Improvement of Soil Fertility by Improved Fallows of *Cajanus cajan*, *Sesbania sesban* and *Tephrosia vogelii* at Gairo in Morogoro, Tanzania

Mgangamundo, M.A., Mugasha, A.G. and S.A.O. Chamshama

Department of Forest Biology, Faculty of Forestry & Nature Conservation,

Sokoine University of Agriculture, P.O. Box 3010, Chuo Kikuu, Morogoro, Tanzania

E-mail: forcons@suanet.ac.tz, Fax: 255 23 260 4648

Abstract

This study was carried out at Gairo in Morogoro, Tanzania to evaluate the effects of fallow periods and fallow types on soil fertility improvement. A split-plot experimental design with three replications was adopted. Three fallow periods (i.e. 1, 2 and 3 years) were involved in this study. Soil pH, EC, OC, total N, available P and total P were significantly (P≤0.05) affected by fallow periods and fallow types. Greater improvement in soil fertility was achieved by the improved fallows of S. sesban, T. vogelii and C. cajan than the natural fallow. Soil fertility was found to increase with increasing fallow period from 1 to 3 years. Continuous cropping for 3 years resulted in greater decline in soil fertility. It is therefore concluded that improved fallows of S. sesban, T. vogelii, and C. cajan have the potential of improving soil fertility and so reduce the problems associated with a decline in soil fertility. Based on the findings of this study, it is recommended that the species be tested on farm and further investigations be carried to examine nutrient dynamics and sustainability of maize crop yield after fallow.

Key words: fallow period, fallow type, natural fallow, continuouns cropping

Introduction

The major soil fertility constraint in the tropics is the inherent low content of nitrogen (N), phosphorus (P), organic matter (OM) and mineral nutrients (Nyamai *et al.*, 1996). Oldeman *et al.* (1991), estimated that about 62 million ha in Africa are affected by the loss of nutrients mainly through agricultural activities. Continuous cropping without external inputs lowers crop yields due to the net removal of nutrients from the soil by the crops. The problem is even more severe in semi-arid areas where soils with low OM, moisture, N, P and other mineral nutrients are common. Sustainable agriculture in these areas therefore requires frequent additions of nutrients and organic materials for maintaining crop growth and yield.

Since poor smallholder farmers cannot afford expensive agricultural inputs, they are looking for alternative ways and means of improving agricultural productivity with low cost inputs. Traditionally, farmers resorted to shifting cultivation farming practice with long fallow period (Mugasha and Nshubemuki, 1988) as a remedial measure to reduced soil fertility and low crop yield. However, with the rapidly escalating population, most farmers cannot practice sufficiently long natural fallow periods to permit complete regeneration of soil fertility. These

*Corresponding author

trends are resulting in shorter fallow periods andsome cases continuous cultivation, rapid soil degradation and decreasing crop yields.

Agroforestry (AF) holds considerable potential as a major land management alternative which is economically sound, and which can ensure increased and sustainable levels of production and at the same time conserve the natural resource base. Following the failure of alley cropping in semi-arid areas due to decline in crop yield as a consequence of increased competition for growth resources especially moisture and nutrients (Chamshama *et al.*, 1998), alternative AF technologies such as improved fallow were then proposed for introduction in these areas. Prinz (1986) defined improved fallow as "an AF technology where soil improving trees or shrubs are planted in a land going to fallow with the aim of improving soil fertility in a short time".

Quantitative information on soil regeneration under fallow is important for soil conservation and for the determination of optimal fallow periods under a set of cultural practices (Jaiyeoba, 1997). Some research work has been done on AF technologies like improved fallow, mixed intercropping and relay cropping (Kwesiga and Coe, 1994; Fasuluku, 1998; Chingonikaya, 1999), however, there is inadequate hard data to substantiate the potential of different fallow-periods of different species on soil fertility improvement. This study was therefore conducted with the aim of comparing the effect of 1, 2, and 3 year old improved fallows of *S. sesban*, *T. vogelii* and *C. cajan* and natural fallow on soil fertility improvement at Gairo, a semi-arid area in Morogoro, Tanzania.

Materials and Methods

Site description

The study site is located at Gairo (36° 45'E, 6° 30'S; 1200 m a.s.l.) in Morogoro Region, Tanzania. The area receives a mean annual rainfall of 499 mm most of which falls between November and May. The experimental area has a slope of approximately 5-10%. Table 1 shows some of the soil physical and chemical properties prior to experimental establishment. The soils are classified as Haplic Lixisols (Msanya and Msaky, 1994).

Prior to experimental establishment, the area was being used for growing maize and sweet potatoes.

Table 1: Some soil chemical and physical properties prior to establishment of the experiment at Gairo, Morogoro, Tanzania

Properties	Soil depth (cm)			
Properties	0-10	10-20	20-30	30-50
Chemical properties				
pH(H_20)	6.00(0.15)[a]	6.19(0.16)	6.24(1.09)	6.33(0.17)
EC dSm^{-1}	0.04(0.06)	0.03(0.06)	0.03(0.08)	0.02(0.06)
OC(%)	1.52(0.13)	1.26(0.12)	0.84(0.20)	0.41(0.08)
Bray-1P(Mgk g^{-1})	3.33 (0.13)	1.87(0.14)	1.76(0.12)	1.31(0.08)
Total P ($mgkg^{-1}$)	243(0.62)	261(0.71)	269(0.92)	232(2.25)
Total N(%)	0.12(0.07)	0.08(0.06)	0.09(0.04)	0.08(0.06)
Physical properties				
Bd(g cm^{-3})	1.18(0.08)	1.31(0.06)	1.34(0.05)	1.37(0.05)
Silt (%)				
Clay (%)	3.20(0.10)	2.40(0.57)	6.26(0.18)	4.24(0.11)
Sand (%)	11.10(0.14)	S17.10)0.08)	21.79(0.36)	29.48(0.74)
Textural class	85.70(0.89)	80.50(0.69)	71.94(0.65)	66.27(0.59)
	Loamy sand	Sand loam	Sandy clay loam	Sandy clay loam

[a]Mean of three replications with standared error in parenthesis.

Experimental design and treatments

The experiment was established using a split-plot design with three replications. The major treatments were 1, 2 and 3 year fallows while minor treatments were S. sesban, T. vogelii, C. cajan, natural fallow and continuous cropping.

Experimental establishment and management

The experimental area was ploughed and harrowed in December 1995. For each block, there were 3 major plots each measuring 20 x 50 m. Each major plot was split into five minor plots of size 10 x 20 m. Planting of shrubs and sowing of maize in the minor plots was done as shown in Table 2. The shrubs were planted at a spacing of 1 x 2 m. Maize variety MTV 1 was planted in the continuously cropped plots at a spacing of 0.45 x 0.9 m. Weeding was done twice during the cropping season and once during the dry season. At the end of the fallow period, all the trees/shrubs were harvested.

Table 2: Planting schedule of an experiment to compare the effect of 1,2 and years improved fallows of three shrub species and natural fallow and different year of cropping at Gairo, Morogoro, Tanzania

Treatment	Year 1	2	3	4
1	Ss[a]	Ss	Ss	C
2	C	Ss	Ss	C
3	C	C	Ss	C
4	Tv	Tv	Tv	C
5	C	Tv	Tv	C
6	C	C	Tv	C
7	Cc	Cc	Cc	C
8	C	Cc	Cc	C
9	C	C	Cc	C
10	Nf	Nf	Nf	C
11	C	Nf	Nf	C
12	C	Nf	Nf	C
13	C	C	C	C
14	Nf	C	C	C
15	Nf	C	C	C

[a]Ss-Sesbania sesban, Tv-Tephrosia vogelii, Cc-Cajanis cajan, Nf - Natural fallow, C- Maize cropping

Soil sampling for initial site characterization after fallow periods

Just after laying out the experiment in December 1995, soil samples were taken to record the initial soil conditions. Within each block, five soil pits were randomly dug, soil samples collected at 0-10, 10-20, 20-30, 30-50 cm soil depth, bulked by soil depth, mixed thoroughly and subsamples taken for laboratory analysis. Soil bulk density (Bd) was determined as described by Landon (1991). To characterize the soils after each fallow period, soil samples were taken from each minor plot soon after harvesting of shrubs. For each minor plot, soil samples were taken from five randomly selected points at 0-10, 10-20, 20-30 and 30-40 cm soil depth, bulked by soil depth, mixed thoroughly and then a subsample taken for laboratory analysis.

Analysis of soil samples for site characterization

Soil particle size analysis was carried out by the hydrometer method as described by Bouyoucos (1962). Total N was was determined by semi-micro Kjeldahl procedure (Bremner and Mulvaney, 1982) while total P was determined calorimetrically as described by Anderson and Ingram (1993). Available P was determined by Bray-1 method. Soil pH was determined by pH-meter using 1:2.5 soil:water ratio as described by Okalebo et al. (1993). Soil OC was determined by wet combustion method and soil bulk density was calculated according to Anderson and Ingram (1993).

Data analysis

All statistical analyses were carried out using General Linear Models (GLM) of Statistical Analysis Systems (SAS) (SAS Inst. Inc. 1987). For the site characterization after fallows, data were sorted by fallow periods and fallow types. All the data were then subjected to analysis of variance (ANOVA) of a split plot design. A fixed equation (model) for split plot design was fitted for carrying out the analysis. Thereafter, Duncan's Multiple Range Test (DMRT) was used to separate significantly different means.

$$Y_{ijk} = \mu + B_i + P_{(ij)} + \epsilon_{(ij)} + S_k + BS_{ik} + PS_{(i)jk} + \epsilon_{(ijk)} \quad \ldots\ldots 1$$

$i = 1, 2, 3 \quad j = 1, 2, 3 \quad k = 1, 2, 3, 4, 5$

Where: Y_{ijkl} = variable to be analysed

μ = overall mean

B_i = effect of the i^{th} block

$P_{(ij)}$ = effect of the j^{th} fallow period (random) in the i^{th} block

$\epsilon_{(ij)}$ = first restriction (Error I)

S_k = effect of the k^{th} fallow type

BS_{ik} = effect of the interaction of the i^{th} block with the k^{th} fallow type

$PS_{(i)jk}$ = effect of the interaction of the j^{th} fallow period in the i^{th} block with the k^{th} fallow type

$\epsilon_{(ijk)}$ = second restriction error (Error II)

Results

Soil pH and electrical conductivity

Significant (P<0.05) differences in soil pH were observed between the fallow types in all the soil depths and between fallow periods at 10 – 20 cm soil depth (Fig. 1a). The general trend in soil pH was an increase with increasing soil depth (0 – 40 cm) (Fig. 1a). For the continuously cropped plots, soil pH kept on declining with increasing years of continuous cropping. Generally a greater improvement in soil pH was observed in *S. sesban* improved fallow, followed by *T. vogelii*, *C. cajan*, natural and continuous cropping in that order (Fig. 1a). In 3 year old improved fallow, at 0 – 10 cm soil depth, *S. sesban* had the highest soil pH of 7.3, followed by *T. vogelii* plots with 7.3, *C. cajan* 7.1 and natural fallow 6.4. The lowest soil pH was observed from plots which have been continuously cropped for 3 years i.e. 5.5.

Soil EC differed significantly ($P<0.05$) between fallow periods and fallow types in all the soil depths (Fig. 1a). In all fallow periods, *S. sesban* resulted into greater soil electrical conductivity than the other fallow species. It was followed by *T. vogelii*, *C. cajan* and the natural fallow (Fig. 1a). The least EC values came from continuously cropped plots. Soil EC in *S. sesban* plots ranged from 0.08 to 0.21 dS m^{-1} (1 - 3 year fallow), *T. vogelii* 0.08 to 0.17 (1 - 3 year fallow), *C. cajan* 0.07 to 0.18 (1 - 3 year fallow) and continuous cropping 0.09 to 0.04 (1 - 3 year fallow).

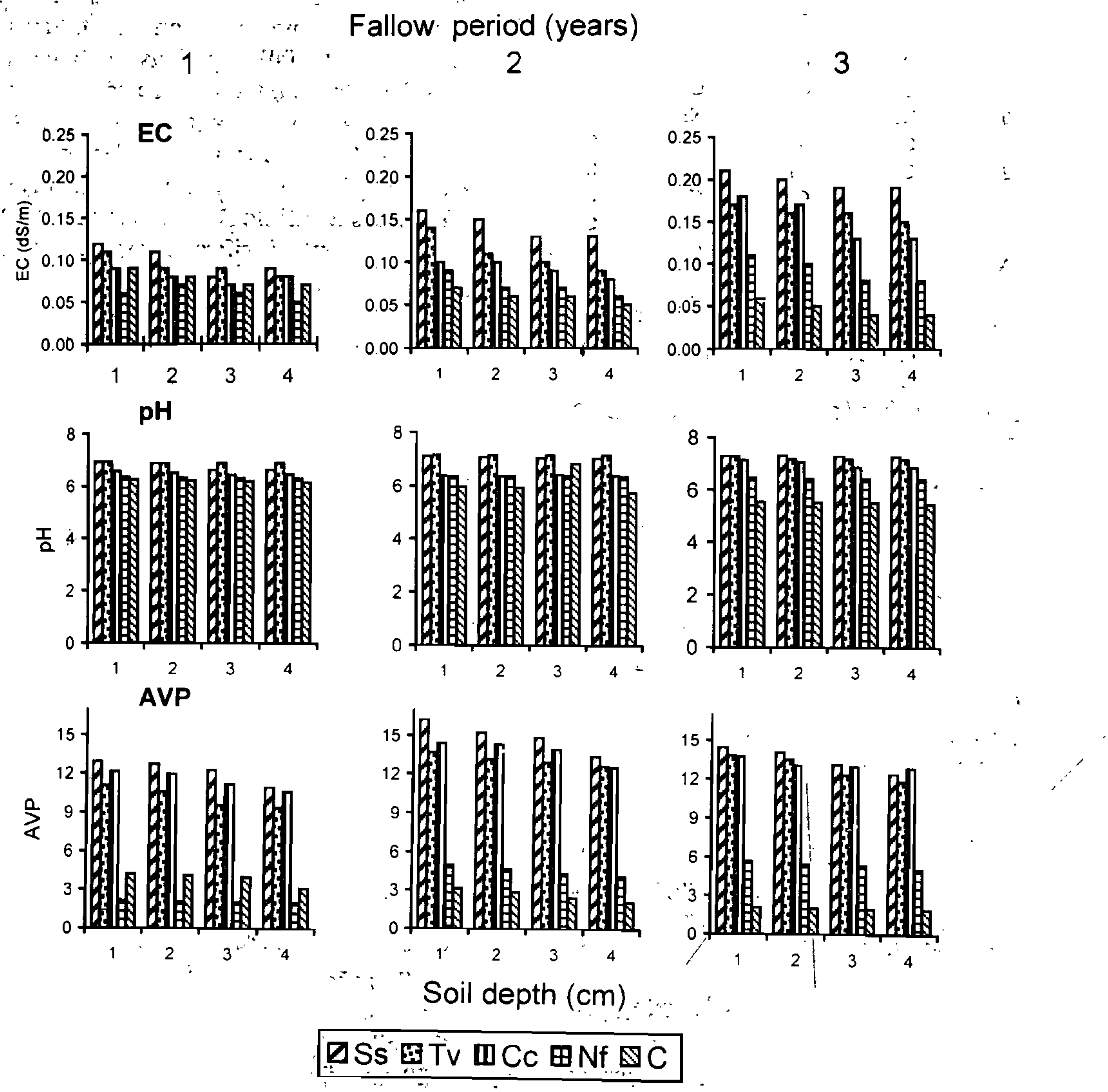

Figure 1a: Effect of improved fallows of leguminous shrubs on selected soil chemical properties at Gairo in Morogoro Tanzania.(Ss= *S.sesban*, Tv=*T.vogelii*, Cc=*C.cajan*, Nf=Natural fallow, C=Continuous cropping. 1=0-10, 2=10-20, 3=20-30, 4=3-40cm. EC=electrical conductivity, AVP=available Phosphorus).

Soil available P

Significant ($P<0.05$) differences were observed in soil available P (Bray-1 P) between fallow periods and fallow types (Fig. 1a). Increase in soil available P was generally observed as the fallow period increased (Fig. 1a). *Sesbania sesban* improved fallow resulted into greater soil available P in all the fallow periods, followed by *C. cajan*, *T. vogelii* and the natural fallow. The least soil available P value was obtained from continuously cropped plots.

In 1 year fallow (0 - 40 cm depth), soil available P from *S. sesban* ranged from 11.1-12.9 mg P kg^{-1}, *C. cajan* (10.6-12.1 mg P kg^{-1}), *T. vogelii* (9.4-11.1 mg P kg^{-1}), natural fallow (2.0-2.1 mg P kg^{-1}) and continuous cropping (3.1-4.2 mg P kg^{-1}). In a 2 year fallow, the results were *S. sesban* (13.4-16.3 mg P kg^{-1}), *C. cajan* (12.6-14.4 mg P kg^{-1}), *T. vogelii* (12.7-13.7 mg P kg^{-1}), natural fallow (4.2-5.0 mg P kg^{-1}) and continuous cropping (2.1-3.1 mg P kg^{-1}). For the 3 year fallow available P from *S. sesban* ranged from 12.4-14.5 mg P kg^{-1},*C. cajan* (12.9-13.7 mg P kg^{-1}), *T. vogelii* (11.9-13.8 mg P kg^{-1}), natural fallow (5.1-5.7 mg P kg^{-1}) and continuous cropping (1.9-2.1 mg P kg^{-1}).

Soil organic carbon

Significant ($P<0.05$) differences were observed on the effects of improved fallows of leguminous shrubs, natural fallow and continuous cropping on soil OC (Fig. 1b). Generally, the trend was an increase in soil OC with increase in fallow period (1 – 3 years) and a decrease in soil OC with increasing soil depth from 0 – 40 cm. For 1 and 2 year fallows in all the soil depths *S. sesban* improved fallow resulted in greater soil OC than the other improved fallow shrub species, the natural fallow and continuous cropping (Fig. 1b). In 1 year fallow (0 - 40 cm depth), soil OC from *S. sesban* fallow ranged from 1.8-1.9%, *T. vogelii* (1.5-1.7%), *C. cajan* (1.1-1.5%), natural fallow (0.6-1.0%), and continuously cropped plot (0.5-0.8%). In the 2 year fallow, soil OC for *S. sesban* ranged from 2.6-2.7%, *T. vogelii* (2.3-2.5%), *C. cajan* (1.2-1.6%), natural fallow (0.7-1.3%) and continuously cropped plot (0.5-0.7). For the 3 year fallow soil OC from *S. sesban* ranged from 1.9-2.4%, *T. vogelii* (2.2-2.3), *C. cajan* (1.1-1.3%), natural fallow (0.8-1.3%) and continuously cropped plot (0.5-0.6%).

Soil total N

Soil total N differed significantly ($P<0.05$) between fallow periods and fallow types at 0 – 10, 20 – 30 and 30 – 40 cm soil depths (Fig. 1b). No significant ($P>0.05$) differences were observed in soil total N between fallow periods and fallow types at 10 – 20 cm soil depth. Generally, greater soil total N was observed from *S. sesban* improved fallow plots, followed by *T. vogelii*, *C. cajan* and the natural fallow. The lowest values of soil total N were obtained from continuously cropped plots.

In 1 year fallow (0 - 40 cm soil depth), soil total N from *S. sesban* ranged from 0.13-0.20%, *T. vogelii* (0.10-0.19%), *C. cajan* (0.08-0.11%), natural fallow (0.05-0.07%) and continuous cropping (0.07-0.10%). In 2 year fallow, the ranges of soil total N were as fallows, *S. sesban* (0.12-0.25%), *T. vogelii* (0.18-0.21%), *C. cajan* (0.09-0.13%), natural fallow (0.07-0.09%) and continuous cropping (0.05-0.08%). From the 3 year fallow, *S. sesban* had 0.13-0.26%, *T. vogelii* (0.17-0.21%), *C. cajan* (0.12-0.15%), natural fallow (0.08-0.11%) and continuous cropping (0.03-0.07%).

Soil total P

Significant ($P<0.05$) differences were observed in soil total P between the fallow periods and fallow types (Fig. 1b). Generally soil total P increased with increasing fallow period in all the fallow types. *Sesbania sesban* improved fallow resulted into the highest soil total P values in all the fallow periods, followed by *T. vogelii*, *C. cajan* and natural fallow. The lowest soil total P values came from the continuously cropped plots.

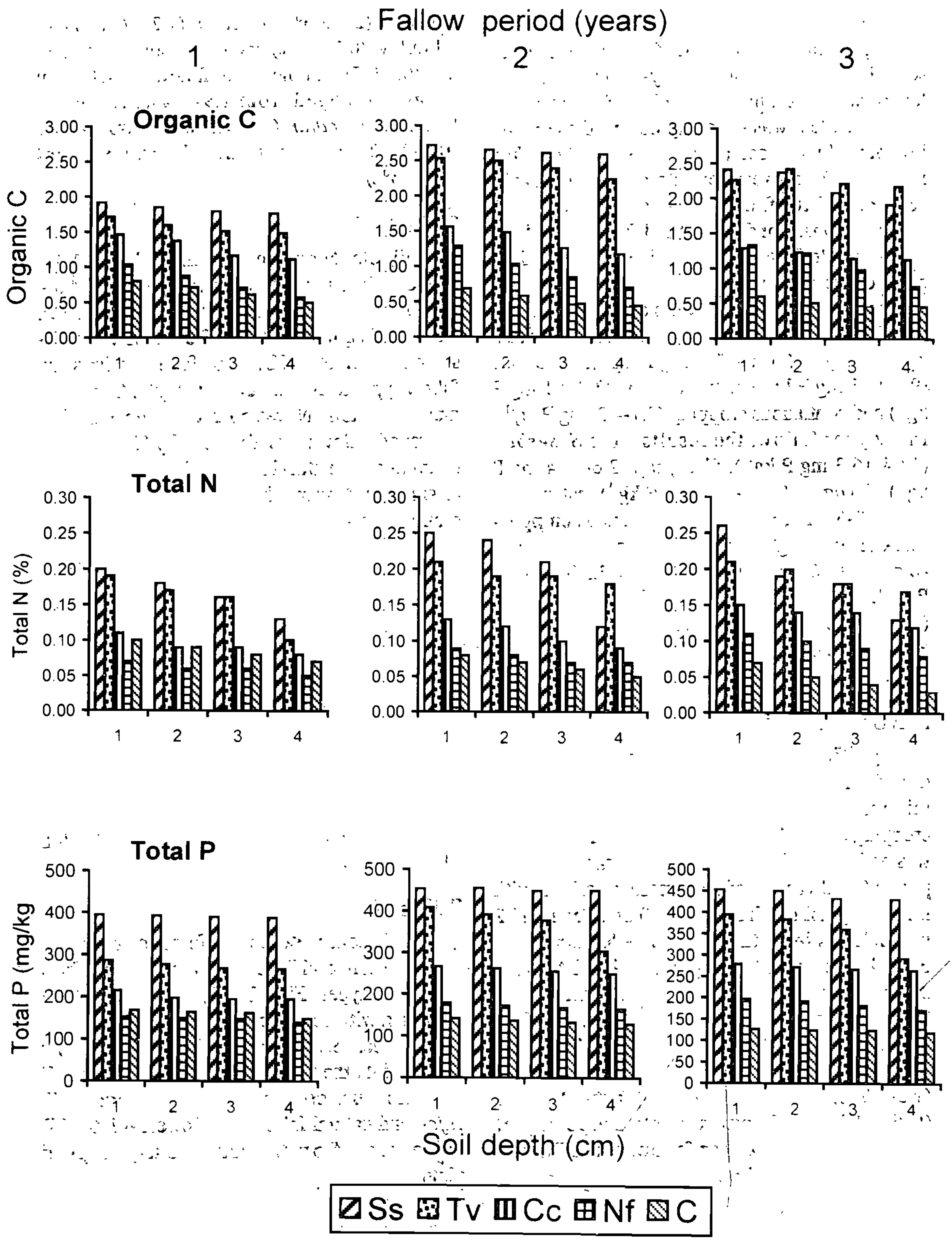

Figure 1b: Effect of improved fallows of leguminous shrubs on selected soil chemical properties at Gairo in Morogoro Tanzania.(Ss= *S.sesban*, Tv=*T.vogelii*, Cc=*C.cajan*, Nf=Natural fallow, C=Continuous cropping. 1=0-10, 2=10-20, 3=20-30, 4=3-40cm. Orgaic C=Organic carbon, N=Nitrogen, P=Phosphorus).

In 1 year fallow (0 - 40 cm soil depth), soil total P from *S. sesban* ranged from 388-395 mg P kg^{-1}, *T. vogelii* (267-287 mg P kg^{-1}), *C. cajan* (195-215 mg P kg^{-1}), natural fallow (139-153 mg P kg^{-1}) and continuous cropping (149-168 mg P kg^{-1}). In 2 year fallow, the results were, *S. sesban* (450-454 mg P kg^{-1}), *T. vogelii* (305-408 mg P kg^{-1}), natural fallow (250-267 mg P kg^{-1}) and continuous cropping (166-180 mg P kg^{-1}). For the 3 year fallow, soil total P from *S. sesban* ranged from 432-454 mg P kg^{-1}, *T. vogelii* (294-395 mg P kg^{-1}), *C. cajan* (265-279 mg P kg^{-1}), natural fallow (172-197 mg P kg^{-1}) and continuous cropping (120-127 mg P kg^{-1}).

Discussion

Soil pH and electrical conductivity

The results on soil pH showed a great change in soil pH following improved fallow practice. Changes in soil pH after a fallow period have been reported by several authors (Juo and Lal, 1977; Onim *et al.*, 1990; Chingonikaya, 1999). The soil pH increase following a fallow period observed in this study is probably due to the capture of the basic cations (accumulated in the subsoil) by the deep rooted shrubs and their subsequent transfer to surface soil in the form of leaf litter, roots and prunings (natural) of shrub leaves and branches. These inputs might have resulted in an increase in the basic cations on the surface soil and thus an increase in soil pH. Deep rooting and capture of subsoil nutrients by the trees has also been reported by Buresh and Tian (1998).

The observed increase in soil pH following improved fallow of the leguminous shrubs agrees with the findings of Juo and Lal (1977) who observed an increase in soil pH following *C. cajan* and *Leucaena leucocephala* improved fallow from a study done in lowland rain forest zone of Nigeria. This observation is also in line with the findings of Onim *et al.* (1990) and Chingonikaya (1999) who noted an increase in soil pH following improved fallows of *L. leucocephala; S. sesban and C. cajan* in Kenya (Onim *et al.*, 1990) and *C. cajan*, *G. sepium*, *S. macrantha* and *S. sesban* at Gairo, Morogoro in Tanzania (Chingonikaya, 1999).

Increases in soil EC after a fallow period were observed in this study. The values of soil EC observed from 2 year fallows in this study are comparable with those reported by Chingonikaya (1999) in a 2 year improved fallow study conducted at Gairo. Very little improvements in EC were noted in the natural fallow plots and a decline in EC was observed in plots which were continuously cropped with maize. The probable cause of the noted increase in soil EC in improved fallow plots is the improvement in soil exchangeable cations following improved fallows of leguminous shrubs.

Soil organic carbon

Studies have shown higher soil OM in topsoil under trees than in open areas (Mordelet *et al.*, 1993; Trouve *et al.*, 1994). Belsky *et al.* (1993) for example, reported higher soil OM at 0 - 15 cm soil depth under *Acacia tortilis* and *Adansonia digitata* in a savanna in Kenya. The increase in soil OC observed in this study under the improved fallows of leguminous shrubs is therefore the result of OM additions to the soil by the shrubs during the fallow period through litter fall and root turnover.

The effect of trees on soil OM varies among tree species and soils. The observed higher values of OC from *S. sesban* than those of *T. vogelii, C. cajan* and the natural fallow (Fig. 1b) are probably the result of high foliage biomass production (Mgangamundo, 2000) and root turnover by this species. In a study by Mgangamundo (2000) on biomass production from improved fallows, 2 years old *S. sesban* fallow was reported to have a foliage biomass production of 18 t ha^{-1}. In the same study the other shrub species had foliage biomass production of 3.65 t ha^{-1} (*T. vogelii*) while *C. cajan* had only 1.45 t ha^{-1}. Additionally, differences in soil OC between the shrub species may also be due to variations in decomposition rates among the legume species. Fasuluku (1998) in a study conducted in Morogoro, Tanzania reported that decomposition rates of *Gliricidia sepium* and *S. sesban* green manure was faster than that of *Senna siamea* and *Albizia lebbeck*, with that of *T. vogelii* showing the slowest rate.

The values of soil OC from 2 year fallows of *C. cajan*, *S. sesban* and the natural fallow are comparable to those reported in improved fallow study at Gairo, Tanzania by Chingonikaya (1999). Higher values of soil OC from improved fallow than the natural fallow have also been reported from improved fallow studies conducted in the forest areas of Nigeria by Adesina (1990). Since high carbon content in the soil is directly associated with larger humus quantities and increased soil fertility (Onim *et al.*, 1990), it implies that the three shrub legumes involved in this study have increased the fertility of the soil.

Soil total N

Improved fallows of leguminous shrubs in this study resulted in some improvements in soil total N. Improvement in soil total N following improved fallows have also been reported in Kenya by Onim *et al.* (1990). Improved fallow of *S. sesban* resulted in greater soil total N than what was observed from other leguminous shrub species. This result was expected since different *Sesbania* species have been reported as good sources of N in green manure studies.

Soil total and available P

Improved fallows of the leguminous shrubs resulted in greater improvement in soil total and available P. Improvement in soil total and available P following improved fallows at Gairo have also been reported by Chingonikaya (1999). Greater soil total and available P values were obtained from *S. sesban* improved fallow plots. The greater soil total P observed in this study following *S. sesban* fallow agrees with the findings of Onim *et al.* (1990). The author reported that *S. sesban* added significantly more P into the soil (31.4 kg P ha^{-1} yr^{-1}) as compared to *C. cajan* and *Leucaena leucocephala* that contributed only 4.1 and 4.6 kg P ha^{-1} yr^{-1} respectively. *Sesbania sesban* with its deep roots is capable of pumping up exchangeable bases from the subsoil. Since P has been observed to have positive relationships with K, Na and Ca with correlation coefficients of 0.75, 0.69 and 0.69 respectively (Onim *et al.* 1990), these facts may partly explain high P addition in *Sesbania* plots than in the other shrub species, the natural fallow and in the continuously cropped plots. The observed decline in soil available P with increasing soil depth agrees with the findings by Hartemink (1997) in a study done in Tanga, Tanzania where he also noted a decrease in soil available P with increasing soil depth.

Conclusions and recommendations

Conclusions

This study has shown that compared with the natural fallows and continuous cropping, significant differences should be expected when leguminous shrubs such as S. sesban, T. vogelii and C. cajan are used as planted fallows in semi arid areas like Gairo, Tanzania. The analysed soil fertility changes following improved fallows of S. sesban, T. vogelii and C. cajan have shown that improved fallows were outstanding in all the aspects measured.

Recommendations

(i) Following the impressive performance of shrub/tree species in soil fertility improvement on farm trials of these species should be initiated so as to examine the performance of the species under farmer managed fields.

(ii) Further investigations should be carried out on the site to examine nutrient dynamics and sustainability in crop yield after 1, 2 and 3 year fallow.

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