999) was significantly affected by the LUS. Average cone penetrometer resistance measured at 4 WAP ranged from 2.2 to 3.9 Mpa for sesbania and maize with fertilizer LUS, respectively (Table 6.5). At 24 WAP no significant difference was observed in cone penetrometer resistance among the LUS (Table 6.5).

Table 6.5: Effects of Land use system on some soil physical properties after 2 years of improved fallow system at Msekera, Chipata-Zambia (November 1998 and May 1999)

Land-use system	Average penetrometer resistance at at 40 cm soil depth (Mpa)		Average water stable aggregates >2.00mm (%)		Average cumulative water intake at 3 hours(mm)	
	Nov. 1998	May 1999	Nov. 1998	May 1999	Nov. 1998	May 1999
Sesbania sesban	2.2^{c}	3.3^{a}	83.3^{a}	65.1^{b}	465^{ab}	399^{a}
Cajanus cajan	2.9^{b}	3.0^{a}	80.8^{a}	76.9^{a}	485^{ab}	221^{b}
Natural fallow	2.9^{b}	4.3^{a}	65.7^{b}	65.8^{b}	572^{a}	246^{ab}
Continuous M+F	3.9^{a}	4.0^{a}	65.6^{b}	58.4^{c}	315^{bc}	184^{b}
Continuous M-F	3.2^{b}	3.3^{a}	61.2^{a}	44.0^{d}	233^{c}	173^{b}
Mean	3.1	3.6	71.5	62.0	414	245
SED	0.19	0.57	3.13	2.74	93.3	72.5

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

Aggregate stability

The percentages of aggregates bigger than 2.00 mm (aggregates > 2.00 mm) were significantly affected by the LUS at fallow termination ($p \leq 0.05$). The highest percentage of water stable aggregates > 2.00 mm at fallow termination was recorded in sesbania LUS (83.3 %) followed by pigeonpea LUS (80.8 %). The least was recorded in maize without fertilizer (61.2 %) (Table 6.5). The highest percentage of aggregates at crop harvest (May 1999) greater than 2.00 mm was recorded in pigeonpea LUS (76.9 %) followed by natural fallow LUS (65.8 %). The least was recorded in maize without fertilizer (44.0 %) (Table 6.5).

Infiltration rate and cumulative water intake

Significant differences ($P \leq 0.05$) were observed at both fallow termination and crop harvest stages in cumulative water intake. At fallow termination, the highest average cumulative water intake at 3 hours was 572 mm in natural fallow followed by pigeonpea (485 mm). The lowest cumulative water intake was recorded in maize without fertilizer (233 mm) (Table 6.5). At crop harvest, the maximum (399 mm) and least (173 mm) average cumulative water intake were recorded in Sesbania and continuous maize without fertilizer, respectively (Table 6.5). Soil water sorptivity at fallow termination was in the order of: pigeonpea > natural fallow > sesbania > m+f > m-f (Table 6.6). On the other hand soil water sorptivity at crop harvest was in the order of: sesbania > natural fallow > pigeonpea > m+f > m-f (Table 6.6).

Table 6.6: Prediction Equations and Correlation Coefficients (r^2) relating to equilibrium infiltration rate (i) in mm min^{-1} with the time (t) in minutes at fallow termination and crop harvest at Msekera, Chipata-Zambia (November 1998 and May 1999)

Land-use system	Kostiakov's model of infiltration rate (mm min^{-1}) $i = akt^{a-1}$			Philip's model of infiltration rate (mm min^{-1}) $i = {}_{1/2}St^{-1/2} + A$		
	a	k	r^2	S	A	r^2
Sesbania (Nov 1998)	0.67	13.52	0.99	15.92	1.44	0.98
Sesbania (May 1999)	0.65	13.02	0.99	14.97	1.09	0.99
Cajanus (Nov 1998)	0.63	18.50	0.99	22.30	1.12	0.88
Cajanus (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

Discussion

Tree growth

Results on the growth performance of pigeonpea fallows showed that survival was very poor and this was probably due to the method of establishment and drought. Pigeonpea was directly seeded as compared to sesbania that was raised from nursery seedlings. Soon after sowing of pigeonpea there was a period of drought that might have contributed to high mortality. Kwesiga *et al.* (1993) reported similar results of poor establishment and high mortality in pigeonpea fallow under similar environmental conditions.

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 Sesbania (fresh leaves + litter) mixture. This was because of the low C-to N ratio of 18. Palm *et al.* (1997) showed that sesbania fresh leaves which have 3-4 % N decompose faster than those species with high C-to-N ratio. The increased growth and grain yield in the sesbania LUS can be attributed to the high concentrations of N, fast nutrient release and decomposition of the fresh leaves and litter. The 4 weeks of N immobilization in pigeonpea (fresh leaves + litter) delayed the release of N to the maize crop. Sakala *et al.* (2000) also reported that senesced cajanus leaves have a short period of N immobilization despite having a narrow C-to-N ratio. Similarly, Mafongoya *et al.* (2000) reported low quality materials initially immobilize nutrients, but later they mineralise and make the nutrients available to the crop for uptake. Therefore a mixture of pigeonpea fresh leaves and litter will only start adding N to the maize crop after a period of 4 weeks as compared to the mixture of sesbania 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).

Plant materials with high lignin concentration decompose more slowly than those with low lignin (Melillo *et al.* 1982). Similarly, the low release of nitrogen in 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. However, work done by Mafongoya *et al.* (1998), Handayanto *et al.* (1995) and Constantinides and Fownes (1994) on nitrogen release patterns of MPT leaves say that 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. Whilst Palm and Sanchez, (1991) showed that nitrogen concentration, lignin and polyphenolic contents are considered to control N release rates of decomposing plant residues. Our results indicate that mixing of litter of low quality with fresh leaves at fallow termination 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 and Constantinides and Fownes 1994).

Pre-season soil mineralizable nitrogen

Our results show that pre-season soil nitrate-N and total inorganic N at lower depths was higher in fertilized plots than the tree or natural fallow plots. This is because most of the nitrate-N in the top layers is bound to be leached to lower depths quickly after heavy rains as compared to the tree based system which releases nitrogen slowly. Buresh (1995) also reported that most of the nitrate-N in the top layers is bound to be leached to lower depths that are beyond the rooting depth of most annual crops. Tree fallows are best since trees are able to capture lost nutrients and transfer them back to surface soil in form of litterfall and leafy biomass which subsequently is made available to the maize crop as compared to the natural fallow (Mekonnen *et al.* 1997). Higher nitrate-N in the topsoil was observed under pigeonpea and sesbania fallow than the natural fallow. Mekonnen *et al.* (1997) and Onim *et al.* (1990) also reported similar results. They attributed this higher topsoil nitrate in pigeonpea and sesbania as being due to faster mineralization under N-fixing trees than under natural fallow. The high level of nitrate-N in the lower depth of maize with fertilizer was probably due to leaching. Similarly, Hartemink *et al.* (1996) and Mekonnen *et al.* (1997) found greater accumulation of subsoil nitrate under maize monoculture on the Oxisol and they attributed this to higher rainfall and leaching of nutrients to lower depths. Low levels of subsoil nitrate were also observed in natural fallow and sesbania LUS.

Dry matter and seasonal nitrogen accumulation in maize topmass

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. Low N accumulation in sesbania, pigeonpea, natural fallow and maize without fertilizer was probably due to low rate of inorganic-N mineralization and lack of synchrony of N release to N demand by the crop. On the other hand, Mafongoya *et al.* (2000) attributed the mechanism contributing to synchrony as being 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 could be: 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 (high penetration resistance, 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.

Maize yields

The increase of grain yields in the sesbania and pigeonpea fallow system was a result of plant-available N from decomposing aboveground biomass (fresh leaves and litter). Other sources of nitrogen was probably from the decomposition of root biomass of sesbania and pigeonpea fallow species. Similar results of increased maize yields after 2 years of sesbania fallows and pigeonpea fallows have been reported (Kwesiga and Coe, 1994; MacColl, 1989). Maroko *et al.* (1997) attributed increase in crop yield after sesbania fallow to rapid release of plant-available N from sesbania litter and leaves resulting in an increased supply of inorganic N at crop planting after fallow period, and increased soil N mineralization rates. On the other hand, the decline in yield in unfertilised and natural fallow plots could be soil fertility depletion and deterioration of soil physical properties such as resistance to root penetration, aggregate stability and infiltration. The other reason for yield component decline is water stress during pollination (Claassen and Shaw, 1970). Sanchez (1976) also 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.

Penetration resistance

The major reason for low penetration resistance in natural fallow, sesbania and pigeonpea LUS at fallow termination, can be attributed to addition of aboveground biomass during fallow phase and improved soil aggregation. On the other hand Harris *et al.* (1996) attributed low penetration resistance to the addition organic matter to soil which increases soil microbial activity and together with the decomposed soil organic matter, this microbial activity promotes aggregation, hence the soil is more porous and as a result, soil penetration resistance is decreased. Decrease in penetration resistance under agroforestry systems have been reported by Torquebiau and Kwesiga (1996), Lal (1989) and Dalland *et al.* (1993). There was an increase in penetration resistance after cropping. This could be as a result of reduced pore space and loss of soil aggregation.

Aggregate stability

The high percent of water stable aggregates >2.00 mm in pigeonpea sesbania and natural fallow at both fallow termination and at crop harvest was probably due to high organic matter content as compared to maize with and without fertilizer LUS. Mapa and Gunasena (1995) and Yamoah *et al.* (1986) reported similar results in hedgerow inter cropping. The importance of soil organic matter in stabilizing soil has been well documented (Tisdall and Oades 1983, and Chaney and Swift 1984). Continuous cultivation breaks large aggregates into smaller aggregates as was evidenced at crop harvest of this experiment. There was a decrease in percent of water stable aggregates >2.00 mm after cropping at crop harvest. The improved size aggregation in sesbania, pigeonpea and natural fallow LUS has an effect on increased water infiltration and water holding capacity, which reduces surface water runoff and hence decreased erosion as compared to the maize mono cropping system.

Infiltration rate and Cumulative water intake

The high cumulative water intake in the natural fallow, sesbania and pigeonpea could have been due to the improvement in the soil physical properties (improved soil aggregation and decreased resistance to penetration). Mapa and Gunasena, (1995) reported that higher wet stable aggregates facilitate higher macro-porosities, higher infiltration rate and reduce soil erosion which is a major contributing factor in degrading soil physical properties under shifting cultivation. Similar results in hedgerow intercropping were reported by Lal, (1989), and Hulugalle and Ndi, (1993). Soil water sorptivity in November 1998 and May 1999 was highest in tree-based system than maize with and without fertilizer. These results show that pigeonpea and sesbania tree based LUS will have a higher affinity for water by soil matrix. Which means that during periods of water stress maize under pigeonpea and sesbania LUS will perform better than the maize with and without fertilizer.

Conclusion

This study shows the importance of improved fallow technology in maintaining soil fertility. Sesbania and pigeonpea have a potential to supply inorganic soil nitrogen through leafy biomass and litter. The nitrogen contribution of sesbania and pigeonpea fallows to subsequent crop was evidenced by increased maize yields after these fallows as compared to no tree treatments. Improved fallows have the potential of improving soil physical conditions as compared to maize mono-cropping systems as shown from high soil aggregation, greater water infiltration, higher soil water sorptivity and reduced resistance to penetration. Continuous cultivation causes the breakdown of numerous soil processes associated with crop productivity.

The results from the incubation study under laboratory condition indicate that mixing of litter (low quality) with fresh leaves (high quality) from the same tree species at fallow termination had an effect on maize N uptake. Maize planted after sesbania fallows will have an immediate benefit from the prunings than maize planted after pigeonpea. This is because pigeonpea mixture (fresh leaves +litter) starts to release nitrogen to the crop after a period of 4 weeks. However there is need to carryout this study under field condition to support the results found under laboratory condition.

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References

Anderson, J. M. and Ingram, J. S. I. (1993) Tropical Soil Biology and Fertility: A Handbook of Methods. 2nd edition. CAB International, Wallingford, UK. pp 221.

Bouwer, H. (1986) Intake rate: Cylinder infiltrometer. p825-844. In: Klute, A.(ed). Methods of soil analysis, part 1, Physical and mineralogical methods-Agronomy Monograph Number 9. *Am. Soc. Agr*. Madison, Wisconsin, USA.

Brady, N. C. (1996) Alternatives to slash-and burn: a global imperative. *Agriculture Ecosystems and Environment* 58: 3-11.

Buresh, R. J. and Tian, G. (1997) Soil improvement by trees in sub-Saharan Africa. *Agroforestry systems* 38: 51-76.

Buresh, R.J. (1995) Nutrient cycling and nutrient supply in agroforestry systems p155-164. In: Dudal, R. and Roy, R.N.(Eds). Integrated plant nutrition systems. FAO fertilizer and plant nutrition Bulletin number 12. Rome, Italy.

Cataldo, D. A., Harron, M., Schrader, L. E. and Youngs, V. L. (1975) Rapid colorimetric determination of nitrate in plant tissue by nitration of salicylic acid. *Commun Soil Sci. Plant Anal*. 6: 71-80.

Chaney, K. and Swift, R. S. (1984) The influence of organic matter on aggregate stability in some British soils. *Journal of Soil science* 35: 223-236.

Claassen, M. M. and Shaw, R. H. (1970) Water deficit effects on corn: II. Grain components. *Agron. J*. 62: 652-655.

Commissaris, A.L.T.M. (1975) Detailed Soil Survey of Msekera Research Station. *Soil Survey report no.* 19.

Constantinides, M. and Fownes, S. H. (1994) Nitrogen mineralization from leaves and litter of tropical plants. Relationship to nitrogen, lignin and soluble polyphenol concentrations. *Soil Biol. Biochem* 26: 49-55.

Dalland, A., Våje, P. I., Mathews, R. B. and Singh, B. R. (1993) The potential of alley cropping in improvement of cultivation systems in the high rainfall areas of Zambia III. Effects on soil chemical and physical properties. *Agroforestry Systems.* 21: 117-132.

De Leenheer, L. and De Boodt, M. (1958) Determination of aggregate stability by the change in mean weight diameter. pp.260-300. In: Proceedings of International Symposium of Soil Structure. Ghent, Belgie.

Dorich, R. A. and Nelson, D. W. (1984) Evaluation of manual cadmium reduction methods for determination of nitrate in potassium chloride extracts of soil. *Soil Sci. Soc. Am. J*. 48: 72-75.

FAO (1988) Soil Map of the World-Revised Legend. World Soil Resources *Report* 60 FAO/UNESCO, Rome.

Genstat 5 Committee. (1988) Genstat 5 reference manual. Oxford Univ. Press, Oxford, England. 749pp.

Giller, K. E., Cadisch, G., Ehaliotis, C., Adams, E., Sakala, W. D. and Mafongoya, P. L. (1997) Building soil nitrogen capital in sub-Saharan Africa. In: Buresh, R. J., Sanchez, P. A. and Calhoum, F. (Eds) Replenishing Soil Fertility in Africa p 151-192. SSSA Special Publication 51. SSSA and ASA, Madison, WI, USA.

Gomez, K. A. and Gomez, A. A. (1984) Statistical procedures for agricultural research 2nd edition. Jony Wiley and Sons Inc.

Handayanto, E. Cadisch, G. Giller, K. E. (1995) Manipulation of quality and mineralization of tropical legume tree prunings by varying nitrogen supply. *Plant Soil* 176: 149-160.

Harris, R. F., Chesters, G. and Allen, O. N. (1996) Dynamics of soil aggregation. *Adv. Agron* 18: 107-169.

Hartemink, A. E. Buresh, R. J. Jama, B. Janssen, B. H. (1996) Soil nitrate and water dynamics in sesbania fallows, weed fallows and maize. *Soil Sci Soc Am J.* 60: 568-574.

Hulugalle, N. R. and Ndi, J. N. (1993) Effects of no-tillage and alley cropping on soil properties and crop yields in a Typic Kandiudult of Southern Cameroon. *Agroforestry Systems.* 22: 207-220.

Kostiakov, A. N. (1932) On the dynamics of the coefficient of water-percolation in soils and on the necessity for studying it from a dynamic point of view for purposes of amelioration. *TRANS. Sixth Intnl. Society of Soil Science*, *Russian* Part A: 17-21.

Kwesiga F. and Coe, R. (1994) The effect of short rotation Sesbania sesban planted fallows on maize yield. *Forest Ecology and Management* 64: 199-208.

Kwesiga, F., Phiri, D. M. and Rauno, A. (1997) Improved fallows with Sesbania in Eastern Zambia. Summary proceedings of a consultative workshop 22-26 April, 1996, Chipata, Zambia. ICRAF Nairobi, Kenya pp. 101.

Kwesiga, F., Phiri, D. M., Simwanza, C. P. and Mwanza, S. (1993) Zambia/ICRAF Agroforestry Research Project, 1993 Annual report. AFRENA Report no. 71.

Lal, R. Wilson, G. F. and Okigbo, B. N. (1978) No-tillage farming after various grasses and leguminous cover crops in tropical Alfisols I. Crop performance. *Field Crops Res.* 1: 71-84.

Lal, R. Wilson, G. F. and Okigbo, B. N. (1979) Changes in properties of an Alfisol produced by various crop covers. *Soil Sci.* 127: 377-382.

Lal, R. (1989) Agroforestry systems and soil surface management of a tropical Alfisol: IV. Effects on soil physical and mechanical properties. *Agroforestry systems* 8: 197-215.

MacColl, D. (1989) Studies on maize (*Zea mays* L.) at Bunda, Malawi: II. Yield in short rotation with legumes. *Exp. Agric.* 25: 367-374.

Mafongoya, P. L. and Nair, P .K. R. (1997) Multipurpose tree prunings as a source of nitrogen to maize (*Zea mays* L.) under semiarid conditions in Zimbabwe. I. Nitrogen recovery rates in relation to pruning quality and method of application. *Agroforestry system* 35: 31-46.

Mafongoya, P. L., Barak, P. and Reed, J. D. (2000) Carbon, nitrogen and phosphorus mineralization of tree leaves and manure. *Biology Fertility Soils* 30: 298-305.

Mafongoya, P. L., Nair, P. K. R. and Dzowela, B. H. (1997) Effect of multipurpose trees, age of cutting and drying method on pruning quality. In: Cadisch, G. and Giller, K.E. (Eds) Driven by nature: plant litter quality and decomposition. CAB International, Wallingford, UK, pp 167-174.

Mafongoya, P. L., Nair, P. K. R. and Dzowela, B. H. (1998) Mineralization of nitrogen from decomposing leaves of multipurpose trees as affected by their chemical composition. *Biology Fertility Soils* 27: 143-148.

Mapa, R. B. and Gunasena, H. P. M. (1995) Effect of alley cropping on soil aggregate stability of a tropical Alfisol. *Agroforestry systems* 32: 237-245.

Maroko, J. B., Buresh, R. J. and Smithson, P. C. (1997) Soil nitrogen availability as affected by fallow-maize systems on two soils in Kenya. *Biol. Fert. Soils.* 26: 229-234.

Mekonnen, K., Buresh, R. J. and Jama. (1997) Root and inorganic nitrogen distributions in sesbania fallow, natural fallow and maize fields. *Plant and soil* 188: 319-327.

Melillo, J. M., Aber, J. D. and Muratone, J. F. (1982) Nitrogen and Lignin control of hard wood leaf litter decomposition dynamics. *Ecology* 63: 621-626.

Migliena, A. M., Rosell, R. A. and Glave, A. E. (1988) Changes of chemical properties of a Haplustoll soil under cultivation in Semi-arid Argentina. p 421-425. In: Unger, P. W. Jordan, W.R. Sneed, T. V. and Jensen R. W. (Eds). Challenge in dryland agriculture- Grobal perspective- proceedings of the International Conference on Dryland Farming, August 15-19, 1988. Texas, USA.

Nye, P. H. and Greenland, D. J. (1960) The soil under shifting cultivation. *Technical Communication* No. 51. Commonwealth Bureau of Soils, Harpenden, UK.

Onim, J. F. M., Mathuva, M., Otieno, K. and Fitzhugh, H. A. (1990) Soil fertility changes and response of maize and deans to green manures of leucaena, sesbania and pigeonpea. *Agroforestry Systems.* 12: 197-215.

Palm, C. A., Myers, R.J. K. and Nandwa, S. M. (1997) Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. In: Replenishing Soil Fertility in Africa. Buresh, R. J., Sanchez, P. A. and Calhoun, F. G. (Eds). pp196-217. SSSA Special Publication No.5!: Soil Science society of America, Madison, WI, USA. Proceedings of an International Symposium.

Palm, C. A. and Sanchez, P. A. (1991) Nitrogen release from the leaves of some tropical legumes as affected by their lignin and polyphenolic contents. *Soil Biol. Biochem* 23: 83-88.

Pereira, H. C., Wood, R. A., Brzostowski, H. W. and Hosegood, P.A. (1958) Water conservation by fallowing in semi-arid tropical East Africa. *Emp. J. Exp. Agr*. 26: 203-228.

Philip, J. R. (1957) The theory of infiltration: 4. Sorptivity and algebraic infiltration equations. *Soil Science* 84: 257-264.

Rhoades, C. C. (1997) Single-tree influences on soil properties in tropical agroforestry systems. *Agroforesty Systems* 38: 3-50.

Sakala, W. D., Gadish, G. and Giller, K. E. (2000) Interactions between residues of maize and pigeonpea and mineral N fertilizers during decomposition and N mineralization. *Soil Biology and Biochemistry.* 32: 679-688.

Sanchez, P. A. (1976) Properties and management of soils in the tropics. New York: John Wiley, pp 618.

Tisdall, J. M. and Oades, J. M. (1983) Organic matter and water stable aggregates in soils. *Journal of Soil Science* 33: 141-163.

Torquebiau, E. F. and Kwesiga, F. (1996) Root development in *Sesbania sesban* fallow-maize system in eastern Zambia. *Agroforestry systems* 34: 193-211.

USDA (United States Department of Agriculture) (1975) Soil Taxonomy, agricultural handbook number 436, Soil Conservation Service, USA.

Yamoah, C. F., Agboola, A. A., Wilson, G. F. and Mulongoy, K. (1986) Soil properties as affected by the use of leguminous shrubs for alley cropping with maize. *Agriculture Ecosystems and Environment.* 18: 167-177.

Yoder, R. E. (1936) A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. *J. Am. Soc. Agron.* 28: 337-351.

Young, A. (1997) Agroforestry for soil management. CAB International, Wallingford, UK and ICRAF, Nairobi, Kenya. pp 276.