

**EFFECT OF FALLOW PERIODS OF *CAJANUS CAJAN*, *SESBANIA SESBAN*
AND *TEPHROSIA VOGELII* ON SOIL FERTILITY IMPROVEMENT AND
MAIZE AND FIREWOOD PRODUCTION AT GAIRO IN MOROGORO,
TANZANIA**

BY

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ABSTRACT

This study was carried out at Gairo, a semi-arid area, in Morogoro, Tanzania to evaluate the effects of fallow periods and fallow types and nitrogen and phosphorus fertilization on soil fertility improvement, maize growth and yield and firewood production. A split-split plot experimental design with three replications was adopted. The major factor was: fallow period (1, 2 and 3 year fallows) and the sub-major factor was fallow type (*Sesbania sesban* (L) Merril, *Tephrosia vogelii* (F) Hook, *Cajanus cajan* (L) Millsp, natural fallow and continuous cropping, while the minor factor was fertilization (0 kg N and 0 kg P ha⁻¹; 0 kg P and 40 kg N ha⁻¹; 0 kg N and 40 kg P ha⁻¹; 40 kg N and 40 kg P ha⁻¹). Tree/shrub species differed significantly ($P < 0.05$) in total biomass production with *C. cajan* outranking others in 1 year fallow i.e. 10 t ha⁻¹ and the least value coming from *T. vogelii* (5.44 t ha⁻¹). In 2 year fallow, *S. sesban* was outstanding (69.84 t ha⁻¹) and the lowest value being achieved by *C. cajan* (6.79 t ha⁻¹) while in 3 year fallow, *S. sesban* was still outstanding with 46.02 t ha⁻¹ and the lowest value was from *C. cajan* (8.25 t ha⁻¹). Shrub wood and foliage N and P concentration also differed significantly with fallow period and shrub species. Wood N concentration from 2 year fallow of *S. sesban* was the highest (1.08%) and the lowest value in 2 year fallows was from *T. vogelii* (0.95%). In wood P concentration, 2 year fallow of *T. vogelii* outranked the other shrub species (0.136%) and the lowest value in 2 year fallows came from *C. cajan* (0.31%). For foliage N concentration, 2

year fallow of *S. sesban* was outstanding (2.94%) and the least foliage N concentration value in 2 year fallows was from *C. cajan* (2.52%). In foliage P concentration from 2 year fallows *T. vogelii* had the highest value (0.198%) and the lowest P concentration value in 2 year fallows came from *C. cajan* (0.179%). In litter N concentration the values were *T. vogelii* (1.75%), *C. cajan* (1.67%) and *S. sesban* (1.61%). While the values for litter P concentration were *T. vogelii* (1.85%), *S. sesban* (1.79%) and *C. cajan* (1.36%). Greater improvement in soil fertility was achieved by *S. sesban*. The soil electrical conductivity ranged from 0.11 dS m⁻¹ for 3 year natural fallow to 0.21 dS m⁻¹ for 3 year *S. sesban* fallow, organic carbon 1.33% (3 year natural fallow) to 2.41% (3 year *S. sesban*), total N 0.11% (3 year natural fallow) to 0.26% (3 year *S. sesban*), available P 5.73 mg P kg⁻¹ (3 year natural fallow) to 14.45 mg P kg⁻¹ (3-year *S. sesban*). Maize growth, yield and N and P uptake and maize leaf N and P concentration and content were significantly ($P < 0.05$) affected by fallow periods, types and fertilization. Maize heights were highest in 3 year fallows than in 2 and 1 year fallows. The range of maize height from 1 to 3 year fallows was *T. vogelii* (1.23 – 1.25 m), *S. sesban* (1.12 – 1.25 m), *C. cajan* (1.12 – 1.24 m), natural fallow (1.00 – 1.17 m) and continuous cropping (1.14 – 0.88 m). *Tephrosia vogelii* was outstanding in maize yield improvement. The range in maize yield from 1 to 3 year fallow without fertilizer application was *T. vogelii* (4.80 – 6.55 t ha⁻¹), *S. sesban* (2.54 – 3.95 t ha⁻¹), *C. cajan* (2.09 – 5.43 t ha⁻¹), natural fallow (1.61 – 3.03 t ha⁻¹) and continuous

cropping (2.66 – 1.63 t ha⁻¹). When fallow period, fallow type and fertilization are considered, maize grain yield from 1, 2 and 3 year unfertilized fallow plots was from *T. vogelii* (3.32, 4.41 and 5.38 t ha⁻¹), *S. sesban* (1.97, 2.48 and 3.24 t ha⁻¹), *C. cajan* (1.66, 2.47 and 4.78 t ha⁻¹), natural fallow (1.02, 1.25 and 2.47 t ha⁻¹) and continuous cropping (2.16, 1.80 and 1.16 t ha⁻¹). Maize grain yield from 1, 2 and 3 year fallow plots which received half of recommended dose of N and recommended full dose of P was *T. vogelii* (7.30, 6.85 and 8.30 t ha⁻¹), *S. sesban* (3.28, 4.26 and 5.04 t ha⁻¹), *C. cajan* (2.87, 7.53 and 6.79 t ha⁻¹), natural fallow (2.16, 2.21 and 3.59 t ha⁻¹) and continuous cropping (3.21, 2.87 and 2.01 t ha⁻¹). Maize grain and stover N and P concentration and content was also found to increase with increasing fallow periods and the highest values being obtained from improved fallows than the natural fallow and continuously cropped plots. It is therefore concluded that improved fallows of *T. vogelii*, *S. sesban* and *C. cajan* have the potential of improving soil fertility and subsequent maize yield and so reduce the problems associated with a decline in soil fertility. Two years is the optimum fallow period for *T. vogelii* and *S. sesban* while for *C. cajan* the period is 3 years under the Gairo conditions. Based on the findings of this study the following are recommended: (i) For greater crop yield improvement *T. vogelii* should be used as a fallow species at Gairo and other areas with similar ecological conditions; (ii) For optimal maize crop yield following a fallow period the use of 40 kg N ha⁻¹ and 40 kg P ha⁻¹ is recommended; (iii) On-farm trials of *T. vogelii*

should be initiated; (iii) Further investigations should be carried out on the same site to examine nutrient dynamics and sustainability of maize crop yield after fallow.

DECLARATION

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

Signature.....

Date.....25/9/2000

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DEDICATION

This dissertation is dedicated to my beloved father Ayubu Mgangamundo and mother Asha, my brother Said and my young sister Fatuma.

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ABBREVIATIONS

AF	Agroforestry
ANOVA	Analysis of variance
a.s.l.	Above sea level
Bd	Bulk density
BNF	Biological nitrogen fixation
C	Continuous cropping
CEC	Cation exchange capacity
Cc	<i>Cajanus cajan</i>
Conc.	Concentration
Cont.	Content
d10	Diameter at 10 cm above ground
d30	Diameter at 30 cm above ground
DAS	Days after sowing
E	East
EC	Electrical conductivity
e.g.	For example
<i>et al.</i>	And others
etc.	And many more
GLM	General linear model
ht	Height
i.e.	That is
ICRAF	International Centre for Research in Agroforestry
ln	Base of natural logarithm
Mineral-N	Mineral nitrogen

N	Nitrogen
Nf	Natural fallow
NO ₃ ⁻	Nitrate ion
NO ₂	Nitrous oxide
OC	Organic carbon
OM	Organic matter
pH	Hydrogen ion concentration
PR	Phosphate rock
R ²	Coefficient of determination
RCD	Root collar diameter
S	South
SAS	Statistical analysis system
Ss	<i>Sesbania sesban</i>
SE	Standard error
SUA	Sokoine University of Agriculture
TP	Total phosphorus
TN	Total nitrogen
Tv	<i>Tephrosia vogelii</i>

SYMBOLS

cm	Centimetre
°C	Degree centigrade
°E	Degree east
°S	Degree south
=	Equal to
g	Gramme
g cm ⁻³	Gramme per cubic centimetre
>	Greater than
<	Less than
ha	Hectare
kg	Kilogramme
m	Metre
M	Molar
mm	Millimetre
%	Percent
t	Tonne

CHAPTER 1

1.0 INTRODUCTION

The continuing decline in soil fertility status has led into low crop production in most tropical countries including Tanzania. The decline of soil fertility has been caused by such factors as continuous cultivation without application of inorganic fertilizer or manure, soil erosion and low inherent soil fertility. 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 (Bharadwaj and Omanwar, 1994; Hartemink, 1997). The removal of large quantities of crop produce from the land depletes soil of its native nutrient reserves (Bohloul *et al.* 1992). Nevertheless, soil fertility depletion and degradation in agricultural systems does not only originate from the removal by crops, but also can occur as a result of soil-working which may increase soil compaction and losses of nutrients either by leaching or erosion.

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). With agriculture being the mainstay of the Tanzanias' economy, low crop production has both social and economic implications. The problem is even more severe in semi-

arid areas where soils with low OM, moisture, N, P and mineral nutrients are common. All these are contributing factors to low crop yields. Sustainable agriculture in these areas therefore requires frequent additions of nutrients and organic materials for maintaining crop growth and yield.

Farmers are quite aware of the potential of inorganic fertilizers to ameliorate poor soil fertility. However, use of inorganic fertilizers seems infeasible because of the meager capital resources of most smallholder farmers. The situation has been exacerbated by recent structural adjustment programmes (SAPs) under which governments have removed subsidies on farm inputs. Agricultural productivity has thus apparently continued to decline with time. Since poor smallholder farmers can not afford expensive agricultural inputs, they are eagerly looking for alternative ways and means of improving agricultural productivity with low cost inputs (ICRAF, 1995).

Traditionally, farmers resorted to shifting cultivation farming practice with long fallow period (Nair, 1984, 1993; Oxyby and Boerboom, 1985; 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 trends are resulting in shorter fallow periods, rapid soil degradation and decreasing crop yields, scarcity of wood and tree products and scarcity of fodder

for livestock (Otsyina and Karachi, 1998). More productive soil and crop management systems must therefore be developed for tropical soils of characteristically low fertility presently under shifting cultivation. This situation has promoted an intensified search for sustainable land-use systems that satisfy human needs without destroying the natural resource base. The consensus is that the low productivity and environmental degradation facing many developing countries could be addressed better through the adoption of integrated land use systems which take into account the physical, biological and socio-economical factors in any locality. Introduction of less land demanding agroforestry technologies was then proposed as one way of reducing deforestation and achieving more sustainable land use practices.

Agroforestry (AF) has been defined as “a dynamic, ecologically based, natural resources management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits” (ICRAF, 1997). Agroforestry 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. The use of AF may avoid many of the problems associated with monoculture plantations reducing the risk to farmers of crop loss and the need for agro-chemical application (Simons and Chagala, 1996). A frequently cited hypothesis for the benefit of intergrating trees with crops is that deep

roots of trees can capture and pump up nutrients such as nitrate, that leach below the crop root zone (Van Noordwijk *et al.* 1996). Different AF technologies such as alley cropping or hedgerow intercropping, mixed intercropping, relay cropping and improved fallow are used to increase yield of cereal crops such as maize in various places (Ngiumbo and Balasubramanian, 1994; Kwesiga and Coe, 1994; Niang *et al.* 1996).

Alley cropping technologies introduced in semi-arid areas of Tanzania and other parts of the tropics to solve problems associated with traditional shifting cultivation have, in most cases failed. This is because two to three years after planting the yield of food crops declines gradually due to competition for growth resources especially moisture and nutrients (Szott *et al.* 1991; Haggar and Beer, 1993; Tilander *et al.* 1995; Matta-Machado and Jordan, 1995; Jama *et al.* 1995; Chamshama *et al.* 1998). Against this background, there is a need for developing alternative AF technologies for semi-arid areas of Tanzania. One of such AF technologies is the "improved fallows". Improved fallow systems are expected to provide faster, yet similar ecological benefits as natural fallow.

Prinz (1986) defined improved fallow as "an agroforestry 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". Traditional fallows take several years to

restore fertility because natural vegetation is slow in reaching the peak of biological productivity (Niang *et al.* 1996). In contrast, in improved fallows, fast growing trees are selected, planted and managed in fallows to grow and mature within a short time thereby enhancing soil fertility by bringing up nutrients from lower soil layers, litter fall and atmospheric nitrogen fixation (Wani *et al.* 1995). Enriched short fallows with suitable tree species as a means of adjusting to the shortening fallow period has potential for adoption by many farmers. This is because it involves minor modification of the traditional system, and does not take the farmers away from what they are familiar with. Such fallows would also allow increased frequency of cultivation while maintaining or even increasing the productivity of the land.

Trees in planted fallows can increase the availability of nutrients to subsequent crops through increased release of nutrients from soil organic matter and recycled organic residues (Buresh and Tian, 1998). The maintenance of adequate levels of soil OM is therefore one of the main components of soil fertility management in low-input land use systems in the tropics (Young, 1989). Organic matter addition is known to improve and maintain soil fertility (Palada *et al.* 1992). This is so because the formation and turn over of soil OM, primarily driven by the activity of the soil microbial biomass, are closely coupled to the cycling of nutrients in the soil (Cambardella and Elliot, 1993). Mineralisation of decomposing residues is a major source of plant nutrients in highly weathered soils with little inherent mineral fertility

(Woomer *et al.* 1994). Yet in many tropical cropping systems, little or no agricultural residues are returned to the soil. This leads to a decline in soil OM which frequently results in lower crop yields. Overcoming soil OM decline is thus an important component in the development of more sustainable agroecosystems and the reduction of natural habitat destruction characteristics of shifting agriculture (Woomer *et al.* 1994). Several studies have reported higher soil OM in top soil under trees than in open areas (Mulongoy *et al.* 1993; Mordelet *et al.* 1993; Trouve *et al.* 1994). One of the major aims of agroforestry is therefore to increase the availability of biomass for soil amendment by introduction of highly productive tree species into cropping systems. Perennial legumes such as *Sesbania sesban* (L) Merril, *Tephrosia vogelii* (F) Hook and *Cajanus cajan* (L) Millsp may provide potential sources of OM necessary for the maintenance of soil fertility status of the soil. Legumes have been used in crop rotations to enhance soil fertility and crop production since ancient times. However, during the past two decades, interest in legumes and their role in cropping systems has increased in response to the energy dependence of inorganic fertilizers, concern over soil erosion, and leaching of nutrients and associated ground water contamination (Watters *et al.* 1992).

The problems of deforestation, soil degradation due to more intensive systems of cultivation and the high costs of purchased inputs resulted in research efforts aiming at developing AF technologies to reduce some of these problems. 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). Recently a great deal of research has been done on AF technologies (eg. Improved fallow, mixed intercropping and relay cropping), and data have been collected on the potential of these systems for improvement of soil fertility (Adejuwon and Adesina, 1990; Kwesiga and Coe, 1994; Baxter, 1995; Fasuluku, 1998; Chingonikaya, 1999). However, there is inadequate hard data to substantiate the potential of different fallow periods of different species on soil fertility, firewood and crop yield improvement in semi-arid areas. Therefore, identification of the appropriate species and short fallow periods for maximized crop yields still need further investigation. 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*, natural fallow and continuous cropping on soil fertility improvement, firewood production and maize yield at Gairo in Morogoro, Tanzania.

The specific objectives were to:

- (a) screen multipurpose shrub species that can improve soil fertility in a shorter time.

- (b) evaluate the effect of different fallow periods of shrubs on soil fertility, and maize and fuelwood yields.
- (c) examine firewood production from the three leguminous shrubs.

In this study the following three hypotheses were tested:

- (a) There is a difference in soil fertility and maize and wood yield improvement between the fallow periods.
- (b) The effects of improved and natural fallows on soil fertility and maize and wood yield are not similar.
- (c) The effects of improved fallows of the tested shrub species on soil fertility and maize and wood yield are not similar.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Soil fertility and crop production

Young (1989) defined soil fertility as “the capacity of soil to support the growth of plants on a sustainable basis under given conditions of climate and other relevant properties of land”. Among the factors characterizing high soil fertility include high water holding capacity, good aeration, moderate temperature, high water infiltration capacity, high OM content, total N, available P and N and high cation exchange capacity (CEC) (Balagopalan and Jose, 1995). The importance of the subject of soil fertility cannot be overemphasized as the viability of any land use system is measured by its ability to maintain soil productivity which in turn is measured mainly by the yield of agricultural crops in that soil (Lundgren and Raintree, 1982). Nevertheless, humankind neglects these resources and soils are exposed to increasing degrees of chemical, physical and biological stress (Greenland and Szabolcs, 1994). As a result many soils deteriorate and this is a pancontinental phenomena (Hartemink, 1997). In order to increase crop yields in degraded areas, the restoration of soil fertility is therefore very essential.

2.1.1 Shifting cultivation and declining soil fertility

Shifting cultivation is considered the oldest system devised by humans to exploit the forest ecosystems (Nair, 1984) and various types of shifting cultivation are still dominant systems of crop production in many parts of the dry and humid tropics (Nair, 1984; Mobbs and Cannell, 1995). By definition “shifting cultivation is an agricultural system characterized by slash-and-burn agriculture, relatively short periods of cultivation followed by longer periods of fallow during which the soil is given the opportunity to restore its fertility” (Oxby and Boerboom, 1985).

Shifting cultivation as the name implies, is of a transient nature, both in time and space, since the area cleared and even the farmers concerned shift the zone of operation after a certain period. This is necessitated by steep fall in productivity in a short span depending on local conditions (Narasimham, 1995). Normally cropping is done for 2 to 3 years and then followed by a fallowing period of 5 to 20 years (Nair, 1984, 1993). Currently, with the increased population pressure in many areas, farmers are forced to rest their fields for shorter periods or even to crop continuously without fallowing the land at all (Rao *et al.* 1993). Van der Pol and Traore (1993) reported that with the growing population pressure and expanding farm sizes the recovery period is being lost. For instance in Kondoa, central Tanzania, the ratio of cultivation to fallow period was 5:2 (Mugasha and Nshubemuki, 1988).

The chief drawback, which has of late become disastrous in shifting cultivation is deforestation, which in turn, starts a chain of climatological and ecological changes resulting in overall degradation of the area and surroundings (Narasimham, 1995). In dryland Africa, shortening fallows, overgrazing and erosion all typically contribute to lowered soil fertility and unsustainable production (Tilander, 1993). Young (1989) defined the decline in soil fertility as “the combined effect of deterioration of soil physical properties, lowering of soil organic matter and nutrient content, and in some cases acidification”. The declining soil fertility has resulted in decreased crop yields, severe weed infestations, and also shortages of firewood, building poles, timber and other forest products (Karim *et al.* 1993). As a result, environmental degradation is now clearly evident. Nearly 2×10^9 ha in the world are affected by human-induced soil degradation of which around one quarter is located in Africa. Several types of human-induced soil degradation can be identified including water and wind erosion, structural degradation, salinization, acidification, contamination and nutrient depletion (Hartemink, 1997). Erosion is the most visible and complete form of land degradation. Of equal importance to soil productivity is the impact of chemical degradation which includes decline in soil fertility (Logan, 1990). The decline in soil fertility is followed in many cases by soil erosion and further decline in soil nutrients (Danso *et al.* 1992). Although soil fertility maintenance can be achieved through widespread application of fertilizers, the use of chemical fertilizers by the resource poor farmers can be limited by their high prices, pollution problems and inefficiency

of use caused by erosion, volatilization, leaching and denitrification (Tisdale *et al.* 1990; Palada *et al.* 1992).

2.1.2 Fertilization and soil fertility improvement

Fertilizers both organic and inorganic have been widely used to improve soil fertility and crop yield in agricultural systems. Increase in nutrient e.g. N, P and Potassium (K) supply during crop growth and improved food crop yield following application of mineral fertilizers have been observed in various studies (IFDC 1986; Kwesiga and Coe 1994; Balasubramanian and Sekayange 1992; Kumpwat and Ranthore 1995; Fasuluku 1998; Chingonikaya 1999). For example in a study done at Gairo in Tanzania while maize grain yield of only 1.56 t ha⁻¹ was obtained from the unfertilized natural fallow plots, a greater yield of 3.07 t ha⁻¹ was obtained from natural fallow plots with full dose of N and P fertilizers (Chingonikaya, 1999). Application of organic fertilizers (e.g. farm yard manure, compost manure and animal manure) has also been reported to increase nutrient supply and crop yield, but their wide use has been limited by such factors as lower content of nutrients per unit weight, nutrient imbalances and transport problems (Maro, 1995).

Despite the fact that chemical fertilizers have had a substantial impact on food production in the recent past, there are, on the other hand, vast areas of developing world where N fertilizers are neither available nor affordable. Furthermore, in most of these countries, removal of fertilizer subsidies, due to balance of payment problems, have resulted in higher prices and lower supplies (Bohloul *et al.* 1992). From the environmental quality considerations, the external costs of environmental degradation and human health also discourage the use of inorganic fertilizers. Fujita *et al.* (1992) reported that the increasing awareness of environmental degradation arising from high chemical inputs gives rise to a search for ways to reduce modern agriculture's overdependence on fertilizers, manufactured mainly with use of fossil energy.

The N (from fertilizers) in run-off and surface waters has led to extensive pollution and eutrophication of rivers and lakes. Furthermore, the gaseous oxides of N, derived from N fertilizers, are highly reactive and pose a threat to the stability of the ozone layer (Bohloul *et al.* 1992). Table 1 summarizes the potential adverse impacts of excessive fertilizer N application.

2.1.3 Agroforestry and soil fertility

The integration of trees into farmlands has been suggested to combat soil nutrient depletion in tropical cropping systems (Sanchez, 1995). Yamoah *et al.* (1995) reported that AF and related fallow systems are innovations that are known to remedy or

Table 1: Potential adverse environmental and health impacts of excessive N use¹

Impact	Causative agent
Human health	
Methemoglobinemia in infants	Excess NO ₃ and NO ₂ in waters and food
Cancer	Nitrosamine illness from NO ₂ , secondary amines
Respiratory illness	Peroxycyl nitrates, alkyl nitrates, NO ₃ aerosols, NO ₂ ⁻ , HNO ₃ vapor in urban atmospheres
Environmental health	
Environment	Excess NO ₃ in feed and water
Eutrophication	Inorganic and organic N in surface waters
Materials and ecosystem damage	HNO ₃ aerosols in rainfall
Plant toxicity	High levels of NO ₂ in soils
Excessive plant growth	Excess available N
Stratosphere ozone depletion	Nitrous oxide from nitrification, denitrification, stack emissions

¹Modified from Keeney (1982)

minimize P sorption and soil acidity, enrich the soil with N and control hillside erosion. A large reduction in nutrient losses can be achieved through control of erosion by AF (Kiepe and Rao, 1994; Craswell *et al.* 1997). Trees are able to mobilise nutrients from the subsoil and then return these nutrients to the topsoil making them

available for an annual crop (Buresh and Tian, 1998). One hypothesis for a benefit of integrating trees with crops is that trees with deep root systems can capture and 'pump-up' nutrients from below the rooting zone of annual crops (Mekonnen *et al.* 1997). Such a land-use system can reduce nitrate (NO_3) leaching and increase subsoil N utilization. Hartemink *et al.* (1996) found lower subsoil nitrate and water in a *Sesbania* fallow than unfertilized maize monoculture and suggested that fast-growing trees or shrubs, such as *Sesbania*, grown in rotation with cultivated annual crops can capture and recycle subsoil nitrate otherwise unavailable to shallow-rooted crops. For example in the same study, very few maize roots were observed below 120 cm, whereas *Sesbania* and weed roots extended below 200 cm.

Other studies revealed that the presence of trees result in a better utilization of N and moisture in the soil, reducing the potential for NO_3 leaching and accumulating N close to the trees (Browaldh, 1995). Higher availability of soil water can be maintained under trees because of interception and redistribution of rainwater within the system, reduced evapotranspiration and increased infiltration (Wallace, 1996). Torquebiau and Kwesiga (1996) revealed that 2-year fallows of *S. sesban* can decrease soil bulk density and resistance to penetration and increase water infiltration on an Alfisol in eastern Zambia. Lehman *et al.* (1999) observed that trees were effectively reducing N leaching by 53% underneath the sorghum in the AF system compared to the sole cropped sorghum. Matta-Machado and Jordan (1995) reported that, because of their

deeper and more extensive root system, and the nitrogen-fixing capability of most leguminous species, the trees and shrubs can increase soil fertility and improve soil physical properties, thereby benefiting the crops.

Growing of legumes is associated with the replenishment of N in the soil to variable extent (Hati and Ray, 1984). Legume materials generally have higher N content and lower carbon (C) ratios than nonlegume material, thereby promoting rapid N mineralization when applied to soil (Fernandes *et al.* 1997). Legumes have thus been incorporated widely in intercropping systems to supplement the N requirements of the associated crop (Buresh and Tian, 1998). Sarrantonio (1992) reported that legumes have been used in cropping systems for soil improvement throughout much of the recorded history. In AF systems like improved fallow, trees increase the OM content of the soil, cycle and trap nutrients from the subsoil, improve soil structure, including aeration, water-holding capacity and tilth (Rocheleau *et al.* 1988). In addition to improved soil physical and chemical conditions, substantial amounts of fuelwood could be produced from improved fallows (Baxter, 1995).

Nair (1984, 1987, 1993) reported that, the inclusion of compatible and desirable species of woody perennials on farmlands can result in a marked improvement in soil fertility. The possible mechanisms for this include:

- increase in the OM content of the soil through addition of leaf litter and other plant parts
- an efficient nutrient cycling within the system
- biological N fixation especially by fast growing trees
- solubilization of difficult available nutrients like P through the activity of mycorrhizae and P solubilizing bacteria
- increase in the plant cycling fraction of nutrients and resultant reduction in loss of nutrients beyond the nutrient absorbing zone of the soil.
- additional nutrient economy because of the different nutrient absorbing zones of the root system
- moderating effect of soil OM on extreme soil reactions and consequent nutrient release/availability patterns.

2.2 Trees and nutrient supply

Trees play a very important and significant role in soil productivity regeneration through nutrient cycling and OM turnover (Otsyina and Karachi, 1998; Amara *et al.* 1996). The intergration of trees with crops can influence both the supply and availability of nutrients in the soil. Trees can increase the supply of nutrients within the rooting zone of crops through (i) input of N by biological N fixation, (ii) capture and pumping up (retrieval) of nutrients from below the rooting zone of crops and (iii)

reduction in nutrient losses from processes such as by leaching and erosion (Dhyani *et al.* 1990; Buresh *et al.* 1996; Buresh and Tian, 1998). The potential of trees to retrieve subsoil nutrients is generally greatest when (i) trees have deep rooting systems and high demand for nutrients, (ii) water and/or nutrient stress occurs in the surface soil and (iii) considerable reserves of plant-available nutrients or weatherable minerals occur in the subsoil (Buresh and Tian, 1998).

Browaldh, (1995) reported that the roots of the trees obviously scavenge mineral N efficiently, as well as water from the soil profile, thus reducing the total loss of N. Trees with deep roots can potentially intercept nutrients leaching down soil profiles and capture nutrients accumulated in subsoil below the rooting depth of annual crops (Van Noordwijk *et al.* 1996). Nutrients captured by trees from outside the rooting zone of annual crops become an input when transferred to surface soil in the form of leaf litter, roots and prunings of tree leaves and branches (Schroth, 1995). The lateral capture and uptake of nutrients from within the rooting zone of crops, however, represents a redistribution of nutrients within the soil–plant system rather than an input (Buresh and Tian, 1998).

Trees can increase the availability of nutrients through increased release of nutrients from soil OM and recycled organic materials. The mineralisation of soil OM is a source of plant-available N and P, and nutrient release from soil OM is normally more

dependent on the portion of the soil OM in biologically active fractions than on total quantity of soil OM (Buresh *et al.* 1996). The decomposition of organic materials from trees not only supplies nutrients but can also increase plant availability of nutrients in soil by processes such as (i) supplying an energy source to soil organisms thereby enhancing nutrient cycling through soil organisms, (ii) reduced P-sorption capacity of soil and (iii) stimulation of plant root growth (Palm *et al.* 1997). Relatively high rates of fresh *T. diversifolia* biomass (5 Mg ha⁻¹ on a dry weight basis), for example, increased soil biological activity and reduced P-sorption on an acid soil in western Kenya (Nziguheba *et al.* 1998). These effects may lead to enhanced plant availability of soil P. Greater capture of subsoil resources by roots would be expected for water and mobile nutrients , such as NO₃, than for less mobile nutrients like P (Buresh and Tian, 1998). However, it has been observed that *Sesbania* fallow can increase the amount of P available to maize probably because it enhances microbial activity and releases P from soil organic P (ICRAF, 1995). Szott and Kass (1993) reported that with the help of leguminous trees, a considerable amount of N can be added to the soil, thus partly replacing mineral fertilizer.

2.3 Legumes and N-fixation

Somani (1989) defined nitrogen fixing plants (NFP's) as "plants which can assimilate and fix N of the atmosphere by the aid of bacteria living in root nodules". Several

trees and shrubs are known to have N fixing qualities. Brewbaker (1987) reported that about 650 tree species are known to be, and several thousands suspected to be, N fixing. However, legumes both herbaceous and woody, with the associated rhizobium bacteria in the root nodules are the most important N fixing plants (Young, 1989). Nitrogen fixation characterizes most legumes i.e. over 90% of Mimosoids and Papilionoids, and 34% of Caesalpinoids (Brewbaker, 1987). Nitrogen fixation by herbaceous legumes has long been recognised in agricultural practices, either as a productive, e.g. pulse and groundnuts, a green manure crop, e.g. *Stylosanthes* spp. and *Centrocema pubescens* or as a cover crop in perennial plantations e.g. *Pueraria phaseoloides* (Young, 1989).

With the increasing prices of chemical N fertilizers and the concern about possible environmental consequences of their continued use, N fixed by legumes has assumed considerable importance as an alternative source of N (Aulakh *et al.* 1991; Ledgard and Steele, 1992; Buresh and Tian, 1998). Bohlool *et al.* (1992) reported that even in wealthier nations, economic and environmental considerations dictate that biological alternatives which can augment, and in some cases replace, N fertilizers must be sought. Biological nitrogen fixation (BNF), a microbiological process in the biosphere, converts atmospheric N into a plant-usable form through the microbial enzyme nitrogenase (Bohlool *et al.* 1992). Nitrogen-fixing systems offer an excellent

opportunity for drawing upon the vast reserve of atmospheric N in an inexpensive and environmentally sound manner for meeting the needs of N which is perhaps the single most important element in AF production (Nair, 1993). There is great potential for BNF to compensate for the shortfall in N fertilizer in African farming systems. Nitrogen input through BNF can help maintain soil N reserves as well as substitute for N fertilizer to attain large crop yields (Peoples and Crasswell, 1992). The use of N fixing trees/shrubs in AF systems is therefore attractive as a source of N and OM needed in the rehabilitation of damaged soils or sustainability in undamaged soils, as protection against erosion, and for fuelwood - the major source of energy for over half the world and a commodity in extremely short supply in many countries (Danso *et al.* 1992).

Long-term sustainability of agricultural systems must rely, as much as possible, on use and effective management of internal resources. Nitrogen-fixing plants offer an economically attractive and ecologically sound means of reducing external inputs and improving the quality and quantity of internal resources. Biological nitrogen fixation can be a major source of N in agriculture when symbiotic N-fixing systems are used. The amount of N input is reported to be as high as 360 kg N ha⁻¹ (Bohloul *et al.* 1992). Among symbiotic N-fixing systems, nodulated legumes have been used in cropping systems for centuries. Nevertheless, the efficiency of symbiotic BNF is markedly dependent on the mutual compatibility of both partners, and is influenced by

a number of environmental factors. Table 2 summarizes the major factors that affect the symbiotic system (Keyser and Fudi, 1992).

Table 2: Factors that affect symbiotic nitrogen fixation¹

Factor	Effect
Macrosymbiont	
Variety	Nodulation and nitrogen fixation
Nodulin (e.g. Leghemoglobin)	Nodule function
Photosynthate availability	Nitrogen-fixing efficiency
Tolerance of stress	Establishment of symbiosis
Microsymbiont	
Ineffectiveness	Nodule formation
Effectiveness	Nitrogen fixation
Competitive ability	Nodule occupancy
Saprophytic competence	Persistence of rhizobia in soil
Environment	
Combined nitrogen	Nodulation and nitrogen fixation
Light	Nitrogen-fixing efficiency
Temperature	Growth and nitrogen fixation
Water and aeration	Nitrogenase activity
Salinity	Reduce nitrogenase activity
Biotic agent	Rhizobium viability and infection

¹Source: Keyser and Fudi (1992)

The amount of N fixed by the legume component in legume-cereal intercropping systems depends on several factors, including species, plant morphology, density of component crops, type of management, and competitive abilities of the component crops (Ofori and Stern, 1987). Variations in nodulation and N fixation behaviour

within and between species and season could be due to changes in climatic conditions (Pokhriyal *et al.* 1993). Some environmental factors known to affect nitrogen fixation include; temperature, soil acidity, nutrient levels in the soil and moisture stress. For example, temperature both air and soil temperature, affect fixation through its effects on the physiological processes of the plant. According to Goh *et al.* (1996) low temperature in winter affect plant metabolism, root formation, rhizobium growth and infection, and nodule formation all of which eventually reduce BNF. Table 3 gives estimates of nitrogen fixation by various N-fixing plant species.

Table 3: Estimates of nitrogen fixation by some N-fixing trees

Species	N-fixation (kg N ha ⁻¹ yr ⁻¹)	Source
<i>Acacia mearnsii</i>	200	Young (1989)
<i>Albizia lebbbeck</i>	94	Danso <i>et al.</i> (1992)
<i>Cacia dealbata</i>	210	Odee (1996)
<i>Cajanus cajan</i>	68 – 88	Odee (1996)
<i>Casuarina equisetifolia</i>	43 - 60	Gauthier <i>et al.</i> (1985)
<i>Erythrina poeppigiana</i>	57 - 60	Nair (1993)
<i>Faidherbia albida</i>	20 - 21	Young (1989)
<i>Gliricidia sepium</i>	86 - 300	Sanginga <i>et al.</i> (1995)
<i>Inga jinicuii</i>	35 - 40	Nair (1993)
<i>Leucaena leucocephala</i>	40 - 194	Lulandala and Hall (1986)
<i>L. leucocephala</i>	448 - 548	Sanginga <i>et al.</i> (1995)
<i>L. leucocephala</i>	100 - 300	Danso <i>et al.</i> (1992)
<i>Prosopis tamarugo</i>	198 - 200	Young (1989)
<i>Sesbania sesban</i>	375 – 600	Onim <i>et al.</i> (1990)
<i>S. rostrata</i>	83 – 109	Nair (1993)

Different methods of estimating N-fixing rates may also be the cause of variations in N-fixing rates reported in some species. Different N-fixing rates have thus been reported for N-fixing plants by various researchers.

2.4 Improved fallows and soil fertility status

Possible benefits from managed fallows include: the provision of economically valuable products, increased nutrient conservation or enrichment, and a more rapid reduction in weed pressure than in natural fallow (Szott *et al.* 1994). Improved fallow management technologies are expected to help accelerate soil restoration and intensify crop production.

While the tree and crop components compete for nutrients and water in simultaneous systems like alley cropping, competition for growth resources is absent or minimal in sequential systems like improved fallow (Rao *et al.* 1997). Properly managed planted fallow will add substantial amounts of fixed N and OM to the soil, recycle nutrients from the subsoil, provide effective ground cover against erosion, suppress weeds and pests, and improve soil physical condition (Prinz, 1986; Hulugalle, 1988; Francis, 1989). Ngiumbo and Balasubramanian (1992) reported that one year's growth of *S. sesban* could effectively shade out the problematic *Chromolaena* weeds at the Minkomeyos site and the *Imperata* weeds at the Yoke site in Cameroon.

Previous studies in humid and semi-arid areas have shown significant effects of fallows on mostly soil chemical properties, in particular pH, boron (B), P (Adesina, 1990), exchangeable calcium (Ca), magnesium (Mg), K, and NO_3 levels in soil solution and also some physical properties such as water-holding capacity and structure (Kang *et al.* 1985; Rosecrance *et al.* 1991; Singh *et al.* 1993). In a study by Chingonikaya (1999) improved soil pH and electrical conductivity was achieved from planted fallows of *Gliricidia sepium*, *Sesbania macrantha*, and *S. sesban*. In the same study, improvements in other nutrient elements was also observed. For example, *G. sepium* fallow improved soil available P by 73% ($26.85 \text{ mg P kg}^{-1}$), *S. sesban* 45% ($13.10 \text{ mg P kg}^{-1}$), *S. macrantha* 35% ($11.18 \text{ mg P kg}^{-1}$) and *C. cajan* 55% ($15.95 \text{ mg P kg}^{-1}$) as compared to the natural fallow ($2.07 \text{ mg P ha}^{-1}$). Observations from a study done in Rwanda revealed that leaf litter and fresh foliage from a 1-year *T. vogelii* fallow added $238 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ to the soil, in contrast to $38 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ from natural regrowth. In addition to the observed soil fertility improvement, the *T. vogelii* fallow produced 9.5 t ha^{-1} of woody stems which could be used as firewood (Balasubramanian and Sekayenge, 1994). These qualities would allow a shortening of the fallow period while maintaining or increasing agroecosystem productivity.

Mekonnen *et al.* (1997) reported that, short-duration planted fallows, especially with *S. sesban* are a promising AF alternative to traditional fallows for increasing the fertility of nutrient-depleted soils. Hartemink *et al.* (1996) and Mekonnen *et al.* (1997)

showed that *S. sesban* grown in rotation with maize in western Kenya can rapidly grow deep roots and take up the sorbed NO_3 that was inaccessible to unfertilized maize. Nitrate at 4 m depth was 51 kg N ha^{-1} for a 15-month *S. sesban* fallow, as compared to 199 kg N ha^{-1} for unfertilized maize (Mekonnen *et al.* 1997). The maximum rooting depth was 1.2 m for maize, whereas roots in a 15-month-old *S. sesban* fallow extended below 4 m. The deep-rooted nature of *Sesbania* might also result in root channels that can improve the rooting depth of the subsequent crops (Van Noordwijk *et al.* 1991). A leguminous fallow, such as *C. cajan* is effective in improving soil structure and soil N accumulation (Juo and Lal, 1977).

2.5 Effect of fallow period on soil fertility and crop yield

The rate of improvement in soil fertility and crop yields derived from planted fallow depends on the amount of biomass produced and nitrogen fixed by the fallow vegetation. Length of growing period on the other hand determines the quality and quantity of the biomass produced (Balasubramanian and Sekayange, 1992). Tree/shrub species vary in their nutrient uptake rates and recycling capacity (Montagnini *et al.* 1993) and so the soil ameliorating effect of trees in fallow varies according to tree/shrub species, soil type, age of plantation and husbandry practices (Kang *et al.* 1994; Tonye *et al.* 1997). Therefore the effects of different fallow periods of different species will obviously be different.

The increased nutrient availability brought about by trees through nutrient pumping effect, N fixation and other ways often provide a good environment for crop growth and thus increase crop yield. Drechsel *et al.* (1996) observed that, after a one year fallow with *T. vogelii*, grain yield of maize increased by 72% over the control in the first season and bean yield by 96% in the second season. ICRAF (1995) reported in a study done in Kenya that after two-year fallows of *S. sesban*, yields of 5.0 and 5.6 t ha⁻¹ were obtained in 1990 and 1991, compared with 4.9 and 4.3 t ha⁻¹ from continuously cropped maize with fertilizer (112 kg N ha⁻¹) and 1.2 and 1.9 t ha⁻¹ without it. In another observation, intensive fallows of 4 to 6 months with *Crotalaria ochroleuca*, *Mucana utilis* and *Mimosa invisa* increased grain yields of subsequent soyabeans, beans and maize by 24, 29 - 44 and 36 - 74% respectively, in comparison with fields under continuous cropping (ICRAF, 1995).

Increased crop yield after a fallow period has also been reported by other authors (Young, 1989; Kwesiga and Coe, 1994; Otsynga *et al.* 1996; Chingonikaya, 1999). In Zambia, Kwesiga and Coe (1994) observed that, *S. sesban* can increase maize yield up to 2.3 t ha⁻¹ in one year fallow, 5.0 t ha⁻¹ in two year fallow and 6.0 t ha⁻¹ in a three year fallow. Increase in maize yield with increasing fallow period was also reported by Hamidou (1996) in a study done in Shinyanga, Tanzania where he observed a higher maize yield (2.70 t ha⁻¹) under the four-year fallow than (1.75 t ha⁻¹) in the three-year fallow. Chingonikaya (1999) also observed a generally higher maize yield

from improved fallow than the natural fallow in a study done at Gairo, Tanzania. The relative increase in maize grain yield ranged from 28 % (*C. cajan*) to 135 % (*G. sepium*) as compared to the natural fallow. Table 4 presents some results obtained from studies carried out in different places.

Table 4: Some results of improved fallow/intercropping on maize yield

Study No.	Species	Fallow period (years)	Cropping period (years)						Source
			1		2		3		
			F ₀ ^a	F ₁	F ₀	F ₁	F ₀	F ₁	
Yield (t ha ⁻¹ yr ⁻¹)									
1 ^b	Control (maize)	-	1.7	-	0.2	-	0.6	-	Chamshama <i>et al.</i> (1998) (Gairo, Tanzania)
	<i>F. albida</i>	-	2.1	-	0.5	-	0.1	-	
	<i>L. leucocephala</i>	-	1.9	-	0.4	-	0.2	-	
2	Control (maize)	-	1.6	6.1	1.2	4.9	1.9	4.3	Kwesiga and Coe (1994) (Chipata, Zambia)
	<i>S. sesban</i>	1	2.3	6.7	3.8	6.0	4.4	6.7	
	<i>S. sesban</i>	2	-	-	5.0	7.2	5.6	7.9	
	<i>S. sesban</i>	3	-	-	-	-	6.0	7.4	
3	Natural fallow	2	-	-	1.6	3.1	-	-	Chingonikaya (1999) (Gairo, Tanzania)
	<i>G. sepium</i>	2	-	-	3.7	4.8	-	-	
	<i>S. sesban</i>	2	-	-	2.7	4.7	-	-	
	<i>C. cajan</i>	2	-	-	2.0	3.7	-	-	
	<i>S. macrantha</i>	2	-	-	2.2	4.6	-	-	
4	Control (maize)	-	1.9	2.2	-	-	-	-	Fasuluku (1998) (Morogoro, Tanzania)
	<i>S. sesban</i>	-	2.3	2.7	-	-	-	-	

^aF₀ – Without fertilization F₁ - With fertilization (Urea, 80 kg N ha⁻¹ and Triple Super Phosphate, 80 kg P ha⁻¹). ^b1- Alley cropping, 2- improved fallow, 3- Improved fallow, 4- Relay cropping

2.6 Fertilizers in agroforestry

2.6.1 The need for fertilizer use in agroforestry

Fertilizers are defined as “any organic or inorganic material which is added to a soil to supply certain elements essential to the growth of plants” (Szott and Kass, 1993). Fertilizers can be organic or inorganic depending on nutrient sources. Simpson (1986) defined inorganic fertilizers as materials commonly synthetic which are rich in one or more of the essential plant nutrients while manures are the bulky organic materials, mainly plant residues, animal excreta and urban wastes, which are returned to the soil either directly or after some sort of processing, to provide nutrients to crops grown. Even in AF systems, the use of fertilizers is inevitable for crops having a high nutrient demand since the capacity of the trees to provide the required elements is limited (Szott and Kass, 1993). For example the main sources of plant-available P are weathering of soil minerals, mineralization of soil OM, fertilizers and organic materials (Buresh *et al.* 1996).

Phosphorus, unlike N, is not biologically fixed from air, and the P content of plant residues and manures is normally insufficient to meet the requirements for sustained

crop production (Palm, 1995). Sustainable crop production in many soils of sub-Saharan Africa requires P inputs because the soils are either derived from parent material with low levels of P or have been depleted of plant-available P through continuous cropping with insufficient P inputs (Sanchez *et al.* 1997). Buresh *et al.* (1996) reported that replenishing P stocks in highly P-deficient soils requires input of P fertilizers rather than sole dependence on P cycling through organic-based systems. Increased fertilizer use in Africa can create a win-win situation, by promoting more efficient crop production and reducing soil degradation.

2.6.2 The role of organic materials on nutrient availability and acquisition

Organic inputs can influence nutrient availability (i) by the total nutrients added, (ii) by controlling the net mineralization-immobilization patterns, (iii) as a source of C and energy to drive microbial activities, (iv) as precursors to soil OM fractions, and (v) through interactions with the mineral soil in complexing toxic cations and reducing the P sorption capacity of the soil (Palm *et al.* 1997). Organic inputs also can have several other effects on soils and plants that can influence nutrient acquisition and uptake by plants. Root growth can increase as a result of reduced exchangeable Al in the soil, caused by complexation with organic anions that are produced by the decomposition of organic materials. It also can increase through an increase in pH

caused by the addition of basic cations from organic materials (Kretzschmar *et al.* 1991).

2.6.3 Combined organic and inorganic fertilizer use

Soil fertility replenishment can be achieved through the use of fertilizers both organic and inorganic. Organic inputs are often proposed as alternatives to inorganic fertilizers, however, the traditional organic inputs – crop residues and animal manures cannot meet crop nutrient demand over large areas because of the limited quantities available, the low nutrient content of the materials, and the high labour demands for processing and application (Palm *et al.* 1988). For example, to supply 20 – 30 % of the requirements of potato crop, Simpson (1986) estimated that 25 – 40 t ha⁻¹ of manures should be added to the soil.

Low soil fertility and low use of organic and mineral fertilizers are the greatest biophysical constraints to increasing agricultural productivity in farming systems in the semi-arid region of Africa (Bekunda *et al.* 1997). Where substantial quantities of nutrients are lost in permanent intensive cultivation systems use of organic farming or fertilizer alone may not be sufficient to increase crop yield on a sustained basis. Adequate soil fertility for sustained crop yields in such areas can therefore be obtained with combined use of mineral fertilizers and organic materials (Bekunda *et al.* 1997).

Giller *et al.* (1997) reported that soil fertility in intensified farming in the semiarid zone can be maintained only through (i) the efficient recycling of organic materials, such as crop residues and manure, in combination with mineral fertilizers and (ii) the use of rotations with legumes. Improvement in effective use of inorganic fertilizers when applied in combination with organic materials has been observed in various places. The solubility of Phosphate Rock (PR) for example has been reported to increase when the PR is mixed and applied with manure. Alexander (1977) reported that the increased availability of P from PR as a result of OM addition has been attributed to the improved soil conditions, water holding capacity and soil nutrients. Numerous trials combining organic and inorganic inputs, have reported positive responses in crop yield. Table 5 shows dry weights of 2 month old maize plants after being treated with both inorganic and organic nutrient sources.

Table 5: Dry weights of 2-month old maize plants grown in pots treated with equal amount of N, P and K added as the green manure of *Tithonia diversifolia* or as inorganic nutrient in Kenya.¹

Treatment	Nutrient added			Weight of maize g pot ⁻¹
	N	P	K	
		kg ha ⁻¹		
Control	0	0	0	1.09
Tithonia leaves	170	14	230	6.04
N-P-K fertilizer	170	14	230	4.58
Tithonia leaves + inorganic P	170	39	230	10.30
N-P-K fertilizer + P	170	39	230	6.23
LSD (<i>P</i> = 0.05)				1.02

¹Source: Palm *et al.* (1997)

2.7 Description of study species

2.7.1 *Sesbania sesban* (L) Merril

Sesbania sesban is a fast growing N fixing shrub which belongs to the family Papilionaceae. It can be propagated by direct seeding or seedlings and attain a height of up to 6-7 m with a rotation of 1-3 years (Nair, 1993). However, in some other places like Gairo, Tanzania this species has already been found to survive for more than three years (Personal observation). The species is widely distributed in areas with temperature ranging from 12 to 30°C, rainfall at least 300 mm, and altitude range from sea level to 2000 m a.s.l. It is normally found on stream banks and beside seasonal ponds. It can tolerate a wide range of soil conditions, from acidic soils, periodic flooding, waterlogging and salt conditions (Mboye, 1987).

Besides its good potential for improving soil fertility through addition of N and other nutrients into the soil, the species can also produce fodder for livestock, fuelwood and fibres (Karachi *et al.* 1994). *Sesbania sesban* has been observed to have a N-fixing ability of up to 600 kg N ha yr⁻¹ (Onim *et al.* 1990). Because of its suitable attributes such as fast growth, N-fixing ability, easily degradable biomass, adaptability to various climatic and soil conditions and ease of propagation and removal besides its compatibility with succeeding crops i.e. no allelopathy to cereals (Kwesiga and Coe, 1994), *S. sesban* has been used in various agroforestry systems. In AF systems like

alley cropping, relay cropping and improved fallow, *S. sesban* has been found to be a promising species towards improving soil fertility and food crop yields. For example increase in maize grain yield over the controls have been observed under *S. sesban* used in relay cropping at Mafiga, Tanzania (Fasuluku *et al.* 1998), and in improved fallow at Gairo, Tanzania (Chingonikaya, 1999) (see also section 2.5). Increase in maize yield following *S. sesban* fallows have also been reported in Zambia by Kwesiga and Coe (1994) and in Kenya by Niang *et al.* (1996) see also section 2.5).

2.7.2 *Tephrosia vogelii* (F) Hook

Tephrosia vogelii is a nitrogen fixing legume 1- 4 m tall belonging to the family Fabaceae. It is widely distributed in dry and moist tropics 500-2500 mm rainfall, and altitude up to 2100 m a.s.l. with temperature range from 12.5 to 26°C. In East Africa, it is widely used as a fish poison. However because of its ability to fix nitrogen, fast growth, high biomass production and nutrient uptake this species has been planted in fallow land. Farmers in West Cameroon plant *Tephrosia* seeds into fallowed land, then cut the plants after a few years to farm again (Rocheleau *et al.* 1988). In observation plots at Kagasa, Rwanda, a 1-year *T. vogelii* fallow produced dry weight equivalents of 4.8 t ha⁻¹ of leaf, 2.6 t ha⁻¹ of foliage and 9.5 t ha⁻¹ of woody stems at harvest. The leaf litter and fresh foliage added 238 kg N ha⁻¹ year⁻¹ (Balasubramanian and Sekayange, 1992). In Kenya, maize grain yield of 4.16 – 4.85 t ha⁻¹ was obtained

following 12 months of fallow with *T. vogelii* (Niang *et al.* 1996). *Tephrosia vogelii* can also be used as fuelwood and sometimes as pesticide (Duke, 1981).

2.7.3 *Cajanus cajan* (L) Millsp

Cajanus cajan is a fast growing, deep rooted shrub belonging to the family Leguminosae. It is found in a range of habitats up to 300 m a.s.l. with mean annual rainfall of 400-2500 mm per year (Nair, 1993). This species is propagated by seeds and may grow up to 4-6 m in height. Together with fast growth and deep rooting, it is also characterised with high nutrient uptake, ability of breaking hardpans and high N fixing capacity (Nair, 1993). Odee (1996) estimated that *C. cajan* can have a N-fixing ability of 68 – 88 kg N ha⁻¹ yr⁻¹.

Cajanus cajan is widely grown as an intercrop (Reddy and Venkateswarlu, 1992). In AF systems leaves and roots of *C. cajan* when left in farm can add about 36-40 kg N ha⁻¹ (Nair, 1993). *Cajanus cajan* can produce leaf litter with high crude protein content of about 2.00-3.33 t ha⁻¹ yr⁻¹ (Boehringer and Caldwell, 1989). Nair (1993) reported that *Cajanus cajan* can also provide various products and services such as fodder, fuelwood, food, medicine, soil erosion control, addition of nutrients to the soil and reducing weeds. *Cajanus cajan* has been used in various places in relay intercropping and improved fallow systems. Increase in sorghum and maize yield

following *Cajanus cajan* fallow have been reported in various places. For example a higher sorghum yield of 1.19 t ha⁻¹ was obtained following a *C. cajan* fallow as compared to the 0.76 t ha⁻¹ which were obtained following a natural fallow at Kagasa, Rwanda (Balasubramanian and Sekayange 1992). Maize grain yield increase ranging from 3.0 to 3.2 t ha⁻¹ were also observed following *C. cajan* fallows (Tonye *et al.* 1997).

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Site description

The study site is located at Gairo (36° 45'E, 6° 30'S; 1200 m a.s.l.) in Morogoro Region, Tanzania. Since there is no meteorological station at the experimental site, rainfall data collected at Kongwa Ranch (Table 6) in Dodoma which is about 40 km from the study site can be used to show rainfall pattern of the study site. The experimental area has a slope of approximately 5-10%. Table 7 shows some of the selected soil properties prior to experimental establishment. The soil pH in the upper 50 cm ranges from 6.00 – 6.33. Other soil properties are as follows: organic C content 0.41 – 1.52 %, electrical conductivity 0.02 – 0.05 dS m⁻¹, total P 232 – 269 mg kg⁻¹, total N 0.08 – 0.12 %, and Bray-I available P 1.31 – 3.33 mg P kg⁻¹. The natural vegetation around the site is sparse consisting of shrubs and a few scattered trees. Prior to experimental establishment, the area was being used for growing maize and sweet potatoes. This study was based on an ongoing experiment which is a part of the Sokoine University of Agriculture (SUA) - Norwegian Agency for Development Cooperation (NORAD) Research Project conducted simultaneously at SUA farm and Gairo in Morogoro, Tanzania.

Table 6: Monthly means of rainfall data (1961 – 1978) for Kongwa Ranch in Dodoma, Tanzania¹.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
Rainfall (mm)	126	126	127	70	7	4	1	2	1	3	43	197	639
Raindays	11	9	13	9	2	2	1	1	1	2	7	14	59

¹Source: Nshubemuki *et al.* (1978)

Table 7: Some soil chemical and physical properties prior to establishment of the experiment at Gairo, Morogoro, Tanzania.

Properties	Soil depth (cm)			
	0 – 10	10 – 20	20 – 30	30 – 50
Chemical properties				
pH (H ₂ O)	6.00 (0.15) ^a	6.19 (0.16)	6.24 (1.09)	6.33 (0.17)
EC dS m ⁻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-1 P (mg kg ⁻¹)	3.33 (0.13)	1.87 (0.14)	1.76 (0.12)	1.31 (0.08)
Total P (mg kg ⁻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 (%)	3.31 (0.10)	2.43 (0.57)	6.26 (0.18)	3.23 (0.11)
Clay (%)	11.23 (0.14)	17.23 (0.08)	20.69 (0.36)	28.67 (0.74)
Sand (%)	86.71 (0.89)	80.59 (0.69)	70.67 (0.65)	65.26 (0.59)
Textural class	Loamy sand	Sandy loam	Sandy clay loam	Sandy clay loam

^aMean of three replications with standard error in parenthesis.

3.2 Experimental design and treatments

The experiment was established using a split-split plot design with three replications.

The experimental treatments were as follows:

(a) Fallow period (Major treatment)

- . 1 year fallow
- . 2 year fallow
- . 3 year fallow

(b) Type of fallow (Sub-major treatment)

- . *S. sesban*
- . *T. vogelii*
- . *C. cajan*
- . Natural fallow
- . Continuous cropping

(c) Fertilization (Minor treatment)

- . F₁ N₀ P₀: Control, i.e 0 kg N ha⁻¹ and 0 kg P ha⁻¹
- . F₂ N_{1/2}P₀: Half of recommended dose of N i.e. 40 kg N ha⁻¹ and 0 kg P ha⁻¹
- . F₃ N₀ P₁: Full recommended dose of P i.e. 40 kg P ha⁻¹ and 0 kg N ha⁻¹
- . F₄ N_{1/2}P₁: Half of recommended dose of N and recommended full dose of P i.e. 40 kg N ha⁻¹ and 40 kg P ha⁻¹

3.3 Experimental establishment and management

The experimental area was ploughed and harrowed in December 1995. For each block, there were 3 major plots of fallow period each measuring 20 x 50 m. Distance between major plots within each block was 3 m and between blocks 4 m. Each major plot was split into five sub-major plots of types of fallow, measuring 10 x 20 m and separated by 2 m from each other. Planting of shrubs and sowing of maize in the sub-major plots was done in December of 1995, 1996 and 1997 so that by December of 1998 sub-major plots of 3, 2 and 1 year fallows were obtained. Table 8 shows the schedule of maize and shrubs planting. At the beginning of the fourth cropping season, each sub-major plot was split into 4 minor plots each measuring 4.2 x 10 m separated by 1 m from each other. Within each sub-major plot, four fertilization treatments were randomly assigned to the minor plots. Figure 1 shows a simplified experimental design for just one block.

The shrubs were planted at an inter-row spacing of 2 m and an intra-row spacing of 1 m to give an equivalent of 5,000 shrubs per ha (*S. sesban*), which were planted using potted seedlings raised in the nursery. For *T. vogelii* and *C. cajan* two seeds were sown per planting hole. This resulted in an equivalent of 10,000 plants per ha which was then reduced to 5000 plants per ha following the removal of one plant from each planting hole. Hybrid maize variety MTV 1 was planted during the three consecutive

seasons in the continuously cropped plots at a spacing of 0.9 m (between rows) and 0.45 m (within rows). With the exception of the natural fallow plots which were not weeded at all, all the plots were weeded twice during the cropping seasons and once during the dry seasons.

Table 8: Planting schedule of an experiment to compare the effects of 1, 2 and 3 years improved fallows of three shrub species and natural fallow and different years 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	C	Nf	C
13	C	C	C	C
14	Nf	C	C	C
15	Nf	Nf	C	C

Ss^a - *Sesbania sesban*, Tv - *Tephrosia vogelii*, Cc - *Cajanus cajan*, Nf - Natural fallow, C - Maize cropping

At the end of the fallow period, i.e. just before the onset of the fourth growing season, all the trees/shrubs were measured for height and root-collar diameter as described in section 3.4.3. This was followed by destructive sampling of trees/shrubs for

development of allometric equations which were used in the estimation of trees/shrubs above ground biomass production as described in section 3.4.3.1.

Block 1

Fallow period

I					II					III				
Ss ^a	Tv	Cc	Nf	C	Cc	Nf	Tv	C	Ss	Nf	Cc	C	Tv	Ss
F2	F4	F3	F2	F1	F3	F1	F2	F4	F3	F4	F1	F3	F2	F3
F4	F2	F1	F3	F3	F2	F4	F3	F1	F2	F3	F4	F1	F4	F1
F3	F1	F4	F1	F4	F1	F2	F4	F3	F4	F1	F2	F4	F3	F2
F1	F3	F2	F4	F2	F4	F3	F1	F2	F1	F2	F3	F2	F1	F4

Figure 1: A simplified experimental design of block 1 of the improved fallow experiment at Gairo, Morogoro, Tanzania.

Ss^a – *Sesbania sesban*, Tv – *Tephrosia vogelii*, Cc – *Cajanus cajan*, Nf – Natural fallow, C – Maize cropping, F = fertilization

Thereafter, all trees/shrubs were harvested and partitioned into leaves/twigs, and wood components. The leaves/twigs were left in the field while the wood components were collected by the villagers for use as firewood. Thereafter all the plots were hand hoed, (cultivated) incorporating all non woody materials and litter into the soil.

Immediately after the start of the first rain in the fourth growing season, the variety of maize used previously was planted in all the plots at a spacing of 0.45 by 0.9 m. The P fertilizer (Minjingu Rock Phosphate with a concentration of P₂O₅ = 30%) was

thoroughly mixed with the soil in each hole before sowing of maize. Three maize seeds were sown in each planting hole. This number was later on reduced to two maize plants per planting hole after the germination of maize. For the N fertilizer (Urea), a split application was adopted with equal portions of the dose being applied at the 8th and 10th week after the sowing of maize. Spot application was used in this case by applying fertilizer around each maize plant. Usually fertilizer is applied during the 4th and 6th week after sowing of maize. However, this schedule could not be adopted because two weeks after maize germination there was a dry spell which continued for some weeks. This slowed down the rate of maize growth. By the 4th and 6th weeks after sowing maize plants were too small to be fertilized. They attained appropriate size during the 8th week. The dry spell also posed a threat of fertilizer loss of N through volatilization and reduced uptake by the targeted plants. All plots were weeded twice during the cropping season.

3.4 Data collection

3.4.1 Site characterization

(a) Soil sampling for initial site characterization

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 was determined as described by Landon (1991). Soil samples were collected with coring cylinders measuring 5 cm diameter and 5 cm length. Soil samples from the cores were oven dried at 105°C for 24 hours. Soil bulk density was then calculated according to Anderson and Ingram (1993). All the soil samples were then analysed for organic C, pH, electrical conductivity (EC), total N, available P and total P as described in section 3.4.5.1.

(b) Soil sampling for site characterization after fallow periods

To characterize the soils after each fallow period, soil samples were taken again from each sub-major plot soon after harvesting of shrubs. For each sub-major 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 as described in section 3.4.5.1.

3.4.2 Sampling of shrubs for development of allometric equations

Just after the end of the 3rd cropping season (July, 1998), i.e. after rain period when shrubs were in good condition with maximum leaf retention, destructive sampling

was done for development of allometric equations for *T. vogelii* and *C. cajan*. For each shrub species, a total of 40 shrubs were randomly selected from the whole experiment including all root-collar diameter classes. Each shrub was measured for height and root-collar diameter (10 cm above ground) before felling. After felling, the shrubs were partitioned into biomass components (foliar, branch and stem). The components were then oven dried (70°C) to constant weight and weighed. Shrub components' oven dry weights were used in developing allometric equations. For each study shrub, four sub-samples of ground litter and from each biomass component were also taken for analysis of N and P concentration.

3.4.2.1 Tree/shrub survival, growth and biomass production

Tree/shrub survival was assessed by counting the number of individual trees/shrubs present in a plot at the time of assessment. Percentage survival was then computed basing on the original number of trees/shrubs initially present in a plot. All the trees/shrubs in each plot were measured for height and diameters (at 10 and/or 30 cm above ground) before clearfelling i.e. just before onset of third cropping season. Root collar diameter was measured with a small calliper to the nearest 0.01 cm while height was measured with the digital measuring pole to the nearest 0.1 m. These measurements were used for estimation of wood and foliage biomass production using allometric equations.

3.4.3 Measurements of maize growth and yield

For each minor-plot, measurement of maize height at 12 weeks i.e. 84 days after sowing (DAS) was done i.e. at the beginning of the delayed maize tasselling due to moisture stress. All plants in the middle two rows were measured for height using a scaled metric wood bar to the nearest 0.1 cm. At the same time, a 4th leaf from the top of maize plant was collected from four maize plants for biomass and N and P content determination.

At the end of the cropping season, maize was harvested from the two middle rows of each minor plot and separated into grain, cobs and stover. These maize components were weighed in order to determine their field weight. The subsamples of each component were then taken to the laboratory where they were weighed and oven-dried at 70°C to constant weight for determination of moisture content. The components dry weights were then converted into a hectare basis.

3.4.4 Laboratory procedures

3.4.4.1 Analysis of soil samples for site characterization

Soil samples for initial and after fallow site characterization were air dried and sieved with a 2 mm sieve before being subjected to laboratory analyses. Soil particle size analysis was carried out by the hydrometer method as described by Bouyoucos (1962).

For the determination of total N and P concentrations, 0.5 g of soil sample was

digested using a digestion mixture. The digestion mixture consisted of 0.42 g Selenium powder, 14 g Lithium sulphate, 350 mls of 30 % Hydrogen peroxide and 420 mls of concentrated Sulphuric acid. Total N in each digest was determined by semi-micro Kjeldahl procedure (Bremner and Mulvaney, 1982). Total P in each digest was determined calorimetrically as described by Anderson and Ingram (1993). Available P was determined by Bray-1 using 0.05M Hydrochloric acid and 0.03M Ammonium fluoride as acid extractants (Bremner and Mulvaney, 1982). Soil pH was determined potentiometrically by a glass electrode pH-electrical conductivity meter using 1:2:5 soil:water ratio as described by Okalebo *et al.* (1993). Soil organic C (OC) was determined by oxidation-titration method (Anderson and Ingram, 1993).

3.4.4.2 Analysis of N and P concentrations in maize leaves, grain and stover and tree/shrub samples

For the maize, subsamples of maize leaves, stover/cobs and grain were weighed and oven dried (70°C) to constant weight. In the case of trees/shrubs, samples collected from the stem, wood/bark, leaves and litter were also oven dried. During the determination of total N and P concentration subsamples of maize leaves, stover and grain and tree/shrub stem wood/bark, leaves and litter were ground in a Wiley mill to

pass through a 1 mm sieve. This was followed by the digestion of 0.2 g of each ground sample and then analysed for total N and P concentration as described in section 3.4.5.1 a.

3.5 Data analysis

All statistical analyses were carried out using General Linear Models (GLM) of Statistical Analysis Systems (SAS) (SAS Inst. Inc. 1987).

3.5.1 Site characterization

The data for some soil physical (i.e. bulk density, silt %, clay %, and sand %) and chemical (i.e. pH, EC, organic C, total N, total P and Bray-1 available P) properties were sorted by soil depths for the initial site characterization. For the site characterization after fallows, data were also sorted by fallow periods, fallow types and soil depth. All the data for each soil depth after fallows were then subjected to analysis of variance (ANOVA) of a split plot design where fallow period was a major factor while fallow type was a minor factor. A fixed model (equation 1) for split-plot design was used for carrying out the analysis (see eq. 1). Thereafter, Duncan's Multiple Range Test (DMRT) was used to separate significantly different means.

$$Y_{ijk} = \mu + B_i + P_{(ij)} + \sigma_{(ij)} + S_k + BS_{ik} + PS_{(ijk)} + \omega_{(ijk)} \dots \dots \dots 1$$

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

- 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
 - $\sigma_{(ij)}$ = 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
 - $PS_{(ijk)}$ = effect of the interaction of the j^{th} fallow period in the i^{th} block with the k^{th} fallow type
 - $\omega_{(ijk)}$ = second restriction error (Error II)

3.5.2 Tree/shrub biomass production

(a) Allometric equations

For *S. sesban* allometric equations developed by Mugasha *et al.* (2000) were used, while for the *T. vogelii* and *C. cajan* allometric equations were developed. For each species, i.e. *T. vogelii* and *C. cajan*, two allometric equations were fitted for determination of tree/shrub wood and foliar biomass as follows:

$$X = b_0 + b_1(Y_1) + b_2(Y_2) \dots \dots \dots (2)$$

$$\ln(X) = b_0 + b_1 \ln(Y_1) + b_2 \ln(Y_2) \dots \dots \dots (3)$$

Where: ln = base of natural logarithm

X = dependent variable (biomass of stem/ branch or foliage)

Y₁ = root collar diameter or diameter at 10 or 30 cm above ground

Y₂ = total shrub height (m)

The allometric equation (model) number three was selected because of being superior in terms of goodness of fit (R^2) and standard error (SE). These models are also simple to use. Intercepts were corrected for bias occurring when doing conversions from logarithmic units (Baskerville, 1972). The equations were used to derive wood and

foliar biomass per tree basis. Plot totals were then established and expanded to a hectare basis (Maghembe and Prins, 1994). Analysis of variance was then carried out to test the hypothesis that biomass components of different tree species are similar. Means of biomass components were separated using DMRT.

3.5.3 Maize growth, yield, N and P uptake

For all statistical analyses a fixed model (equation 4) was fitted and a type III SS analysis was carried out.

$$Y_{ijkl} = \mu + B_i + P_{(ij)} + \sigma_{(ij)} + S_k + BS_{ik} + PS_{(ijk)} + \omega_{(ijk)} + F_l + BF_{il} + PF_{(ij)l} + SF_{kl} + BSF_{ikl} + PSF_{(ij)kl} + \epsilon_{(ijkl)m} \dots \dots \dots (4)$$

$i = 1, 2, 3$ $j = 1, 2, 3$ $k = 1, 2, 3, 4, 5$ $l = 1, 2, 3, 4$ $m = 1, 2, 3$

- 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
- $\sigma_{(ij)}$ = 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

- $PS_{(ijk)}$ = effect of the interaction of the j^{th} fallow period in the i^{th} block with the k^{th} fallow type
- $\omega(ijk)$ = second restriction error (Error II)
- F_l = effect of the l^{th} fertilizer
- BF_{il} = effect of the interaction of the i^{th} block with the l^{th} fertilizer
- $PF_{(j)il}$ = effect of the interaction of the j^{th} fallow period in the i^{th} block with the l^{th} fertilizer
- SF_{kl} = effect of the interaction of the k^{th} fallow type with the l^{th} fertilizer
- BSF_{ikl} = effect of the interaction of the i^{th} block with the k^{th} fallow type with the l^{th} fertilizer
- $PSF_{(ijk)l}$ = effect of the interaction of the j^{th} fallow period in the i^{th} block with the k^{th} fallow type with the l^{th} fertilizer
- $\varepsilon_{(ijkl)m}$ = within error of specimens within fertilizer, fallow type and fallow period

Each maize variable i.e. height (cm), grain yield ($t\ ha^{-1}$), stover/cob yield ($t\ ha^{-1}$), total N (%) and P (%) and N and P content ($kg\ ha^{-1}$) in grain and stover and total N and P ($kg\ ha^{-1}$) uptake in maize grain and stover and maize leaf biomass and N and P concentration and content were subjected to ANOVA of a split-split plot design using plot means. Means for fallow period and fallow type were separated by DMRT.

CHAPTER 4

4.0 RESULTS

4.1 Tree/shrub survival

Percentage survival of the shrub species 1, 2 and 3 years after planting are presented in Table 9. Survival of the shrub species in 1 year fallows did not differ much. However, while *C. cajan* maintained a constant survival in 2 and 3 year fallows (i.e. 95%) a great drop in survival was observed in *S. sesban* which had the lowest survival (64%) in 3 year fallow as compared to 72% in *T. vogelii* and 95% in *C. cajan*.

Table 9: Percentage survival of the leguminous shrubs 1, 2 and 3 years after planting at Gairo in Morogoro, Tanzania.

Fallow species	Fallow period (years)		
	1	2	3
<i>S. sesban</i>	98	96	64
<i>T. vogelii</i>	97	94	72
<i>C. cajan</i>	97	95	95

4.2 Wood and foliage biomass production

The coefficients of allometric equations used to estimate foliage, wood and total

biomass productions per tree (g) are shown in Tables 10 and 11. Significant ($P < 0.05$) differences in wood, foliage and total biomass production were observed between shrub species and fallow periods (Figure 2 and Appendix 1). For wood biomass production, no significant ($P > 0.05$) differences were observed between shrub species in 1 year fallows. However, in 2 year fallows, *S. sesban* differed significantly ($P < 0.05$) from the other two species i.e. *T. vogelii* and *C. cajan*, with an outstanding wood biomass production of 51.8 t ha^{-1} , followed by *C. cajan* with wood biomass production of 5.2 t ha^{-1} and lastly *T. vogelii* with 4.6 t ha^{-1} . There were no significant ($P > 0.05$) differences in wood biomass production between *C. cajan* and *T. vogelii* from 2 year fallows. In 3 year fallows despite the drop in biomass production still *S. sesban* performed better than the other species with a wood biomass production of 41 t ha^{-1} , followed by *C. cajan* with 6.9 t ha^{-1} and *T. vogelii* 4.8 t ha^{-1} .

For the foliage biomass production, no significant ($P > 0.05$) differences were observed between the species from 1 year fallow. However, in 2 and 3 year fallows, significant ($P < 0.05$) differences were observed between the species in foliage biomass production. In all these fallow periods i.e. 2 and 3 years fallows, *S. sesban* produced higher foliage biomass than the other two species. In 2 year fallows, foliage biomass production from *S. sesban*, *T. vogelii* and *C. cajan* were 18.1 , 3.6 and 1.5 t ha^{-1}

Table 10: Coefficients of allometric equation and their goodness of fit for *Tephrosia vogelii* grown at Gairo, Morogoro, Tanzania.

Dependent variable	Eq. No. ^a	Regression estimator			R ²	SE
		b ₀	b ₁	b ₂		
Foliar biomass (g per tree)	1	2.6440 (0.2051)	2.9493 (0.2536)	-0.1100 (0.5987)	0.87	0.33
Woody biomass (g per tree)	2	3.1779 (0.1455)	2.3661 (0.1799)	0.8678 (0.4247)	0.91	0.29
Total tree biomass (g per tree)	3	3.6510 (0.1481)	2.5912 (0.1831)	0.5021 (0.4322)	0.92	0.29

^aEquation 1 through 3 follow the general form; $\ln(x) = b_0 + \ln(d30) + \ln(ht)$. Where, X = dependent variable (biomass of stem/branch or foliage), d30 = tree diameter (cm) at 30 cm above ground, ht = total tree height (m). All intercepts were corrected for bias that occurs when converting from logarithmic units (Baskarville 1972). Numbers in parentheses are standard errors of the regression coefficients.

Table 11: Coefficients of allometric equation and their goodness of fit for *Cajanus cajan* grown in Morogoro, Tanzania.

Dependent variable	Eq. No. ^a	Regression estimator			R ²	SE
		b ₀	b ₁	b ₂		
Foliar biomass (g per tree)	1	3.2139 (0.4716)	2.1524 (0.2235)	-0.2968 (0.5336)	0.77	0.29
Woody biomass (g per tree)	2	3.4661 (0.5544)	2.2455 (0.2627)	0.5840 (0.6272)	0.76	0.41
Total tree biomass (g per tree)	3	3.9350 (0.4311)	2.1878 (0.2043)	0.4665 (0.4877)	0.83	0.32

^aEquation 1 through 3 follow the general form; $\ln(x) = b_0 + \ln(d30) + \ln(ht)$. Where, X = dependent variable (biomass of stem/branch or foliage), d30 = tree diameter (cm) at 30 cm above ground, ht = total tree height (m). All intercepts were corrected for bias that occur when converting from logarithmic units (Baskarville 1972). Numbers in parantheses are standard errors of the regression coefficients.



Figure 2: Effect of fallow period and the three shrub species on biomass production at Gairo in Morogoro, Tanzania. Ss = *S. sesban*. Tv = *T. vogelii*. Cc = *C. cujan*.

respectively. In 3 year fallows although there was a drop in foliage biomass production from *S. sesban* (11.7 t ha⁻¹), nevertheless, it was still higher than the yield from *T. vogelii* (4.1 t ha⁻¹) and *C. cajan* (1.6 t ha⁻¹).

In total biomass production, for 1 year fallows no significant ($P>0.05$) differences were observed between the fallow species. However, in 2 and 3 year fallows *S. sesban* differed significantly ($P>0.05$) from the other two species in total biomass production. The total biomass production from a 2 year fallow of *S. sesban* was outstanding (69.8 t ha⁻¹). This was followed by *T. vogelii* (8.3 t ha⁻¹) and lastly *C. cajan* (6.8 t ha⁻¹). In 3 year fallows again *S. sesban* had higher total biomass production (46.0 t ha⁻¹), followed by *T. vogelii* (8.9 t ha⁻¹) and *C. cajan* (8.2 t ha⁻¹).

4.3 Wood, foliage and litter N and P concentration

The results of wood, foliage and litter N and P content and concentration are presented in Tables 12a and b. For all the shrub species, generally higher values of wood and foliage N and P concentration (%) were obtained from the 1 year fallows. A decline in wood and foliage N and P concentration was observed in 2 and 3 year fallows of these shrub species.

Table 12a: Effect of fallow period and fallow type on shrub N and P concentration and content at Gairo in Morogoro, Tanzania.

Species	Fallow Period (years)	Nutrient concentration and content							
		Wood N		Wood P		Foliage N		Foliage P	
		Conc.	Cont.	Conc.	Cont.	Conc.	Cont.	Conc.	Cont.
		%	kg ha ⁻¹						
<i>S. sesban</i>	1	0.80 ^a (0.02)	49.34 (1.50)	0.062 (0.03)	3.76 (0.02)	2.94 (0.02)	54.42 (0.01)	0.195 (0.06)	3.45 (0.21)
	2	0.39 (0.03)	201.94 (1.40)	0.027 (0.01)	13.98 (0.36)	2.80 (0.05)	505.31 (0.06)	0.184 (0.41)	33.16 (0.03)
	3	0.25 (0.02)	83.81 (0.84)	0.022 (0.01)	7.53 (0.24)	2.73 (0.01)	320.17 (0.04)	0.170 (0.56)	19.61 (0.23)
<i>T. vogelii</i>	1	0.73 (0.02)	25.21 (0.90)	0.067 (0.01)	2.29 (0.02)	2.59 (0.01)	54.44 (0.14)	0.198 (0.72)	4.14 (0.02)
	2	0.38 (0.07)	17.67 (0.34)	0.045 (0.02)	2.04 (0.08)	2.17 (0.01)	79.15 (0.03)	0.172 (0.47)	6.19 (0.02)
	3	0.28 (0.04)	13.35 (0.23)	0.029 (0.03)	1.41 (0.02)	1.89 (0.02)	77.43 (0.17)	0.151 (0.47)	6.01 (0.02)
<i>C. cajan</i>	1	0.59 (0.02)	44.80 (1.80)	0.047 (0.01)	3.31 (0.05)	2.58 (0.01)	55.01 (0.02)	0.184 (0.27)	23.62 (0.24)
	2	0.31 (0.07)	16.34 (3.30)	0.043 (0.03)	2.21 (0.02)	2.52 (0.01)	37.21 (0.06)	0.179 (0.01)	2.45 (0.14)
	3	0.24 (0.02)	16.88 (1.70)	0.036 (0.03)	2.51 (0.02)	2.45 (0.02)	39.10 (0.07)	0.147 (0.94)	2.24 (0.08)

^a Mean of three replications followed by the standard error in parenthesis

Table 12b: Effect of shrub species on litter N and P concentration and content at Gairo in Morogoro, Tanzania.

	Shrub species		
	<i>S. sesban</i>	<i>T. vogelii</i>	<i>C. cajan</i>
Litter N%	1.61 ^a (0.01)	1.75 (0.02)	1.67 (0.01)
Litter P%	0.179 (0.03)	0.185 (0.09)	0.136 (0.14)

^a As defined in Table 12a

For *S. sesban*, wood N and P concentrations and contents from 1 year fallow were 0.80% and 49.34 kg ha⁻¹ for N and 0.062% and 3.76 kg ha⁻¹ for P. The values of N and P concentrations and contents obtained from 2 year fallows were as follows 0.39% and 201.94 kg ha⁻¹ for N and 0.027% and 13.98 kg ha⁻¹ for P. For the 3 year fallow, N concentration and content were 0.25% and 83.81 kg ha⁻¹, respectively while P concentration and content were 0.022% and 7.53 kg ha⁻¹, respectively. Foliage N and P concentration and content from 1 year fallow were 2.94% and 54.42 kg ha⁻¹ for N and 0.195% and 3.45 kg ha⁻¹ for P.

Wood N and P concentrations and contents from 1 year fallow of *T. vogelii* were 0.73% and 25.21 kg ha⁻¹ for N and 0.067% and 2.29 kg ha⁻¹ for P. For the 2 year fallow, the values were 0.38% and 17.67 kg ha⁻¹ for N and 0.045% and 2.04 kg ha⁻¹ for P. The values of N and P concentrations and contents for the 3 year *T. vogelii* fallow were 0.28% and 13.35 kg ha⁻¹ for N and 0.029% and 1.41 kg ha⁻¹ for P. Foliage N and P concentration and content from 1 year *T. vogelii* fallow was 2.59% and 54.44 kg ha⁻¹ for N and 0.198% and 4.14 kg ha⁻¹ for P.

For *C. cajan* wood N and P concentrations and contents from 1 year fallow were 0.59% and 44.80 kg ha⁻¹ for N and 0.047% and 3.31 kg ha⁻¹ for P. Foliage N and P concentration and content from 1 year *C. cajan* fallow were 2.59% and 55.01 kg ha⁻¹ for N and 0.184 and 3.62 kg ha⁻¹ for P. For the 2 year fallow, the values of wood N

and P were 0.31% and 16.34 kg ha⁻¹ for N and 0.043% and 2.21 kg ha⁻¹ for P. Foliage N and P concentrations and contents were 2.52% and 37.21 kg ha⁻¹ for N and 0.179% and 2.45 kg ha⁻¹ for P.

Tephrosia vogelii had the highest litter N and P concentration values of 1.75% and 0.185% respectively. For litter N concentration, it was followed by *C. cajan* with 1.67% and lastly *S. sesban* with 1.61%. While for litter P concentration, *S. sesban* ranked the second with 1.79% followed by *C. cajan* with 1.36%.

4.4 Soil fertility improvement

4.4.1 Soil pH and electrical conductivity

For all the soil depths significant ($P < 0.05$) differences in soil pH were observed between the fallow periods and fallow types (Table 13; Figure. 3a; Appendix 2). The general trend in soil pH was an increase with increasing soil depth (0 – 40 cm). 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. In 3 year old improved fallow, at 0 – 10 cm soil depth, *S. sesban* had the highest soil pH of 7.31, followed by *T. vogelii* plots with

Table 13: Probability of F-ratio for significant differences between fallows of different types and periods on soil fertility improvement attributes at Gairo in Morogoro, Tanzania.

0 – 10 cm soil depth						
Source	EC	pH	OC	AVP	TN	TP
Block	0.3482	0.1808	0.7732	0.3447	0.0563	0.5065
FP	0.0009	0.0001	0.0001	0.0009	0.0053	0.0001
Error I	-	-	-	-	-	-
FT	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
FP*FT	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Error II	-	-	-	-	-	-

10 – 20 cm soil depth						
Source	EC	pH	OC	AVP	TN	TP
Block	0.6152	0.3825	0.7953	0.4794	0.3629	0.1867
FP	0.0013	0.0149	0.0012	0.0002	0.4931	0.0001
Error I	-	-	-	-	-	-
FT	0.0001	0.0001	0.0001	0.0001	0.0785	0.0001
FP*FT	0.0001	0.0001	0.0001	0.0001	0.4243	0.0001
Error II	-	-	-	-	-	-

20 – 30 cm soil depth						
Source	EC	pH	OC	AVP	TN	TP
Block	0.8635	0.1808	0.8321	0.7422	0.2138	0.4368
FP	0.0011	0.0002	0.0006	0.0013	0.0966	0.0001
Error I	-	-	-	-	-	-
FT	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
FP*FT	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Error II	-	-	-	-	-	-

30 – 40 cm soil depth						
Source	EC	pH	OC	AVP	TN	TP
Block	0.2161	0.3721	0.8138	0.9457	0.0728	0.2423
FP	0.0021	0.0017	0.0028	0.0020	0.0001	0.0009
Error I	-	-	-	-	-	-
FT	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
FP*FT	0.0001	0.0001	0.0019	0.0001	0.0001	0.0001
Error II	-	-	-	-	-	-

FP = Fallow period, FT = Fallow type, EC = Electrical conductivity, OC = Organic carbon, AVP = Available phosphorus, TN = Total nitrogen, TP = Total phosphorus

7.29, *C. cajan* 7.13 and natural fallow 6.44. The lowest soil pH was observed from plots which have been continuously cropped for 3 years i.e. 5.53.

Soil electrical conductivity (EC) differed significantly ($P < 0.05$) between the fallow period and fallow type in all the soil depths (Table 13, Figure 3a and Appendix 2). 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. The least EC values came from continuously cropped plots.

4.4.2 Soil available P

Significant ($P < 0.05$) differences were observed in soil available P (Bray-1 P) between the fallow period and fallow type. Increase in soil available P was generally observed as the fallow period increased (Table 13; Figure 3a and Appendix 2). *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, soil available P from *S. sesban* ranged from 12.92 – 11.11 mg P kg⁻¹, *C. cajan* (12.14 – 10.62 mg P kg⁻¹), *T. vogelii* (11.06 – 9.40 mg P kg⁻¹), natural fallow (2.14 – 2.03 mg P kg⁻¹) and continuous cropping (4.23 – 3.14 mg P kg⁻¹) from the 0 –

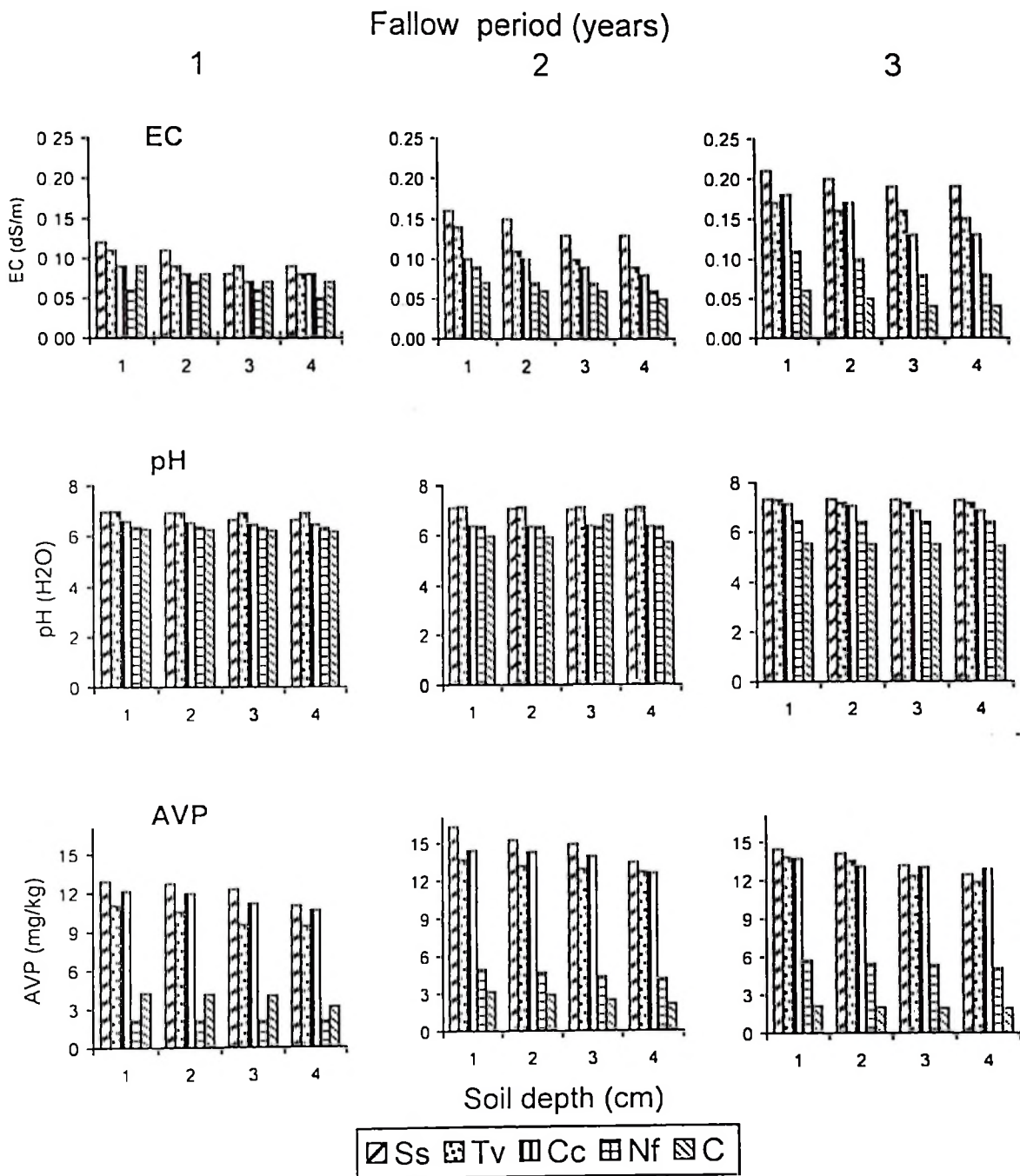


Figure 3a: Effect of improved fallows of leguminous shrubs on selected soil chemical properties at Gairo in Morogoro, Tanzania. Ss = *S. sesban*, Tv = *T. vogelii*, Cc = *C. cajan*, Nf = Natural fallow, C = continuous cropping. 1 = 0 – 10, 2 = 10 – 20, 3 = 20 – 30, 4 = 30 – 40 cm. EC = electrical conductivity,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

40 cm soil depth. In a 2 year fallow, the results were *S. sesban* (16.29 – 13.42 mg P kg⁻¹), *C. cajan* (14.41 – 12.55 mg P kg⁻¹), *T. vogelii* (13.68 – 12.65 mg P kg⁻¹), natural fallow (4.95 – 4.15 mg P kg⁻¹) and continuous cropping (3.13 – 2.13 mg P kg⁻¹). For the 3 year fallow available P from *S. sesban* ranged from 14.45 – 12.43 mg P kg⁻¹, *C. cajan* (13.72 – 12.86 mg P kg⁻¹), *T. vogelii* (13.83 – 11.85 mg P kg⁻¹), natural fallow (5.73 – 5.06 mg P kg⁻¹) and continuous cropping (2.11 – 1.92 mg P kg⁻¹) from the 0 – 40 cm soil depth.

4.4.3 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 (Table 13). Generally, the trend was an increase in soil OC with an increase in fallow period from 1 to 2 year, but slight decrease in 3 year and a decrease in soil organic carbon 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. (Figure 3b). In 1 year fallow, soil OC from *S. sesban* fallow ranged from 1.92 – 1.76%, *T. vogelii* (1.71 – 1.48%), *C. cajan* (1.46 – 1.11%), natural fallow (1.04 – 0.58%), and continuously cropped plot (0.80 – 0.50%) from the 0 – 40 cm soil depth. In the 2 year fallow soil OC for *S. sesban* ranged from 2.72 – 2.60%, *T. vogelii* (2.53 – 2.25%), *C. cajan* (1.56

– 1.18%), natural fallow (1.29 – 0.71%) and continuously cropped plot (0.69 – 0.45%) from the 0 – 40 cm soil depth. For the 3 year fallow soil OC from *S. sesban* ranged from 2.41 – 1.91%, *T. vogelii* (2.26 – 2.17%), *C. cajan* (1.29 – 1.13%), natural fallow (1.33 – 0.75%) and continuously cropped plot (0.60 – 0.46%) from the 0 – 40 cm soil depth.

4.4.4 Soil total N

Soil total N differed significantly ($P < 0.05$) between fallow period and fallow type at 0 – 10, 20 – 30 and 30 – 40 cm soil depths. No significant ($P > 0.05$) differences were observed in soil total N between the fallow period and fallow type at 10 – 20 cm soil depth (Table 13; Figure 3b; Appendix 2). 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 (Appendix 2).

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

cropping (0.08 – 0.05%) from 0 – 40 cm soil depth. From the 3 year fallow, *S. sesban* had 0.26 – 0.13%, *T. vogelii* (0.21 – 0.17%), *C. cajan* (0.15 – 0.12%), natural fallow (0.11 – 0.08%) and continuous cropping (0.07 – 0.03%) from the 0 – 40 cm soil depth.

4.4.5 Soil total P

Significant ($P < 0.05$) differences were observed in soil total P between the fallow period and fallow type (Table 13). 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 3b).

In 1 year fallow, soil total P from *S. sesban* ranged from 395 – 388 mg P kg⁻¹, *T. vogelii* (287 – 267 mg P kg⁻¹), *C. cajan* (215 – 195 mg P kg⁻¹), natural fallow (153 – 139 mg P kg⁻¹) and continuous cropping (168 – 149 mg P kg⁻¹) from the 0 – 40 cm soil depth (Figure 3b).

In 2 year fallow, the results were, *S. sesban* (454 – 450 mg P kg⁻¹), *T. vogelii* (408 – 305 mg P kg⁻¹), natural fallow (267 – 250 mg P kg⁻¹) and continuous cropping (180 –

166 mg P kg⁻¹) from the 0 – 40 cm soil depth. For the 3 year fallow, soil total P from *S. sesban* ranged from 454 – 432 mg P kg⁻¹, *T. vogelii* (395 – 294 mg P kg⁻¹), *C. cajan* (279 – 265 mg P kg⁻¹), natural fallow (197 – 172 mg P kg⁻¹) and continuous cropping (127 – 265 mg P kg⁻¹) from the 0 – 40 cm soil depth (Appendix 2).

4.5 Maize plant leaf N and P content and biomass at 84 DAS

The results of N and P content (amount of nutrient/leaf) and leaf biomass at 84 DAS are presented in Table 14 and Appendices 3a and b. Maize leaf N and P contents were significantly ($P < 0.05$) different between the fallow periods and fallow types. Significant differences in maize leaf N and P content were also observed between plots with different fertilizer treatments (Table 14). Maize leaf biomass differed significantly ($P < 0.05$) between the fallow types and the different fertilizer treatments. Generally, maize plant leaves from improved fallow plots contained more N and P than the maize leaves from the natural fallow and continuously cropped plots. This general trend was also observed for the maize leaf biomass.

The highest mean maize leaf N content regardless of the fallow period and fertilizer treatments came from *T. vogelii* improved fallow (11.53 mg N leaf⁻¹). This was followed by *C. cajan* (10.37 mg N leaf⁻¹), *S. sesban* (9.735 mg N leaf⁻¹) and the natural

fallow (5.15 mg N leaf⁻¹). The least maize leaf N content was observed from the continuously cropped plots (4.18 mg N leaf⁻¹). For the maize leaf P content, again regardless of the fallow period and fertilizer treatments were 1.63, 1.16, 1.11, 0.56 and 0.47 mg P leaf⁻¹ for improved fallows of *T. vogelii*, *C. cajan*, *S. sesban*, natural fallow and continuous cropping, respectively. The maize plant leaf biomass were 2.36, 2.10, 2.01, 1.73 and 1.61 g leaf⁻¹ from *T. vogelii*, *C. cajan*, *S. sesban*, natural fallow and continuous cropping, respectively.

Table 14: Probability of F – ratio for significant effects of fallow periods, fallow types and fertilization on maize growth and maize leaf N and P content at Gairo in Morogoro, Tanzania.

Source	Height (m)	Leaf wt. (g leaf ⁻¹)	Leaf N (mg leaf ⁻¹)	Leaf P (mg leaf ⁻¹)
Block	0.3496	0.0001	0.0001	0.0968
FP	0.1568	0.5303	0.0053	0.0162
Error I	-	-	-	-
FT	0.0001	0.0001	0.0001	0.0001
FP*FT	0.0001	0.0001	0.0001	0.0001
Error II	-	-	-	-
Fert	0.0001	0.0001	0.0001	0.0001
	0.0068	0.0001	0.0001	0.0001
FT*Fert				
FP*Fert	0.4588	0.5007	0.0511	0.3401
FP*FT*Fert	0.7725	0.5987	0.0532	0.4321
Error III	-	-	-	-

FP = Fallow period, FT = Fallow type Fert. = fertilization

The effect of different fertilizer treatments on maize leaf N and P and leaf biomass without considering the fallow period and type was significantly ($P < 0.05$) different (Table 14). Plots which received half of recommended dose of N and recommended full dose of P, resulted in the highest maize leaf N content of $9.96 \text{ mg N leaf}^{-1}$. This was followed by plots with half recommended dose of N ($9.67 \text{ mg N leaf}^{-1}$). Maize leaf N content from plots with recommended full dose of P ($0.89 \text{ mg N leaf}^{-1}$) did not differ much from the unfertilized control plots ($0.87 \text{ mg N leaf}^{-1}$).

For the maize leaf P content, plots with recommended full dose of P ranked higher with the maize leaf P content of $1.12 \text{ mg P leaf}^{-1}$. This was followed by plots with half of recommended dose of N and recommended full dose of P ($1.10 \text{ mg P leaf}^{-1}$). However, the difference in maize leaf P content from these two fertilizer treatments was not statistically significant. Following behind these two treatments in maize leaf P content were the plots with half of recommended dose of N ($0.90 \text{ mg P leaf}^{-1}$) and lastly the unfertilized control plots with $0.88 \text{ mg P leaf}^{-1}$.

For the maize leaf biomass at 84 DAS, plots with half of recommended dose of N and recommended full dose of P resulted in greater maize leaf biomass of 2.36 g leaf^{-1} . This was followed by plots with half of recommended dose of N (2.08 g leaf^{-1}) and plots with recommended full dose of P (1.81 g leaf^{-1}). The least maize leaf biomass came from the unfertilized control plots (1.63 g leaf^{-1}).

The effect of the interaction of fallow period, fallow type and fertilization on maize plant leaf N and P and leaf biomass is summarized in Appendix 3b. For *T. vogelii* improved fallow, maize leaf N content from the unfertilized control plots were 7.14, 8.19 and 11.9 mg N leaf⁻¹ from 1, 2 and 3 year fallows respectively. *Tephrosia vogelii* plots which received half of recommended dose of N and recommended full dose of P resulted in the greatest maize leaf N content of 12.80, 14.13 and 20.52 mg N leaf⁻¹ from the respective 1, 2 and 3 year fallows. Maize leaf P from the unfertilized control plots of *T. vogelii* were 0.95, 1.33 and 1.54 mg leaf⁻¹ from 1, 2 and 3 year fallows respectively. Greater maize leaf P content came from *T. vogelii* plots which received half of recommended dose of N and recommended full dose of P i.e. 1.63, 2.27 and 2.74 mg leaf⁻¹ from the respective 1, 2 and 3 year fallows. Maize leaf biomass from *T. vogelii* unfertilized control plots was 1.83, 1.99 and 1.95 g leaf⁻¹ from 1, 2 and 3 year fallows, respectively. Maize leaf biomass from plots with half of recommended dose of N and recommended full dose of P was 2.64, 2.77 and 2.89 g leaf⁻¹ from the respective 1, 2 and 3 year fallows.

For *C. cajan*, maize leaf N from the unfertilized control plots were 5.12, 5.71 and 7.74 mg leaf⁻¹ from 1, 2 and 3 year fallows. Maize leaf N content from plots, which were treated with half of recommended dose of N and recommended full dose of P, were 11.09, 13.20 and 16.24 mg N leaf⁻¹ from 1, 2 and 3 year fallows. Maize leaf P content from the unfertilized control plots of *C. cajan* were 0.53, 0.81 and 1.10 mg P leaf⁻¹

from 1, 2 and 3 year fallows. While maize leaf P content from plots with half of recommended dose of N and recommended full dose of P were 1.29, 2.01 and 2.38 mg P leaf⁻¹ from 1, 2 and 3 year fallow. Maize leaf biomass from the unfertilized control plots were 1.52, 1.63 and 1.72 g leaf⁻¹ from 1, 2 and 3 year fallows. Plots with half of recommended dose of N and recommended full dose of P resulted in maize leaf biomass of 2.45, 2.75 and 2.80 g leaf⁻¹ from 1, 2 and 3 year fallows, respectively.

For *S. sesban* improved fallow, from the unfertilized control plots maize leaf N contents were 4.91, 6.56 and 6.01 mg N leaf⁻¹, maize leaf P contents were 0.50, 1.02 and 1.18 mg P leaf⁻¹, maize leaf biomass were 1.52, 1.93 and 1.88 g leaf⁻¹ from 1, 2 and 3 year fallows respectively. From plots which were treated with half of recommended dose of N and recommended full dose of P maize leaf N contents were 7.85, 8.91 and 7.47 mg N leaf⁻¹, maize leaf P content were 1.17, 1.66 and 1.95 mg P leaf⁻¹, maize leaf biomass was 2.31, 2.35 and 2.41 g leaf⁻¹ from 1, 2 and 3 year fallows respectively.

In the natural fallow, from the unfertilized control plots maize leaf N contents were 2.93, 3.19 and 5.44 mg N leaf⁻¹, maize leaf P contents were 0.36, 0.57 and 0.89 mg P leaf⁻¹, maize leaf biomass were 1.31, 1.33 and 1.60 g leaf⁻¹ from 1, 2 and 3 year fallows respectively. In plots which received half of recommended dose of N and recommended full dose of P maize leaf N contents were 7.03, 7.16 and 9.79 mg N

leaf⁻¹, maize leaf P contents were 0.74, 1.11 and 1.46 mg P leaf⁻¹, maize leaf biomass was 2.07, 1.99 and 2.13 g leaf⁻¹ from the respective 1, 2 and 3 year fallows.

For the continuously cropped plots, from the unfertilized control plots maize leaf N contents were 3.50, 3.13 and 2.25 mg N leaf⁻¹, maize leaf P contents were 0.42, 0.34 and 0.23 mg P leaf⁻¹, maize leaf biomass was 1.49, 1.39 and 1.10 g leaf⁻¹ from the respective 1, 2 and 3 year continuously cropped plots. In plots which were treated with half of recommended dose of N and recommended full dose of P maize leaf N contents were 6.54, 4.60 and 4.57 mg N leaf⁻¹, maize leaf P contents were 0.95, 0.67 and 0.55 mg P leaf⁻¹, maize leaf biomass were 2.32, 1.77 and 1.54 g leaf⁻¹ from the respective 1, 2 and 3 year continuously cropped plots.

4.6 Maize grain and stover N and P concentration and content

The results of maize grain and stover N and P concentrations and contents are presented in Table 15 and Appendices 4a-f. Significant ($P < 0.05$) differences in maize grain and stover P concentrations and contents were observed between the fallow periods, fallow types and fertilizer treatments. The interaction of fallow type and fertilizer treatment also resulted in significant differences in maize grain and stover P concentrations and contents (Table 15). For maize grain and stover N concentrations and contents, there were no significant ($P > 0.05$) differences between

fallow periods. However, significant differences in N concentration and content were observed between the fallow types and fertilizer treatments. The highest values of maize grain and stover N and P concentration and contents were obtained from *T. vogelii* fallows. The least values were observed from plots which have been continuously cropped with maize (Appendices 4a - f).

Within the individual species (fallow types) some variations were observed in maize grain and stover N and P concentration and content and total N and P uptake (grain + stover) between the different fallow periods. The generally noted trend was increased nutrient uptake with increasing fallow period from 1 to 3 years. The reverse was true for the continuously cropped plots where an increase in the period of continuous cropping from 1 to 3 years resulted in a decrease in nutrient uptake by the maize plants. It was also noted in this study that, where N and P fertilizers were applied maize grain and stover N and P concentration and content from the corresponding plots increased.

For *T. vogelii*, N concentrations and contents (Appendices 4e and f) in maize grain from the unfertilized control plots were 1.24% N and 41.03 kg N ha⁻¹, 1.25% N and 55.26 kg N ha⁻¹, and 1.27% N and 69.33 kg N ha⁻¹ from 1, 2 and 3 year fallows, respectively. Nitrogen concentrations and contents from *T. vogelii* plots which were treated with half recommended dose of N were 1.38% N and 69.66 kg N ha⁻¹, 1.42%

and 78.81 kg N ha⁻¹ and 1.43% and 91.05 kg N ha⁻¹ from the respective 1, 2 and 3 year fallows. The values of stover N concentration and content from the unfertilized plots were 0.30% and 10.69 kg N ha⁻¹, 0.35% and 15.01 kg N ha⁻¹ and 0.37% and 20.74 kg N ha⁻¹ from 1, 2 and 3 year fallows respectively. Total N concentration and content from *T. vogelii* plots treated with half recommended dose of N was 1.80% N and 89.93 kg N ha⁻¹, 1.81% N and 104.3 kg N ha⁻¹ and 1.88% N and 128.3 kg N ha⁻¹ from 1, 2 and 3 year fallows respectively. Maize grain and stover P values were higher from plots which were treated with full recommended dose of P than from plots which received the other treatments. Total P concentrations and contents from the P treated plots were 0.13% P and 5.20 kg P ha⁻¹, 0.16% P and 8.62 kg P ha⁻¹ and 0.15% P and 9.73 kg P ha⁻¹ from 1, 2 and 3 year fallows, respectively.

In *C. cajan* the values of maize grain N concentrations and contents from the unfertilized plots were 1.13% N and 18.80 kg N ha⁻¹, 1.16% N and 27.05 kg N ha⁻¹ and 1.18% N and 50.72 kg N ha⁻¹ from 1, 2 and 3 year fallows, respectively. In plots which were treated with half recommended dose of N maize grain N concentrations and contents were 1.22% N and 27.09 kg N ha⁻¹, 1.24% N and 22.84 kg N ha⁻¹ and 1.27% N and 50.72 kg N ha⁻¹ from the respective 1, 2 and 3 year fallows. Total N concentration and content from plots treated with half recommended dose of N were 1.32% N and 31.07 kg N ha⁻¹, 1.46% N and 33.22 kg N ha⁻¹ and 1.47% N and 75.02 kg N ha⁻¹ from 1, 2 and 3 year fallows, respectively. Like N, the application of P

fertilizer resulted in greater P uptake by the above ground maize components. Total P concentrations and contents from the plots treated with recommended full dose of P were 0.13% P and 2.91 kg P ha⁻¹, 0.15% P and 4.53 kg P ha⁻¹ and 0.15% P and 8.50 kg P ha⁻¹ from the respective 1, 2 and 3 year fallows.

In the natural fallow maize grain N concentrations and contents from the unfertilized plots were 0.86% N and 8.84 kg N ha⁻¹, 1.01% N and 12.71 kg N ha⁻¹ and 1.28% N and 28.01 kg N ha⁻¹ from 1, 2 and 3 year fallows, respectively. From plots treated with half recommended dose of N, the values were 1.14% N and 23.49 kg N ha⁻¹, 1.22% N and 29.88 kg ha⁻¹ and 1.24% N and 37.48 kg N ha⁻¹ from 1, 2 and 3 year fallows respectively. Total N concentrations and contents from the N treated plots were 1.25% N and 27.39 kg N ha⁻¹, 1.38% N and 35.81 kg N ha⁻¹ and 1.47% N and 52.05 kg N ha⁻¹ from 1, 2 and 3 year fallows respectively. The values of total P from plots treated with recommended full dose of P were 0.11% P and 2.10 kg P ha⁻¹, 0.12% P and 2.78 kg P ha⁻¹ and 0.13% and 4.35 kg P ha⁻¹ from the respective 1, 2 and 3 year fallows.

For the continuously cropped plots, grain N concentrations and contents from the unfertilized plots were 0.84% N and 19.16 kg N ha⁻¹, 0.75% N and 13.81 kg N ha⁻¹ and 0.67% N and 7.62 kg N ha⁻¹ from 1, 2 and 3 years continuously cropped plots respectively. The values of total N uptake from plots treated with half recommended dose of N were 1.36% N and 39.17 kg N ha⁻¹, 1.27% N and 32.27 kg N ha⁻¹ and

1.04% N and 19.86 kg N ha⁻¹ from the respective 1, 2 and 3 years continuously cropped plots. Total P uptake from plots treated with recommended full dose of P were 0.10% P and 3.09 kg P ha⁻¹, 0.09% P and 2.67 kg P ha⁻¹ and 0.08% P and 1.66 kg P ha⁻¹ from the 1, 2 and 3 years continuously cropped plots, respectively.

4.7 Maize growth and yield

4.7.1 Maize height at 84 DAS

The results of maize height growth are presented in Table 14 and Appendices 5a, b and c. Significant ($P < 0.05$) differences were observed in mean maize height at 84 days after sowing (DAS) between fallows of different types and with different fertilizer treatments. Generally mean maize height from the improved fallow plots were higher than the heights from the natural fallow and continuously cropped plots (Appendices 5a, b and c).

Although not significant, height growth was also observed to be higher in 3 year fallows than in 2 and 1 year fallows, and it was also higher in plots which received both half of recommended dose of N and recommended full dose of P than in plots which were treated with half of recommended dose of N and full recommended dose of P being applied separately. Nevertheless, height from plots treated with N alone

was better than that from plots treated with P alone.

The unfertilized control plots of *T. vogelii* fallow produced the highest maize height as compared to the unfertilized control plots of the other fallow types. The heights growth from the unfertilized control plots of *T. vogelii* were 1.03, 1.09 and 1.10 m in 1, 2 and 3 year fallows respectively. Plots which were treated with recommended full dose of P and half of recommended dose of N resulted in greater mean maize height of 1.46, 1.51 m and 1.61 in 1, 2 and 3 year fallows. Plots with half of recommended dose of N were the second in height growth with 1.25, 1.37 and 1.35 m in the respective 1, 2 and 3 year fallows. This was followed by plots with full recommended dose of P which resulted in mean maize height of 1.17, 1.14 and 1.25 m in 1, 2 and 3 year fallows respectively.

For *C. cajan* improved fallow, mean maize heights from the unfertilized control plots was 0.94, 1.01 and 1.08 m in 1, 2 and 3 year fallows. In plots which received half of recommended dose of N and recommended full dose of P, maize height growth was 1.34, 1.36 and 1.46 m in 1, 2 and 3 year fallows respectively. The other treatments resulted into intermediate maize height growth results.

For *S. sesban* mean maize height growth from the unfertilized control plots were 0.96, 1.01 and 1.12 m in 1, 2 and 3 year fallows respectively. In plots with half of

recommended dose of N and recommended full dose of P, mean maize heights were 1.23, 1.34 and 1.44 m in 1, 2 and 3 year fallows. Intermediate results were obtained from the other treatments.

In the natural fallow, maize heights from the unfertilized control plots were 0.81, 0.94 and 1.04 m in 1, 2 and 3 year fallows. Plots which received half of recommended dose of N and recommended full dose of P resulted in maize height growth of 1.15, 1.22 and 1.26 m in 1, 2 and 3 year fallow respectively. The other treatments gave intermediate results.

In the continuously cropped plots mean maize height growth from the unfertilized control plots were 0.95, 0.84 and 0.75 m in the respective 1, 2 and 3 year continuously cropped plots. In plots which were treated with recommended half dose of N and full recommended dose of P mean maize heights were 1.31 m in 1 year continuous cropping, 1.24 m in 2 years continuous cropping and 1.01 m in 3 years continuous cropping. Intermediate results were obtained from plots which received the other treatments.

4.7.2 Maize grain yield

The results of maize grain yield from 1, 2 and 3 year improved fallows of *T. vogelii*,

C. cajan, and *S. sesban*, natural fallow and continuous cropping are presented in Figure 4 and 5 and Appendices 5a, b and c. Significant ($P < 0.05$) differences were observed in maize grain yield between fallow periods and types (Table 15). Generally, the yield from improved fallow treatments were better than those from natural fallow and continuous cropping treatments.

The effect of fallow periods on maize grain yield without considering fallow types and fertilization also showed some interesting results. Greater mean maize grain yield was from 3 year fallows (4.30 t ha^{-1}). This was followed by the yield from 2 year fallows (3.23 t ha^{-1}) and lastly 1 year fallows (2.74 t ha^{-1}).

The overall effect of fallow types on maize grain yield without regard to fallow periods and fertilizer treatments were as follows: Greater mean maize yield was from the improved fallow of *T. vogelii* (5.65 t ha^{-1}), followed by *C. cajan* (3.60 t ha^{-1}), *S. sesban* (3.24 t ha^{-1}) and the natural fallow (2.26 t ha^{-1}). Plots continuously cropped with maize gave the least mean maize grain yield of (2.13 t ha^{-1}).

The effect of fertilizer treatments on maize grain and stover yield, without considering fallow types and periods was significantly ($P < 0.05$) different. Plots which received half of recommended dose of N and recommended full dose of P (i.e. 40 kg N ha^{-1} and 40 kg P ha^{-1}) resulted in the highest mean maize grain yield of 4.61 t ha^{-1} . This was

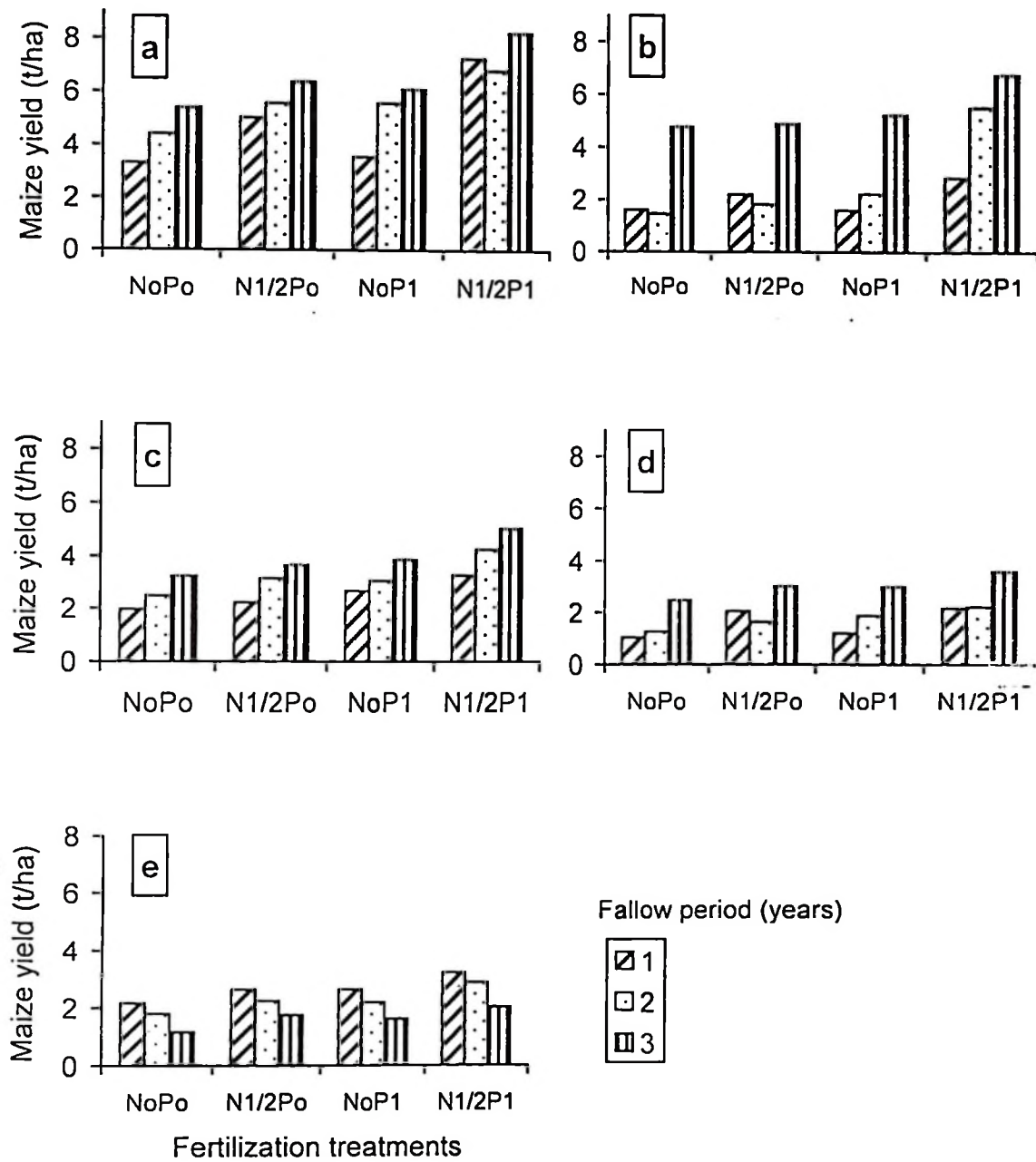


Figure 4: Effect of fallow periods and fertilization on maize grain yield at Gairo in Morogoro, Tanzania. a = *T. vogelii*, b = *C. cajan*, c = *S. sesban*, d = Natural fallow, e = Continuous cropping.

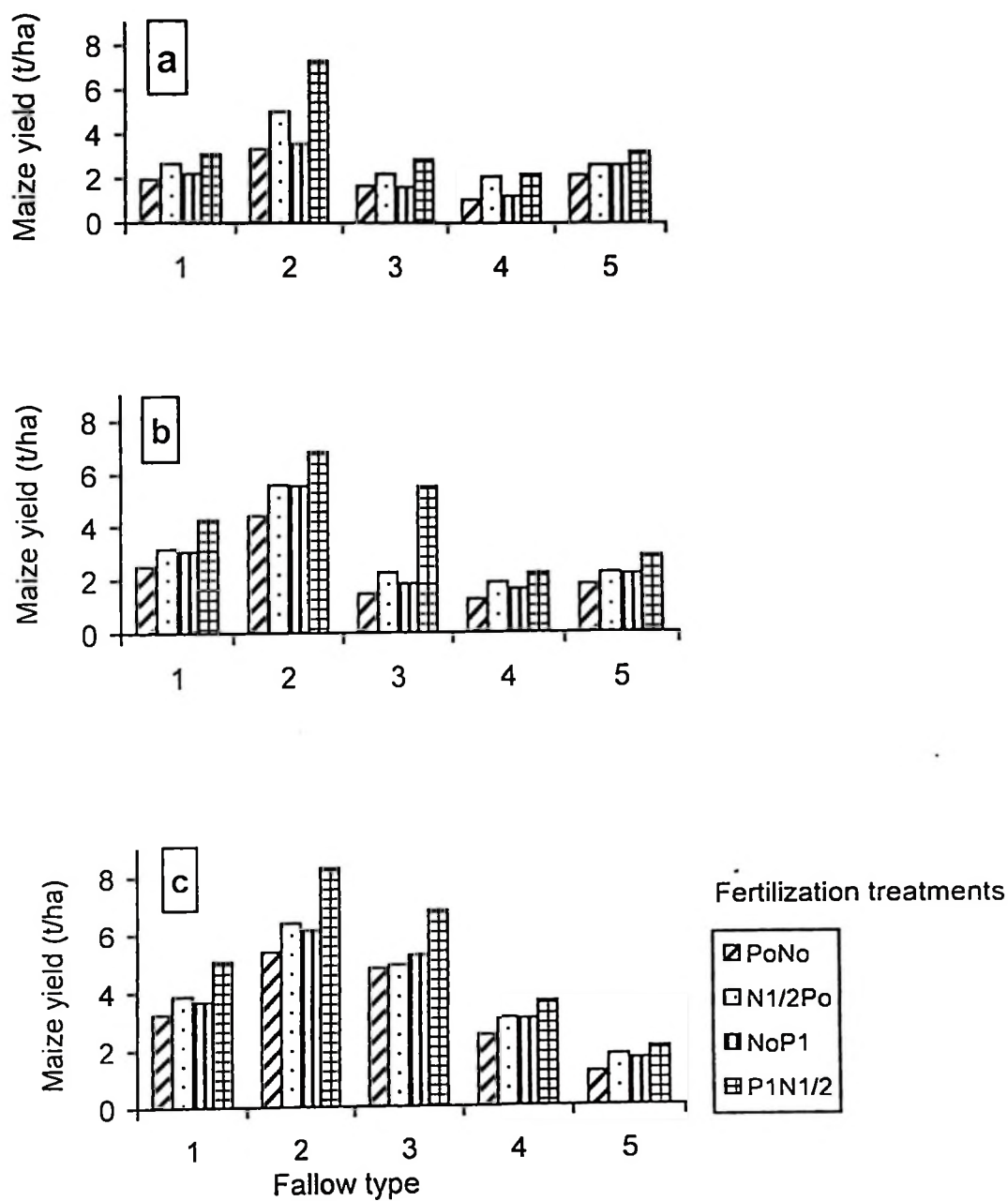


Figure 5: Effect of fallow type and fertilization on maize grain yield at Gairo in Morogoro, Tanzania. a = 1 year fallow, b = 2 year fallow, c = 3 year fallow. 1 = *S. sesban*, 2 = *T. vogelii*, 3 = *C. cajun*, 4 = Natural fallow, 5 = continuous cropping.



Table 15: Probability of F – ratio for significant differences on the effect of fallow periods, fallow types and fertilization on maize grain and stover yield and maize grain and stover N and P concentration.

Source of variation	Grain yield	Stover yield	Grain N		Grain P		Stover N		Stover P		Total uptake	
			conc.	cont.	conc.	cont.	conc.	cont.	conc.	cont.	N	P
Block	0.0493	0.1806	0.1256	0.0715	0.0780	0.4926	0.1078	0.3638	0.0769	0.2607	0.0579	0.2607
FP	0.0582	0.0221	0.3153	0.0635	0.0211	0.0159	0.3712	0.1667	0.1998	0.0219	0.0559	0.0140
Error I	-	-	-	-	-	-	-	-	-	-	-	-
FT	0.0001	0.0053	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
FP*FT	0.1247	0.0629	0.0001	0.0549	0.0086	0.0942	0.0669	0.1369	0.9696	0.0374	0.0188	0.1154
Error II	-	-	-	-	-	-	-	-	-	-	-	-
Fert	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
FT*Fert.	0.2436	0.7210	0.0001	0.0733	0.0001	0.0129	0.7074	0.5830	0.0001	0.0022	0.0442	0.0022
FP*Fert.	0.8741	0.9057	0.0001	0.9028	0.0368	0.5072	0.4031	0.4370	0.0001	0.7105	0.9023	0.7105
FP*FT*Fert	0.8532	0.7713	0.0001	0.8820	0.0063	0.9385	0.4390	0.9989	0.0001	0.8009	0.9046	0.8009
Error III	-	-	-	-	-	-	-	-	-	-	-	-

FP = Fallow period, FT = Fallow type, Fert. = Fertilization

followed by plots which received half of recommended dose of N (3.25 t ha^{-1}) and plots with recommended full dose of P (3.13 t ha^{-1}). The lowest mean maize grain yield was from unfertilized control plots (2.61 t ha^{-1}).

Results showing the effect of fallow periods and fertilization on maize grain yield in each fallow type are presented in Figure 4 and Appendix 5c. Significant ($P < 0.05$) differences were observed between fertilizer treatments in improved fallows of *T. vogelii* and *S. sesban*, natural fallow and continuously cropped plots (Table 15). Generally, maize grain yield increased significantly with increasing fallow periods,

with the plots which received half recommended dose of N and recommended full dose of P giving greater grain yield in each fallow period than the rest of the fertilizer treatments (Figures 4 and 5 and Appendix 5c).

In *T. vogelii* improved fallow, plots without fertilizer treatment gave some impressive results where in 3 year fallow maize grain yield of 5.39 t ha⁻¹ was obtained. It was followed by 4.41 t ha⁻¹ and 3.32 t ha⁻¹ in 2 and 1 year unfertilized fallows respectively. If compared with the yield from unfertilized control plots of the natural fallow i.e. 1.03, 1.25 and 2.48 t ha⁻¹ (in 1, 2 and 3 year fallows respectively), *T. vogelii* increased maize grain yield by 222, 252, and 117% in 1, 2 and 3 year fallows over the natural fallow. Greatest maize grain yield of 8.30 t ha⁻¹ was obtained from 3 year fallow plot which received half and full recommended doses of N and P respectively. Corresponding maize grain yield from 2 and 1 year fallows were 7.86 and 7.30 t ha⁻¹ respectively. Grain yield from plots which received half of recommended dose of N was higher 5.02, 5.59 and 6.38 t ha⁻¹ from 1, 2 and 3 year fallows respectively and those from plots which received recommended full dose of P were 3.57, 5.56 and 6.11 t ha⁻¹ from 1, 2 and 3 year fallows respectively.

For *C. cajan* improved fallow, maize grain yield from plots without fertilizer treatment was 1.61, 1.47 and 4.79 t ha⁻¹ in 1, 2 and 3 year fallows, respectively. Thus yield increased by 56, 17 % and 93 % in 1, 2 and 3 year fallows respectively over the

unfertilized control plots of the natural fallow. In plots which received half of recommended dose of N and recommended full dose of P, maize grain yield was 2.87, 5.54 and 6.79 t ha⁻¹ in 1, 2 and 3 year fallows respectively. Intermediate results were obtained from plots which received either N or P alone, but again greater maize grain yield was obtained from plots which were treated with half recommended dose of N.

For *S. sesban*, maize grain yield from unfertilized control plots were 1.97 t ha⁻¹ from 1 year fallow, 2.49 t ha⁻¹ from 2 year fallow and 3.24 t ha⁻¹ from 3 year fallow. The corresponding increase in maize grain yield from *S. sesban* over the unfertilized control plots of the natural fallow were 94 %, 99 % and 31 %. In plots which received half recommended dose of N and recommended full dose of P, maize grain yield obtained was 3.28, 4.26 and 5.05 t ha⁻¹ from 1, 2 and 3 year fallows respectively. Plots which received the other treatments gave intermediate results.

In the natural fallow, maize grain yield from unfertilized control plots were 1.03 t ha⁻¹ from 1 year fallow, 1.25 t ha⁻¹ from 2 year fallow and 2.48 t ha⁻¹ from 3 year fallow. In plots which were treated with half recommended dose of N and recommended full dose of P, maize grain yield obtained were 2.16 t ha⁻¹ from 1 year fallow, 2.26 t ha⁻¹ and 3.59 t ha⁻¹ from 2 and 3 year fallows respectively. Intermediate results of maize grain yield were obtained from plots which received the other fertilizer treatments.

For the continuously cropped plots, maize grain yield were as follows: In the unfertilized control plots, yield from 1, 2 and 3 year continuous cropping was 2.16, 1.80 and 1.16 t ha⁻¹ respectively. Maize grain yield in plots with recommended half dose of N and recommended full dose of P were 3.22 t ha⁻¹ from 1 year continuous cropping, 2.87 t ha⁻¹ from 2 years continuous cropping and 2.01 t ha⁻¹ from 3 years continuous cropping. In plots with recommended half dose of N, maize grain yield were 2.63 t ha⁻¹, 2.24 t ha⁻¹ and 1.75 t ha⁻¹ from the 1, 2 and 3 years continuously cropped plots respectively. On the other hand, maize grain yield from plots which received recommended full dose of P were as follows: 2.63 t ha⁻¹ from 1 year continuous cropping, 2.19 t ha⁻¹ from 2 years continuous cropping and 1.61 t ha⁻¹ from 3 years continuous cropping.

4.7.3 Maize stover yield

Stover yield was generally greater from improved fallows of the three leguminous shrubs (i.e. *T. vogelii*, *C. cajan* and *S. sesban*) as compared to the yield from the natural fallow and continuously cropped plots. The highest mean maize stover yield without considering fallow periods and fertilization was from the improved fallow of *T. vogelii* (6.01 t ha⁻¹). This was followed by *S. sesban* (5.18 t ha⁻¹), *C. cajan* (4.97 t ha⁻¹) and continuous cropping (4.96 t ha⁻¹). The lowest stover yield was obtained from the natural fallow (4.17 t ha⁻¹).

Maize stover yield from different fallow periods without considering fallow types and fertilization was also different. Mean maize stover yield from 3 year fallows was higher (5.84 t ha⁻¹), as compared to 2 year fallows (5.08 t ha⁻¹) and 1 year fallows (4.31 t ha⁻¹).

The effect of fertilization on maize stover yield regardless of the fallow types and periods was significantly (P<0.05) different. Plots which received half of recommended dose of N and recommended full dose of P had greater mean stover yield of 5.93 t ha⁻¹, followed by plots with recommended full dose of P (5.21 t ha⁻¹) and plots with half of recommended dose of N (5.11 t ha⁻¹). Unfertilized control plots had the lowest mean stover yield of (3.99 t ha⁻¹).

Summarized results of the effect of fallow periods and fertilization on maize stover yield are shown in Figures 6 and 7 and Appendices 5a, b and c. Significant (P<0.05) differences were observed between fertilizer treatments in improved fallows of *T. vogelii*, *S. sesban* and *C. cajan*, natural fallow and continuous cropping. The general observation was that, maize stover yield increased with increasing fallow period.

For *T. vogelii*, maize stover yield from unfertilized control plots were 3.60 t ha⁻¹, 4.80 t ha⁻¹ and 5.27 t ha⁻¹ from 1, 2 and 3 year fallows respectively. Greater stover yield was obtained from plots which received half recommended dose of N and

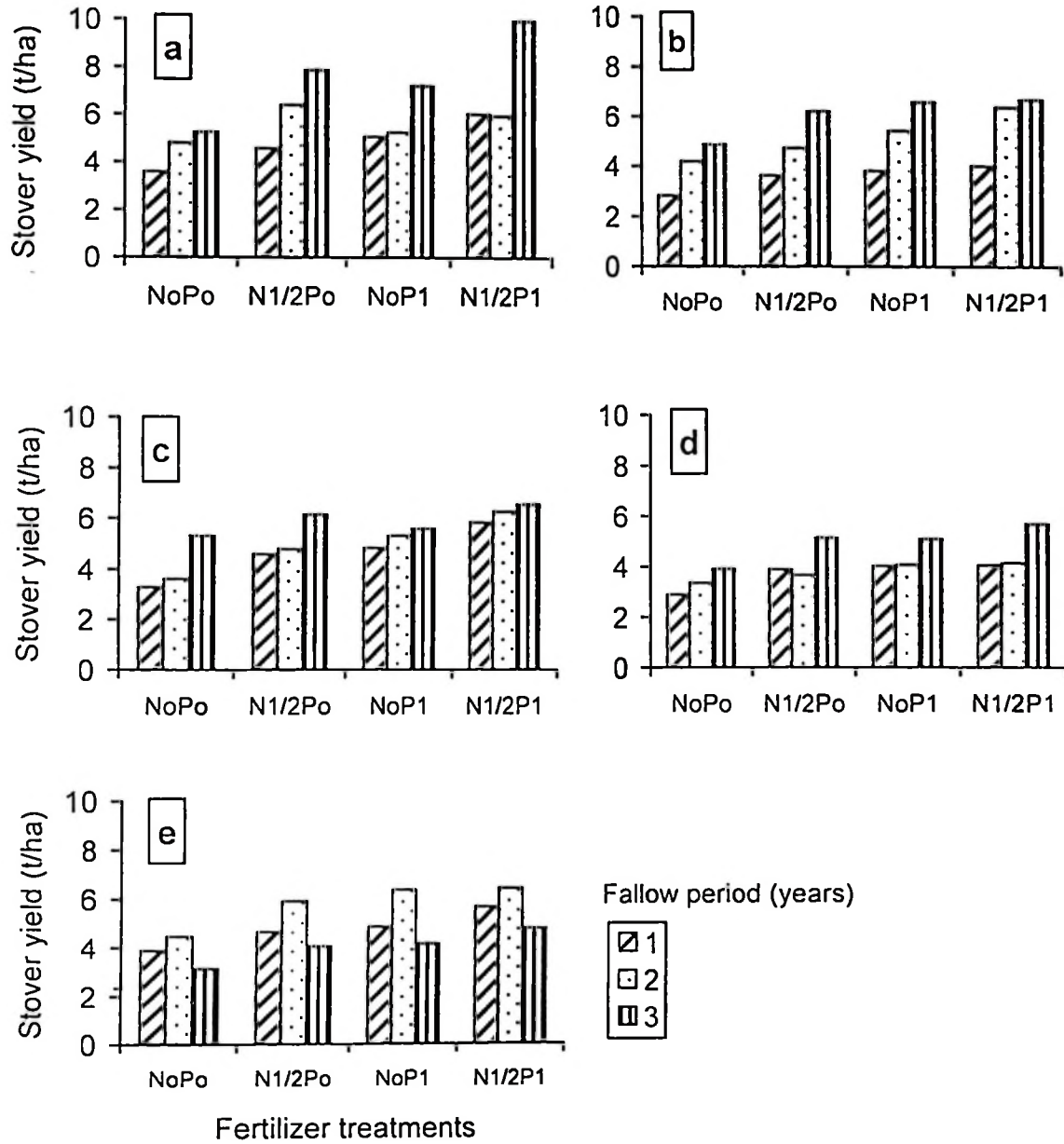


Figure 6: Effect of fallow periods and fertilization on maize stover yield at Gairo in Morogoro, Tanzania. a = *T. vogelii*, b = *C. cajan*, c = *S. sesban*, d = Natural fallow, e = Continuous cropping.

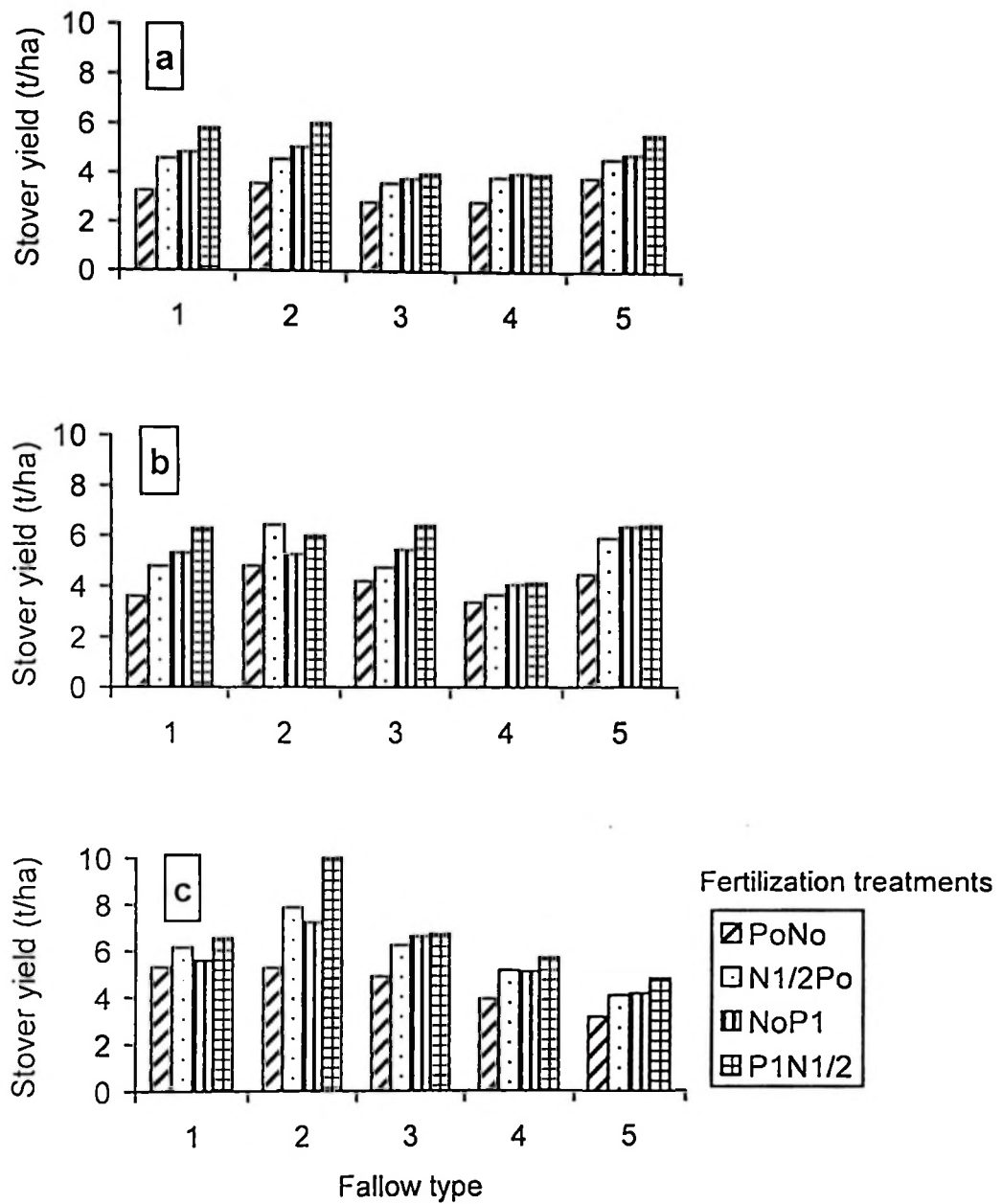


Figure 7: Effect of fallow type and fertilization on maize stover yield at Gairo in Morogoro, Tanzania. a = 1 year fallow, b = 2 year fallow, c = 3 year fallow. 1 = *S. sesban*, 2 = *T. vogelii*, 3 = *C. cajan*, 4 = Natural fallow, 5 = Continuous cropping.

recommended full dose of P. The stover yield in these plots were 6.06, 5.98 and 9.99 t ha⁻¹ from 1, 2 and 3 year fallows, respectively. Stover yield obtained from plots which received recommended half dose of N were 4.58, 6.42 and 7.88 t ha⁻¹ from 1, 2 and 3 year fallows respectively. This stover yield with the exception of 1 year fallow was somehow higher than the yield obtained from plots which were treated with recommended full dose of P. Stover yield from these plots from 1, 2 and 3 year fallow was 5.07, 5.27 and 7.23 t ha⁻¹, respectively.

In *C. cajan* maize stover yield obtained from unfertilized control plots was 2.86, 4.20 and 4.88 t ha⁻¹ from 1, 2 and 3 year fallows respectively. Stover yield from plots which received half recommended dose of N and recommended full dose of P were 4.04, 6.41 and 6.71 t ha⁻¹ from 1, 2 and 3 year fallows; respectively. Maize stover yield results from the other fertilizer treatments were intermediate.

For *S. sesban*, maize stover yield from unfertilized control plots was 3.29 t ha⁻¹ from 1 year fallow, 3.61 t ha⁻¹ from 2 year fallow and 5.30 t ha⁻¹ from 3 year fallow. Stover yield from 1, 2 and 3 year fallow plots which were treated with recommended half dose of N and full recommended dose of P were 5.83, 6.27 and 6.55 t ha⁻¹ respectively. Other fertilizer treatments gave intermediate results.

In the 1, 2 and 3 year old unfertilized natural fallow maize stover yield were 2.89,

3.37 and 3.90 t ha⁻¹, respectively. Stover yield achieved in plots which received half recommended dose of N and recommended full dose of P were 4.07 t ha⁻¹ from 1 year fallow, 4.14 t ha⁻¹ from 2 year fallow and 5.68 t ha⁻¹ from 3 year fallow. Intermediate results were obtained from the other treatments.

For continuously cropped plots stover yield from unfertilized control plots were 3.89, 4.47 and 3.15 t ha⁻¹ from 1, 2 and 3 year fallows respectively. Corresponding stover yield from plots which were treated with half recommended dose of N and recommended full dose of P was 5.66, 6.42 and 4.78 t ha⁻¹, respectively. In plots which received recommended half dose of N stover yield was 4.66, 5.91 and 4.06 t ha⁻¹ for 1, 2 and 3 year fallows respectively. On the other hand, plots which received recommended full dose of P had a stover yield of 4.85, 6.36 and 4.13 t ha⁻¹ from respectively 1, 2 and 3 years continuously cropped plots.

CHAPTER 5

5.0 DISCUSSION

5.1 Wood and foliage yields and leaf and litter N and P concentration and content

The nutrient concentration and content of wood, foliage and litter depend on among other factors the tree/shrub species. Young (1989) reported that even among the leguminous trees, the N concentration of the leaves varies from 1.5 to 3.4%. Results on wood, foliage and litter N and P concentration and content obtained from this study as expected indicate that the three shrub species i.e. *S. sesban*, *T. vogelii* and *C. cajan* differ in nutrient concentrations and contents. Wood, foliage and litter nutrient concentration and content results obtained from this study are within the range of those reported by other authors for leguminous trees (Young, 1989; Szott *et al.* 1991; Palm, 1995).

Higher value of foliage N concentration from *S. sesban* than *T. vogelii* observed in this study agrees with the findings of Fasuluku (1998) who observed a higher value of foliage N concentration from *S. sesban* (2.92%) as compared to the value for *T. vogelii* (2.56%). The observed greater value of foliage P concentration from 2 year fallow of *T. vogelii* than from *S. sesban* also agrees with the results reported by

Fasuluku (1998) when he noted greater foliage P concentration from *T. vogelii* than from *S. sesban*. The Greater foliage P content (35 kg ha^{-1}) reported in 2 year fallow of *S. sesban* than *T. vogelii* (7.25 kg ha^{-1}) despite the fact that the reverse was true for foliage P concentration is the result of higher foliage biomass production from *S. sesban* (18 t ha^{-1}) as compared to lower foliage biomass yield of 4 t ha^{-1} obtained from *T. vogelii* plots.

The values of foliage N concentration observed from *S. sesban* and *T. vogelii* in this study are slightly higher than those reported by Fasuluku (1998). Differences in nutrient concentrations within a species can be due to a number of factors, including differences in provenances, soil fertility, climate, season, age of leaves or plant, frequency of pruning, or even differences in the laboratory or methodologies used to analyse nutrients (Palm, 1995). However, Budelman (1989) suggested that soil nutrient status is the most important factor influencing nutrient concentrations within a species. The magnitude of the effect, however, varies among species (Palm, 1995).

The larger foliage N content from 2 year fallows of *S. sesban* (505 kg ha^{-1}) and *T. vogelii* (79 kg ha^{-1}) indicates that substantial amount of nutrients may be lost if leaves are removed from the field during shrub harvesting. This high nutrient export through shrub harvesting might result into further nutrient depletion and so making the whole

attempt of shrub planting for soil improvement during the fallow period a meaningless exercise. In order to make the practice (improved fallow) meaningful, all the leaves and twigs should always be retained in the field during tree/shrub harvesting after fallow so that nutrients contained in this biomass component can be returned to the soil after decomposition. Though the demand for firewood necessitates removal of the woody component from the field, this may also result in higher nutrient export from the site (see Table 12a). The implication here is therefore that in future there might be a need to apply inorganic fertilizers so as to recover the removed nutrients.

5.2 Wood and foliage biomass production

The results of this study show considerable variation in biomass production between the shrub species and fallow periods (Figure 2). Variations in biomass production between shrub species have also been reported elsewhere (Duguma and Tonye, 1994; Karachi *et al.* 1994) and with age of the shrub species (Kwesiga and Coe, 1994). The total biomass yield attained by 1 year old *S. sesban* in this study is higher than the total biomass attained from a 1 year old *S. sesban* planted at a spacing of 0.75 m x 1 m in a study conducted at Tabora, Tanzania (Karachi *et al.* 1994) and is also

higher than the values reported by Fasuluku (1998) from 1 year old *S. sesban* planted at a spacing of 0.9 m x 1.5 m at SUA farm Morogoro. These differences could be a result of differences in factors affecting potential biomass production such as tree density, nutrient status of the soils, cutting regimes and the general environmental conditions.

The decline in biomass yield observed in 3 year old *S. sesban* was due to the increased mortality of the species which occurred in the third year. In the 3 year old *S. sesban* plots the survival dropped by 46%. The lack of significant ($P>0.05$) differences between the shrub species in biomass production from 1 year fallows could probably be due to the fact that these shrub species during the first year allocated more photosynthate to below ground for developing extensive deep root system which can trap water and nutrients from deep soil layer. This probable low allocation of photosynthate to the above ground parts resulted into slow growth of the above ground parts and consequent low above ground biomass production in 1 year fallows of all the shrub species.

The biomass yield for *T. vogelii* obtained in this study is lower than the one reported by Balasubramanian and Sekayange (1992) with a 1 year old *T. vogelii* grown at a high population density in Kagasa, Rwanda. This observation is in agreement with

what was observed by Niang *et al.* (1996) where an increase in plant population density resulted into greater biomass yield. Biomass yield from 1 year old *C. cajan* attained in this study is higher than the one attained with 1 year *C. cajan* reported in Rwanda by Balasubramanian and Sekayange (1992), but it is lower than the one reported by Niang *et al.* (1996) from 1 year old *C. cajan* planted in the highlands of western Kenya (i.e. 14 t ha⁻¹ of wood and 3.6 t ha⁻¹ of foliar biomass). Besides other already stated factors differences in biomass yield within a species could also result from the differences in provenances or genetic constitution of the individuals.

Out of the three species included in this study, outstanding performance in both foliage and wood biomass production was achieved by *S. sesban*. *Tephrosia vogelii* had lower wood biomass production than *C. cajan*, but it had higher foliage biomass production than *C. cajan*. The higher biomass production attained by *S. sesban* in this study shows that this species has advantage over other tree/shrub species. Because of its fast growth and greater biomass yield, *S. sesban* will therefore be suitable for planting to restore soil fertility and production of fuelwood and fodder. This is so because for effective nutrient recycling and enhancement of soil organic matter, fast growth and high foliage biomass productivity are essential (Duguma and Mollet, 1997).

The high leaf biomass from *S. sesban* indicates that this species can be a suitable species for use in improved fallows and relay cropping systems. Research conducted in Zambia and Malawi has shown that the enrichment or replacement of natural fallows with well chosen agroforestry trees and shrubs such as *S. sesban* has potential to improve soil fertility and yield of maize (Kwesiga and Coe, 1964).

Firewood yield of 51.8 t ha⁻¹ obtained from 2 year old *S. sesban* is sufficiently high for the duration of growth and the environmental limitations. This also confirms the potential of *S. sesban* as a useful agroforestry tree for alleviating firewood shortages. However, the biomass yield from *T. vogelii* and *C. cajan*, besides being lower than that of *S. sesban* does not mean that they are not suitable for inclusion in improved fallow and relay intercropping system.

5.3 Soil fertility improvement

5.3.1 Soil pH and electrical conductivity

The results of this study showed a great change in soil pH following improved fallow. The change in soil pH after a fallow period have been reported by several authors (Juo and Lal, 1977; Onim *et al.* 1990; Adejuwan and Adesina, 1990; Drechsel *et al.*

1996; 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 been reported by among the other authors, Van Noordwijk *et al.* (1996) and 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. Increase in soil pH following improved fallow have also been reported for *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).

An increase in soil EC after a fallow period has been 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 and the reverse was a probable cause of a decrease in EC in continuously cropped plots.

5.3.2 Soil organic carbon

Several authors have reported higher soil organic matter in topsoil under trees than in open areas (Mordelet *et al.* 1993; Trouve *et al.* 1994; Young, 1987). Belsky *et al.* (1993) for example, reported higher soil organic matter at 0 – 15 cm soil depth under *Acacia tortilis* and *Adansonia digitata* in a savanna in Kenya. The increase in soil organic carbon observed in this study under the improved fallows of leguminous shrubs is therefore the result of organic matter additions to the soil by the shrubs during the fallow period through litter fall and root turnover.

The effect of trees on soil organic matter varies among tree species and soils (Kang *et al.* 1994). The observed higher values of organic carbon from *S. sesban* than those of *T. vogelii*, *C. cajan* and the natural fallow are probably the result of high foliage biomass production and root turnover by this species (Appendix 1 and Figure 3b).

Additionally, differences in soil organic carbon 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 lebbbeck*, with that of *T. vogelii* showing slowest rate.

The values of organic carbon 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 organic carbon 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 soil organic carbon content 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.

5.3.3 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 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 (Onim *et al.* 1990).

5.3.4 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, Tanzania has 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 ($31.4 \text{ kg P ha}^{-1} \text{ yr}^{-1}$) as compared to *C. cujan* and *Leucaena leucocephala* that contributed only 4.1 and 4.6 $\text{kg P ha}^{-1} \text{ yr}^{-1}$ 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. The values of available P obtained in this study are higher than the values reported from *G. sepium* improved fallow study done in the forest areas of Nigeria by Adesina (1990). However, the soil available P obtained in this study are lower than the values reported from *Prosopis* hedgerow study done in Argentina by Mazzarino *et al.* (1991) who found soil available P ranging between 24 – 39 mg P kg⁻¹. The lower values of soil available P in this study may be explained by the immobilization of P by the plant biomass and the fact that unlike N which can be fixed, P cannot be fixed by the trees/shrubs.

5.4 Maize leaf N and P content and biomass at 84 DAS

The results of maize leaf N and P content and biomass indicate that these attributes were greatly affected by fallow period, fallow type and fertilizer treatments (Table 14 and Appendices 3a and b). An increase in maize leaf N and P content and biomass with increasing fallow period was noted in most of the fallow types. The possible reason could be an improvement in nutrient supply from planted fallows with increasing fallow period. Maize leaf N and P content and biomass values from improved fallows were generally higher than the values from natural fallow and continuously cropped plots. Higher maize leaf N and P content and biomass from improved fallow plots than the natural fallow have also been reported by Chingonikaya (1999).

Improved fallow of *T. vogelii* resulted in the highest leaf N and P and biomass of maize as compared to *C. cajan*, *S. sesban*, natural fallow and continuously cropping. This can probably be attributed to the fact that the slow release of nutrients from decomposing *T. vogelii* biomass (Fasuluku, 1998), turned out to be advantageous by providing a better synchrony with nutrient demand and uptake by the maize plants. This explanation is considered to be the most possible because analysis of soil samples collected just at the end of the fallow period indicated a higher nutrient status under *S. sesban* fallow than the other fallow types, and these nutrients are suspected to have been leached away before being taken up by the maize plants. See also section 5.3.

The effect of different fertilizer treatments on maize leaf N and P content and biomass was apparent in this study. Higher values of maize leaf N content were observed in plots which were treated with N fertilizer than from plots which were not N fertilized. The same was for maize leaf P content where P fertilized plots resulted into higher maize leaf P content than from the plots which were not P fertilized. These observations are in agreement with the findings by Rehm *et al.* (1983) who observed that P content at early growth stages increased linearly as the rates of P application were increased. Maize leaf biomass values from the fertilized plots were greater than those from the unfertilized control plots. This can be attributed by the increased supply of nutrients which are required for normal functioning of the plant tissues.

Maize leaf P content from the unfertilized plots of the improved and natural fallow were lower than the values from the fertilized plots. The fact that maize plant leaf N and P content at early growth stages depend on among other factors the initial amount of soil nutrient content can be used to explain the low maize leaf P content observed in this study. The low soil available P values obtained from soil samples analysed just at the end of the fallow period might therefore have contributed to the low maize plant leaf P content. See also section 5.2.4.

5.5 Maize grain and stover N and P concentration and content

The results of N and P concentration and content obtained in this study showed that, the presence of trees in improved fallows can increase N and P uptake by maize grown after the fallow period. This can be attributed to the increased nutrient supply resulting from the planted trees through N fixation, nutrient pumping effect and root turnover. Higher values of N and P uptake by the above ground components of maize from improved fallows than the natural fallow have also been reported by Chingonikaya (1999).

Fallow periods have also showed significant effects on nutrient uptake and especially P. Significant differences were noted in the values of maize grain and stover P concentration and content between fallow periods. The generally noted trend of

significant increase in P uptake by above ground maize components with increasing fallow period could be attributed by the improvements in soil available phosphorus (see also Figure 3a). The increase in N uptake by maize (though not significant) with increasing fallow period may as well be associated with the improvements in soil N (see also Figure 3b).

It was also noted in this study that the application of N and P fertilizers resulted in higher N and P uptake by the above ground maize components. Higher values of N and P uptake by maize following the application of N and P fertilizers observed in this study agree with the findings of Myers *et al.* (1994) who reported that N uptake by plant is directly proportional to the rate of N fertilization. Similar observations had also been reported in Kenya by Okalebo (1977) and by some other authors (Utumo, 1995; Fasuluku, 1998; Gachengo *et al.* 1999) who observed a positive correlation between P application and P uptake by the above ground maize components.

Considerably greater values of N and P uptake by the above ground maize components were obtained from the interaction of N and P fertilization with improved fallows of the leguminous shrubs as compared to the natural fallow and continuously cropped plots. Similar observations have also been reported by Yamoah *et al.* (1986).

5.6 Maize growth and yield

Maize growth and maize grain and stover yield from improved fallow treatments were better than those from natural fallow and continuous cropping treatments. The significant increase in maize yield in *T. vogelii*, *C. cajan* and *S. sesban* planted fallows demonstrates the beneficial role that improved fallows play in soil fertility improvement process. Increased crop yield following improved fallows has been widely reported (Palm *et al.* 1988; Nair, 1993; Kwesiga and Coe, 1995; ICRAF, 1995; Niang *et al.* 1996; Drechsel *et al.* 1996; Otsyna *et al.* 1996; Tonye *et al.* 1997; Chingonikaya, 1999). Significant ($P < 0.05$) differences in maize yield were also observed among the fallow types (Figure 5 and Appendices 5a, b and c). However, the yields obtained from the natural fallow were not significantly ($P > 0.05$) different from those obtained from continuous cropping. A similar observation was made by Niang *et al.* (1996) from a study conducted in the highlands of western Kenya.

Light fraction SOM under maize can be increased by addition of tree biomass (Barrios *et al.* 1996) and by the rotation of maize with planted tree fallow (Barrios *et al.* 1997). Since the N in this light fraction correlates with N mineralization of the whole soil (Hassink, 1994), the increase in maize grain yield recorded in this study from *T. vogelii*, *C. cajan* and *S. sesban* fallows can presumably be attributed to the

supply of plant-available N from decomposing litter and biomass. For example, a study in eastern Zambia showed that 2- and 3-year-old planted fallows with *S. sesban* or *G. sepium* can increase soil inorganic N, the amount of N in light fraction SOM, and N mineralization as compared to unfertilized continuous cropping maize (Barrios *et al.* 1997).

It is important to note that before nutrients from any agroforestry system become available to crops, they must be mineralized and be released to the soil (Onim *et al.* 1990). It is also important to note that, different plant materials decompose at different rates (Fasuluku, 1998), and tree legumes differ in their effects on soil N availability (Barrios *et al.* 1997). These facts may account for the variations in maize crop yield among the fallow types observed in this study.

Tephrosia vogelii fallow resulted highest maize grain yield in all the fallow periods, followed by *C. cajan* and *S. sesban* fallow (Figure 3 and 4 and Appendices 5 a, b and c). The significantly greater maize yield increase in *T. vogelii* fallow indicates that, this species holds considerable potential as a soil improving species under Gairo conditions. The soil improvement potential of *T. vogelii* fallow has also been reported in Rwanda (Prinz, 1987; Balasubramanian and Sekayange, 1992) as well as in the western highlands of Cameroon (Prinz and Rauch, 1987) and in the highlands of western Kenya (Niang *et al.* 1996).

The rate of decomposition of roots, litter and leaves is the main factor causing observed differences between shrub species. Although *S. sesban* was expected to be outstanding in increasing soil nitrogen availability and subsequent maize yield, surprisingly it was not the case in this study. The most probable reason for this could be that *S. sesban* had lost most of its leaves long before they were felled and might have started to decompose before the sowing of maize. For example in the decomposition study by Fasuluku (1998) it was noted that most of the N was released from the decomposing leaves of tree/shrub species including *S. sesban* between weeks one and four. The nutrients released from decomposition and mineralization of *Sesbania* biomass could thus have been leached away before the maize plants reached the peak of nutrient requirement and uptake. But *S. sesban* and *T. vogelii* did not decompose at the same rate (Fasuluku, 1998).

It is hypothesized that high quality materials will release nutrients too quickly, similar to the use of inorganic fertilizers, resulting in large losses and low nutrient use efficiency whereas low quality materials will release them too slowly. Based on this hypothesis materials of intermediate quality would be expected to show nutrient release patterns in closer synchrony with plant nutrient demand (Palm, 1995). Thus, despite giving greater maize yield, this may not necessarily imply that the quality of plant materials of *T. vogelii* is higher than those of *S. sesban*. This argument can be supported by Fasuluku's (1998) decomposition study where he noted that *T. vogelii*

green manure decomposed most slowly, while *G sepium* and *S. sesban* green manure decomposed faster. A slow rate of decomposition of *T. vogelii* is related to the presence of certain poisonous compounds (Milne-Redhead and Polhill, 1971) which might have reduced microbial and fauna activity. However, this attribute may be very useful because of the better synchrony with plant nutrient demand as observed in this study. This suggests that *T. vogelii* could be used as a good fallow species as a sustainable source of nutrient supply for a period of time (Drechsel *et al.* 1996).

Furthermore, it was also noted that, the generally higher maize yield in *C. cajan* than *S. sesban* might be the result of the confounding effect of fertilizers. This could probably be true because in 1 and 2 year fallows, maize yield from the unfertilized control plots of *S. sesban* were greater (1.97 t ha⁻¹ and 2.49 t ha⁻¹) than those from *C. cajan* (1.61 t ha⁻¹ and 1.47 t ha⁻¹). On the other hand, the possible explanation for the lower maize yield from 3 year fallows of *S. sesban* than *C. cajan* could be due to the fact that most of *S. sesban* shrubs were dying after 2 years resulting into lower leaves and litter in 3 year fallow. Additionally, the contribution of roots declined with deaths of *S. sesban* while that of *C. cajan* increased since they were still alive. This might have led into low nutrient supply from 3 year fallows of *S. sesban* as compared to *C. cajan*.

One of the important issues that has to be addressed in assessing the suitability of a tree/shrub for short-fallow management is the determination of the minimum duration of its fallow. The maize grain yield of 3.32, 4.41 and 5.39 t ha⁻¹ obtained from the unfertilized control plots of *T. vogelii* in 1, 2 and 3 year fallows respectively, indicates that even a 1 year fallow of *Tephrosia* could give satisfactory returns to a small-holder farmer who cannot afford chemical fertilizers. However, it was interesting to note that to attain a maize yield achieved by the 1 year *Tephrosia* fallow (unfertilized), *S. sesban* and *C. cajan* (unfertilized) would need each 3 years. This implies that if *S. sesban* and *C. cajan* are to be used in improved fallow system under the Gairo conditions, the minimum fallow length for which these species must stay on the land should not be less than 3 years if no fertilizer supplement is going to be applied. Though maize yield from unfertilized control plots of *C. cajan* and *S. sesban* were lower than those of *T. vogelii*, they were still higher than the yield obtained from the unfertilized plots of the natural fallow and continuous cropping. Higher crop yield from planted fallow than the natural fallow and continuous cropping has also been reported by Niang *et al.* (1996).

The effect of fallow period on maize grain yield was significant in *T. vogelii*, *C. cajan* and *S. sesban*. All the three fallow periods significantly ($P < 0.05$) differed from each other, with the maize yield increasing with an increase in the fallow period. Faster

growth and increasing capacity for replenishing soil fertility with increasing age might be the possible cause of observed increase in maize grain yield responses. Significant differences in maize grain yield after 1, 2 and 3 year fallows have also been reported in a *S. sesban* planted fallow study done in Zambia by Kwesiga and Coe (1994).

It was also noted in this study that maize grain yields from 1 and 2 year natural fallow were not significantly ($P>0.05$) different, although yield from 3 year natural fallow differed significantly with the other two fallows. This could be due to the slow growth rate of the natural regrowth and so its effect on soil fertility and subsequent maize yield improvement could not be apparent until after 3 years of fallow. This finding supports the general observation that short natural fallow have been resulting in decline in soil fertility and crop yields.

In the continuously cropped plots, although there was a drop in yield from 1 to 2 years continuously cropped plots maize yield in these plots did not differ significantly. A great drop in yield with significant ($P<0.05$) difference from the other plots was observed in plots which were continuously cropped for 3 years. This shows that the then nutrient status of soil in the experimental site, however low could it be, it could not be depleted further with significant differences within the first two years of continuous cropping. But cropping the site in the third year largely increased the

extent of soil exhaustion leading into significantly lower maize yield in the fourth continuous cropping season.

The values for maize yield obtained from this study are within the range for maize yield following improved fallows reported in various places (Kwesiga and Coe, 1994; Niang *et al.* 1996). However, the maize yield values obtained from *S. sesban* in this study are lower than those reported in improved fallow studies by Kwesiga and Coe (1994) and in intercropping studies by Ngiumbo and Balasubramanian (1992), but they are comparable to those reported in improved fallow studies by Chingonikaya (1999). The observed lower values of maize yield as compared to the Chipata's results may be explained by two reasons. One is that, the delay in maturity of maize might have contributed to further losses of nutrients since roots did not develop in time to capture nutrients. And the second reason may be the differences in environment conditions especially rainfall which is higher at Chipata and low at Gairo.

On the other hand, the maize yield figures from *T. vogelii* and *C. cajan* are higher than those reported in improved fallow studies (Balasubramanian and Sekayange, 1992; Kwesiga and Coe, 1994; Niang *et al.* 1996), and in alley cropping studies (Mwangi *et al.* 1996; Chamshama *et al.* 1998) and in a relay intercropping study Fasuluku (1998).

Maize yield in this study was increased significantly with the application of fertilizers. Results from several experiments have reported a positive crop response to fertilizer treatments (Szott and Kass, 1993; Kwesiga and Coe, 1994; Chirwa *et al.* 1994; Niang

et al. 1996; Chingonikaya, 1999). According to Aihou *et al.* (1999) alley cropping, with *Leucaena* supplemented with mineral fertilizer was able to increase crop production on the degraded site and maintain crop production on the non-degraded site. However, adding fertilizer containing N, P, K, S and B without prunings did not lead to increased maize yields on the degraded site and did not maintain maize yield on the non-degraded site, and the result was a drop in maize yield on both sites. This implies that in order to increase and maintain crop yield on a sustained basis a combination of both organic materials and inorganic fertilizers is needed.

Fertilization especially with recommended half dose of N and full recommended dose of P being applied together resulted in greater maize yield than the unfertilized control plots. However, it was noted that, in the *T. vogelii*, *C. cajan* and *S. sesban* fallow plots, fertilization with recommended half dose of N alone and with full recommended dose of P alone could not give significantly ($P > 0.05$) different yield response between the two treatments, even though, yield from N fertilized plots was higher than the yield from P fertilized plots.

On the other hand, trends in maize yield from fertilized plots of the natural fallow and continuous cropping were different. While plots which were treated with recommended half dose of N and recommended full dose of P still maintained higher rank, maize yield from plots treated with recommended half dose of N and full recommended dose of P separately were significantly ($P>0.05$) different. However, N treated plots gave greater yield than the P treated plots. The significantly greater yield response to N than P fertilization shown in the natural fallow and continuously cropped plots indicates that, in Gairo N is more limiting than P.

Lack of significant differences in yield between the N and P fertilized plots of the improved fallows could be due to large amount of N and P added in the soil during tree/shrub fallow. Similar observations were also reported in *C. cajan* (Chingonikaya, 1999). Short-duration fallows with planted trees, including N-fixing tree legumes, are known to have the potential to restore soil fertility in N-limited soils (Kwesiga and Coe, 1994; Barrios *et al.* 1997; Kwesiga *et al.* 1998), by adding substantial amounts of fixed N and organic matter to the soil (Francis, 1989). It has also been observed that rotation of maize with a *S. sesban* fallow significantly increased P in microbial biomass and light fraction soil organic matter and slightly reduced P deficiency for subsequent maize crops (Buresh and Tian, 1998; Buresh *et al.* 1996).

The observed greater increase in crop yield following fertilizer application (i.e. half dose of N + full dose of P) in improved fallow plots do not necessarily indicate a direct contribution of fertilizer to crop growth, but may partly be the result of an improved use efficiency of fertilizer or soil derived nutrients due to the presence of organic matter from planted fallows. Juo and Lal (1977) also reported that the yield of maize grown on plots cleared from various fallow treatments was highly correlated with soil organic matter content. This can further be substantiated by the observation from this study where fertilizer additions could not sufficiently counteract the adverse soil characteristics, as shown by the low maize yields in the continuously cropped plots despite the application of fertilizer. The results of this study show that even with the addition of 40 kg N ha⁻¹ in combination with 40 kg P ha⁻¹, yield in the continuously cropped plots was 3.22, 2.87 and 2.01 t ha⁻¹ in the respective 1, 2 and 3 years continuously cropped plots. Decline in maize yield despite of fertilizer application in the continuous cropped plots has also been reported in other studies (Kwesiga and Coe, 1994; Niang *et al.* 1996).

The noted response to fertilization in plots which were subjected to planted fallows, is also an important finding as it signifies that, on top of what could be obtained following planted fallows, a small-holder farmer can increase further the crop yield by providing a fertilizer supplement. This gives a room to farmers who can afford

CHAPTER 6

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Analysis of wood and foliage samples for N and P concentration and content has shown that the foliage biomass components contain quite substantial amount of nutrients. This observation poses a threat of nutrient mining from the site if this biomass component is removed from the site for any reason and if there is generally no proper management of the residues from planted fallows.

High wood and foliage biomass production from *S. sesban* indicates that this species is best suited as an agroforestry species for the supply of firewood as a source of energy and fodder for livestock and as green manure.

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 observed soil fertility changes following improved fallows of *S. sesban*, *T. vogelii* and *C. cajan* were verified by the improvements in yield of the test

crop of maize. Improved fallows were outstanding in all the aspects measured on the test maize crop from the growth parameters to final crop yield.

Maize N and P uptake from planted fallows of the leguminous shrubs was higher than the uptake from natural fallow and continuously cropped plots. This indicates the potential of improved fallows in increasing the supply of nutrients to the soil. The noted increased nutrient uptake following N and P fertilization substantiate the potential role that fertilizer supplement could play in increasing nutrient supply and subsequent maize yield even in areas where agroforestry practices like improved fallow are in use.

The change in N and P uptake (often an increase) by the above ground maize components with an increase in fallow period has an implication on choice of the appropriate fallow period as nutrient uptake has relationship with crop yield. Since the increase in nutrient uptake by maize on the other side indicates nutrient mining from the site the results from this study may provide a useful information in the designing management options for the crop residues.

Bearing in mind the fact that a farmer would always be interested in the quantity of output that can be obtained from the farm, the findings of this study indicate that *T.vogelii* is the best agroforestry species for use in improved fallow systems under the

Gairo conditions. The slow decomposition rate of *T. vogelii* biomass has been observed to be very advantageous under certain circumstances as it provides a better synchrony with the crops nutrient demand, something which is of paramount importance for nutrient use efficiency and ultimately maximized crop yield.

The yield of test crop of maize from the unfertilized control plots of 1 year fallow *T. vogelii* indicate that even a 1 year fallow of this species is sufficient to improve crop yield to an appreciable level. Although 1 year is a short time to determine long term soil fertility changes, this observation is important because it reflect a workable rotation management period that is typical to what most of the small scale farmers who run short of farming land practice.

The observed highly significant response in maize yield to N fertilizer application shows that N is more limiting than P at Gairo. This fact together with the general observation that crop growth and yield increased with the application of fertilizers even in improved fallow plots indicate that, addition of a fertilizer supplement is required in order to optimize maize crop yield at Gairo.

6.2 Recommendations

- (i) For better improvement of maize crop yield following a fallow period *T. vogelii* should be used as a fallow species under the Gairo conditions.
- (ii) Considering both the results of shrubs' survival, biomass production, nutrient dynamics and crop yield improvement the optimum fallow periods under the tested environmental condition are for *T. vogelii* = 1 year, *S. sesban* = 2 years while for *C. cajan* = 3 years.
- (iii) For achieving an optimal maize crop yield the recommended fertilizer dose is $40 \text{ kg N ha}^{-1} + 40 \text{ kg P ha}^{-1}$.
- (iv) In order to avoid or minimize nutrients mining from the site as much as possible shrub biomass should be left on the site after the fallow period, since the shrubs' biomass components are rich in N and P. Since the results of this study have shown that even maize stover contain some considerable amounts of N and P, in an attempt to again minimize nutrient mining from the site, this crop residue should not be removed from the field.

- (v) Following the impressive performance of *T. vogelii* in maize yield improvement on farm trials of this species should be initiated so as to examine the performance the species under farmer managed fields.

- (vi) Further investigations should be carried out on the site to examine nutrient dynamics and sustainability in crop yield during the second and third cropping seasons after 1, 2 and 3 year fallow.

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APPENDICES

Appendix 1: Biomass production from 1, 2 and 3 year old leguminous shrubs planted at Gairo in Morogoro, Tanzania.

Species	Fallow period (years)	Biomass yield (t ha ⁻¹)		
		Wood	Foliage	Total
<i>S. sesban</i>	1	6.13 ¹ (0.50)	1.92 (0.17)	8.00 (0.71)
	2	51.79 (0.39)	18.05 (0.08)	69.84 (0.49)
	3	34.21 (4.99)	11.73 (1.87)	46.02 (6.83)
<i>T. vogelii</i>	1	3.43 (0.25)	2.11 (0.18)	5.44 (1.10)
	2	4.59 (0.52)	3.65 (0.58)	8.29 (1.10)
	3	4.77 (0.56)	4.11 (0.41)	8.95 (1.00)
<i>C. cajan</i>	1	7.53 (2.10)	2.15 (0.60)	10.01 (2.80)
	2	5.19 (1.19)	1.48 (0.23)	6.79 (1.45)
	3	6.89 (0.01)	1.60 (0.02)	8.25 (0.41)

¹Mean of three replications with standard error in parenthesis

Appendix 2: Effect of the interaction of fallow period and fallow type on soil chemical properties at Gairo in Morogoro, Tanzania.

Fallow type	Soil depth	Fallow period					
		EC (dS m ⁻¹)			pH (H ₂ O)		
		1	2	3	1	2	3
1 ²	1 ³	0.123 ¹ (0.003)	0.156 (0.003)	0.213 (0.008)	6.943 (0.021)	7.100 (0.057)	7.310 (0.094)
	2	0.106 (0.003)	0.150 (0.005)	0.196 (0.006)	6.900 (0.005)	7.070 (0.050)	7.343 (0.039)
	3	0.083 (0.006)	0.130 (0.001)	0.187 (0.006)	6.923 (0.003)	7.026 (0.037)	7.293 (0.003)
	4	0.086 (0.003)	0.133 (0.003)	0.186 (0.007)	6.626 (0.081)	7.020 (0.040)	7.276 (0.0145)
2	1	0.110 (0.005)	0.136 (0.008)	0.170 (0.011)	6.963 (0.003)	7.143 (0.003)	7.290 (0.021)
	2	0.086 (0.003)	0.110 (0.012)	0.160 (0.012)	6.900 (0.008)	7.133 (0.003)	7.173 (0.020)
	3	0.090 (0.001)	0.100 (0.010)	0.163 (0.006)	6.886 (0.009)	7.136 (0.007)	7.160 (0.010)
	4	0.080 (0.001)	0.093 (0.013)	0.153 (0.008)	6.890 (0.011)	7.133 (0.006)	7.150 (0.010)
3	1	0.093 (0.003)	0.100 (0.001)	0.183 (0.013)	6.556 (0.211)	6.366 (0.027)	7.133 (0.148)
	2	0.083 (0.003)	0.096 (0.003)	0.166 (0.012)	6.496 (0.131)	6.350 (0.028)	7.060 (0.115)
	3	0.070 (0.001)	0.086 (0.003)	0.133 (0.003)	6.416 (0.042)	6.393 (0.016)	6.840 (0.238)
	4	0.076 (0.003)	0.080 (0.001)	0.136 (0.003)	6.446 (0.087)	6.566 (0.062)	6.840 (0.240)
4	1	0.063 (0.003)	0.086 (0.003)	0.113 (0.006)	6.336 (0.003)	6.356 (0.012)	6.436 (0.008)
	2	0.070 (0.006)	0.073 (0.003)	0.096 (0.003)	6.326 (0.003)	6.346 (0.003)	6.400 (0.015)
	3	0.056 (0.007)	0.070 (0.005)	0.083 (0.006)	6.310 (0.013)	6.336 (0.007)	6.400 (0.015)
	4	0.050 (0.001)	0.066 (0.003)	0.083 (0.007)	6.300 (0.001)	6.323 (0.003)	6.390 (0.010)
5	1	0.086 (0.003)	0.066 (0.003)	0.055 (0.005)	6.263 (0.031)	5.953 (0.027)	5.523 (0.035)
	2	0.076 (0.004)	0.056 (0.030)	0.045 (0.005)	6.223 (0.033)	5.920 (0.030)	5.505 (0.015)
	3	0.070 (0.005)	0.060 (0.001)	0.040 (0.001)	6.190 (0.058)	5.806 (0.034)	5.500 (0.001)
	4	0.070 (0.005)	0.050 (0.005)	0.040 (0.001)	6.150 (0.079)	5.710 (0.087)	5.425 (0.035)

Appendix 2 continued

Fallow type	Soil depth	Fallow period					
		AVP (mg kg ⁻¹)			OC (%)		
		1	2	3	1	2	3
1	1	12.923 (0.312)	16.290 (0.010)	14.450 (0.275)	1.920 (0.025)	2.720 (0.045)	2.413 (0.027)
	2	12.733 (0.317)	15.246 (0.026)	14.100 (0.100)	1.853 (0.027)	2.663 (0.031)	2.366 (0.012)
	3	12.266 (0.633)	14.896 (0.254)	13.170 (0.035)	1.786 (0.007)	2.616 (0.033)	2.083 (0.108)
	4	11.000 (0.057)	13.416 (0.300)	12.430 (0.339)	1.756 (0.028)	2.603 (0.026)	1.910 (0.196)
2	1	11.056 (0.328)	13.683 (0.334)	13.830 (0.449)	1.713 (0.183)	2.526 (0.003)	2.256 (0.183)
	2	10.566 (0.341)	13.183 (0.434)	13.530 (0.378)	1.586 (0.157)	2.503 (0.008)	2.416 (0.017)
	3	9.560 (0.220)	12.926 (0.414)	12.336 (0.182)	1.513 (0.183)	2.396 (0.057)	2.206 (0.178)
	4	9.400 (0.272)	12.646 (0.508)	11.850 (0.301)	1.480 (0.216)	2.246 (0.160)	2.166 (0.203)
3	1	12.136 (0.036)	14.406 (0.367)	13.723 (0.282)	1.460 (0.006)	1.556 (0.008)	1.290 (0.037)
	2	11.956 (0.029)	14.293 (0.365)	13.066 (0.066)	1.373 (0.003)	1.476 (0.014)	1.233 (0.051)
	3	11.193 (0.397)	13.933 (0.548)	13.003 (0.049)	1.163 (0.018)	1.266 (0.039)	1.136 (0.018)
	4	10.623 (0.327)	12.553 (0.371)	12.860 (0.040)	1.110 (0.006)	1.183 (0.046)	1.130 (0.015)
4	1	2.136 (0.008)	4.946 (0.338)	5.730 (0.135)	1.040 (0.070)	1.290 (0.005)	1.330 (0.010)
	2	2.103 (0.003)	4.660 (0.238)	5.426 (0.087)	0.880 (0.015)	1.040 (0.075)	1.220 (0.015)
	3	2.063 (0.031)	4.343 (0.129)	5.350 (0.086)	0.713 (0.012)	0.846 (0.063)	0.976 (0.003)
	4	2.026 (0.037)	4.150 (0.028)	5.056 (0.072)	0.576 (0.012)	0.710 (0.010)	0.746 (0.008)
5	1	4.226 (0.014)	3.133 (0.192)	2.110 (0.010)	0.796 (0.008)	0.693 (0.003)	0.595 (0.005)
	2	4.133 (0.009)	2.873 (0.086)	2.010 (0.040)	0.706 (0.007)	0.586 (0.058)	0.510 (0.010)
	3	4.013 (0.094)	2.450 (0.144)	1.950 (0.050)	0.606 (0.003)	0.480 (0.012)	0.470 (0.020)
	4	3.136 (0.008)	2.133 (0.072)	1.920 (0.030)	0.503 (0.003)	0.453 (0.029)	0.455 (0.025)

Appendix 2 continued

Fallow type	Soil depth	Fallow period					
		Total N (%)			Total P (mg kg ⁻¹)		
		1	2	3	1	2	3
1	1	0.203 (0.003)	0.250 (0.006)	0.256 (0.003)	395.333 (0.881)	453.667 (1.855)	453.666 (0.333)
	2	0.183 (0.003)	0.240 (0.005)	0.903 (0.668)	393.666 (0.882)	455.666 (0.667)	450.666 (0.667)
	3	0.163 (0.030)	0.210 (0.006)	0.180 (0.026)	390.333 (0.333)	449.660 (0.333)	434.000 (6.658)
	4	0.133 (0.003)	0.116 (0.003)	0.133 (0.003)	388.333 (1.666)	450.000 (0.577)	432.000 (9.165)
2	1	0.187 (0.003)	0.210 (0.006)	0.210 (0.005)	286.667 (1.666)	408.333 (4.409)	395.000 (2.887)
	2	0.170 (0.001)	0.193 (0.003)	0.200 (0.001)	277.333 (4.333)	391.667 (1.667)	384.000 (2.081)
	3	0.156 (0.030)	0.190 (0.005)	0.183 (0.006)	268.321 (1.624)	378.333 (1.666)	360.323 (2.603)
	4	0.103 (0.321)	0.176 (0.004)	0.173 (0.003)	266.667 (1.667)	305.000 (2.886)	294.000 (2.086)
3	1	0.113 (0.003)	0.126 (0.003)	0.153 (0.030)	215.000 (2.887)	266.666 (0.871)	278.667 (8.171)
	2	0.093 (0.004)	0.120 (0.001)	0.143 (0.003)	198.233 (0.882)	262.323 (1.855)	272.000 (9.165)
	3	0.090 (0.001)	0.100 (0.006)	0.136 (0.004)	196.000 (0.577)	255.233 (0.333)	267.000 (6.506)
	4	0.008 (0.003)	0.090 (0.001)	0.123 (0.006)	195.637 (0.881)	250.300 (0.320)	265.000 (5.000)
4	1	0.073 (0.015)	0.087 (0.312)	0.110 (0.005)	152.667 (1.452)	180.000 (0.578)	196.670 (1.667)
	2	0.063 (0.003)	0.083 (0.006)	0.096 (0.004)	149.000 (0.577)	173.000 (2.516)	193.000 (1.527)
	3	0.057 (0.004)	0.073 (0.003)	0.090 (0.001)	147.300 (1.201)	168.300 (0.881)	182.666 (1.452)
	4	0.047 (0.007)	0.067 (0.135)	0.083 (0.310)	139.333 (0.333)	165.670 (2.962)	172.300 (1.450)
5	1	0.096 (0.009)	0.077 (0.004)	0.065 (0.005)	168.300 (1.670)	142.660 (1.800)	126.500 (0.500)
	2	0.087 (0.008)	0.067 (0.006)	0.050 (0.001)	163.670 (0.667)	137.000 (1.732)	124.500 (0.500)
	3	0.73 (0.008)	0.060 (0.005)	0.035 (0.005)	162.000 (0.577)	132.670 (1.294)	124.500 (0.600)
	4	0.067 (0.003)	0.047 (0.003)	0.025 (0.005)	149.000 (0.547)	129.000 (0.535)	119.500 (0.500)

¹ as defined in appendix 1. ² 1 = *S. sesban*, 2 = *T. vogelii*, 3 = *C. cajan*, 4 = Natural fallow, 5 = Continuous cropping. 3 1 = 0 – 10 cm, 2 = 10 - 20 cm, 3 = 20 – 30 cm, 4 = 30 – 40 cm.

Appendix 3a: Effect of the interaction of fallow period, fallow type and N and P fertilization on maize leaf N and P concentration at 84 DAS at Gairo in Morogoro, Tanzania.

Fallow type	Fertilizer treatment ²	Fallow period (years)					
		1		2		3	
		Leaf N (%)	Leaf P (%)	Leaf N (%)	Leaf P (%)	Leaf N (%)	Leaf P (%)
<i>S. sesban</i>	1	0.323 ¹ (0.02)	0.033 (0.01)	0.340 (0.03)	0.053 (0.003)	0.320 (0.05)	0.063 (0.01)
	2	0.359 (0.01)	0.047 (0.01)	0.378 (0.05)	0.062 (0.01)	0.320 (0.03)	0.074 (0.003)
	3	0.279 (0.03)	0.050 (0.030)	0.323 (0.02)	0.070 (0.01)	0.330 (0.03)	0.080 (0.02)
	4	0.340 (0.02)	0.051 (0.01)	0.379 (0.03)	0.071 (0.003)	0.310 (0.02)	0.081 (0.003)
<i>T. vogelii</i>	1	0.390 (0.02)	0.052 (0.02)	0.323 (0.02)	0.067 (0.003)	0.612 (0.02)	0.079 (0.02)
	2	0.481 (0.04)	0.053 (0.01)	0.463 (0.07)	0.068 (0.01)	0.663 (0.01)	0.078 (0.003)
	3	0.335 (0.02)	0.060 (0.01)	0.351 (0.04)	0.080 (0.004)	0.551 (0.03)	0.092 (0.01)
	4	0.485 (0.01)	0.062 (0.02)	0.510 (0.02)	0.082 (0.004)	0.710 (0.01)	0.095 (0.004)
<i>C. cajan</i>	1	0.337 (0.01)	0.035 (0.03)	0.350 (0.01)	0.050 (0.01)	0.450 (0.05)	0.064 (0.003)
	2	0.436 (0.02)	0.048 (0.01)	0.323 (0.02)	0.063 (0.003)	0.570 (0.03)	0.073 (0.002)
	3	0.325 (0.01)	0.051 (0.01)	0.340 (0.04)	0.071 (0.002)	0.490 (0.04)	0.084 (0.02)
	4	0.453 (0.02)	0.053 (0.02)	0.480 (0.04)	0.073 (0.004)	0.580 (0.04)	0.085 (0.01)
Natural fallow	1	0.224 (0.04)	0.028 (0.003)	0.240 (0.08)	0.043 (0.01)	0.340 (0.02)	0.056 (0.002)
	2	0.352 (0.05)	0.036 (0.003)	0.323 (0.02)	0.051 (0.002)	0.470 (0.04)	0.065 (0.01)
	3	0.244 (0.01)	0.035 (0.02)	0.270 (0.01)	0.055 (0.01)	0.370 (0.02)	0.065 (0.002)
	4	0.340 (0.03)	0.036 (0.02)	0.323 (0.02)	0.056 (0.01)	0.460 (0.03)	0.069 (0.01)
Continuous cultivation	1	0.235 (0.06)	0.028 (0.004)	0.225 (0.04)	0.025 (0.01)	0.205 (0.01)	0.021 (0.004)
	2	0.280 (0.04)	0.030 (0.01)	0.270 (0.01)	0.029 (0.004)	0.260 (0.02)	0.027 (0.01)
	3	0.235 (0.05)	0.040 (0.01)	0.200 (0.02)	0.037 (0.01)	0.188 (0.05)	0.036 (0.01)
	4	0.282 (0.02)	0.041 (0.003)	0.260 (0.03)	0.038 (0.01)	0.245 (0.03)	0.036 (0.01)

¹ as defined in appendix 1. DAS = Days after sowing. ²F₁ = 0 kg N ha⁻¹ + 0 kg P ha⁻¹, F₂ = 40 kg N ha⁻¹, F₃ = 40 kg P ha⁻¹, F₄ = 40 kg N ha⁻¹ + 40 kg P ha⁻¹.

Appendix 3b: Effect of the interaction of fallow period, fallow type and N and P fertilization on maize plant leaf biomass and N and P content at 84 DAS at Gairo in Morogoro, Tanzania.

Fallow type	Fertilizer treatment ²	Fallow period (years)									
		1			2			3			
		Leaf wt.	Leaf N	Leaf P	Leaf wt.	Leaf N	Leaf P	Leaf wt.	Leaf N	Leaf P	
	(g leaf ⁻¹)	(mg leaf ⁻¹)	(mg leaf ⁻¹)								
<i>S. sesban</i>	1	1.52 ¹	4.91	0.50	1.93	6.56	1.02	1.88	6.01	1.18	
		(0.07)	(0.19)	(0.04)	(0.09)	(0.25)	(0.04)	(0.10)	(0.07)	(0.01)	
	2	1.97	7.07	0.92	1.96	7.41	1.21	2.16	6.91	1.54	
		(0.15)	(0.16)	(0.02)	(0.09)	(0.59)	(0.06)	(0.17)	(0.08)	(0.01)	
	3	1.74	4.85	0.87	1.94	6.47	1.35	1.93	6.36	1.59	
		(0.01)	(0.15)	(0.04)	(0.13)	(0.10)	(0.01)	(0.21)	(0.29)	(0.04)	
	4	2.31	7.85	1.17	2.35	8.91	1.66	2.41	7.47	1.95	
		(0.13)	(0.29)	(0.02)	(0.05)	(0.69)	(0.01)	(0.15)	(0.14)	(0.03)	
	<i>T. vogelii</i>	1	1.83	7.14	0.95	1.99	8.19	1.33	1.95	11.93	1.54
			(0.19)	(0.08)	(0.01)	(0.08)	(0.14)	(0.01)	(0.10)	(0.16)	(0.02)
		2	2.25	10.82	1.19	2.64	12.22	1.79	2.73	18.09	2.07
			(0.05)	(0.23)	(0.01)	(0.05)	(0.30)	(0.01)	(0.07)	(0.63)	(0.06)
3		2.10	7.04	1.26	2.29	8.04	1.83	2.25	12.39	2.12	
		(0.18)	(0.05)	(0.01)	(0.27)	(0.05)	(0.04)	(0.16)	(0.17)	(0.77)	
4		2.64	12.80	1.63	2.77	14.13	2.27	2.89	20.52	2.74	
		(0.04)	(0.09)	(0.01)	(0.04)	(0.10)	(0.03)	(0.03)	(0.39)	(0.05)	
<i>C. cajan</i>		1	1.52	5.12	0.53	1.63	5.71	0.81	1.72	7.74	1.10
			(0.04)	(0.25)	(0.05)	(0.06)	(0.06)	(0.01)	(0.20)	(0.08)	(0.01)
		2	2.18	9.50	0.89	2.32	10.90	1.29	2.37	13.51	1.52
			(0.17)	(0.29)	(0.01)	(0.08)	(0.28)	(0.01)	(0.10)	(0.34)	(0.01)
	3	1.75	5.68	1.04	1.83	6.22	1.46	1.82	8.92	1.73	
		(0.09)	(0.07)	(0.01)	(0.11)	(0.28)	(0.03)	(0.20)	(0.36)	(0.01)	
	4	2.45	11.09	1.29	2.75	13.20	2.01	2.80	16.24	2.38	
		(0.05)	(0.97)	(0.34)	(0.06)	(0.34)	(0.05)	(0.05)	(0.31)	(0.02)	
	Natural fallow	1	1.31	2.93	0.36	1.33	3.19	0.57	1.60	5.44	0.89
			(0.09)	(0.23)	(0.02)	(0.07)	(0.06)	(0.01)	(0.08)	(0.12)	(0.01)
		2	1.61	5.67	0.53	1.76	6.51	0.87	1.99	9.35	1.12
			(0.10)	(0.26)	(0.02)	(0.12)	(0.08)	(0.01)	(0.05)	(0.16)	(0.01)
3		1.53	3.73	0.57	1.59	4.29	0.89	1.76	6.51	1.14	
		(0.17)	(0.21)	(0.01)	(0.09)	(0.02)	(0.01)	(0.13)	(0.24)	(0.01)	
4		2.07	7.03	0.74	1.99	7.16	1.11	2.13	9.79	1.46	
		(0.23)	(0.24)	(0.01)	(0.08)	(0.12)	(0.01)	(0.11)	(0.07)	(0.11)	
Continuous cultivation		1	1.49	3.50	0.42	1.39	3.13	0.34	1.10	2.25	0.23
			(0.04)	(0.09)	(0.01)	(0.08)	(0.04)	(0.01)	(0.02)	(0.01)	(0.01)
		2	1.97	5.52	0.59	1.62	4.37	0.46	1.37	3.56	0.36
			(0.11)	(0.18)	(0.01)	(0.05)	(0.04)	(0.02)	(0.11)	(0.13)	(0.02)
	3	1.66	3.90	0.66	1.44	2.88	0.53	1.22	2.29	0.43	
		(0.04)	(0.12)	(0.01)	(0.08)	(0.03)	(0.01)	(0.03)	(0.01)	(0.02)	
	4	2.32	6.54	0.95	1.77	4.60	0.67	1.54	4.77	0.55	
		(0.06)	(0.20)	(0.01)	(0.04)	(0.11)	(0.01)	(0.02)	(0.04)	(0.02)	

¹ as defined in appendix 1. ² as defined in appendix 3a.

Appendix 4a: Effect of the interaction of fallow period and fallow type on maize grain and stover N and P concentrations at Gairo in Morogoro, Tanzania.

Fallow type	Fallow period (years)	N concentration (%)		P concentration (%)		Total concentration (%)	
		Grain	Stover	Grain	Stover	N	P
<i>S. sesban</i>	1	1.01c ¹ (0.04)	0.24b (0.02)	0.06c (0.01)	0.02b (0.01)	1.25c (0.06)	0.08c (0.01)
	2	1.19a (0.02)	0.29a (0.02)	0.07b (0.01)	0.03a (0.01)	1.48a (0.04)	0.10b (0.01)
	3	1.04b (0.01)	0.26ba (0.03)	0.08a (0.01)	0.03a (0.01)	1.30b (0.04)	0.11a (0.01)
<i>T. vogelii</i>	1	1.31c (0.02)	0.38a (0.02)	0.09b (0.01)	0.03b (0.01)	1.69a (0.04)	0.12b (0.01)
	2	1.34b (0.02)	0.38a (0.03)	0.10a (0.01)	0.03b (0.01)	1.72a (0.04)	0.13a (0.01)
	3	1.35a (0.02)	0.37a (0.04)	0.10a (0.01)	0.04a (0.01)	1.72a (0.05)	0.14a (0.01)
<i>C. cajan</i>	1	1.18c (0.01)	0.12b (0.02)	0.09b (0.01)	0.02b (0.01)	1.30b (0.03)	0.11b (0.01)
	2	1.20b (0.01)	0.23a (0.03)	0.10ba (0.01)	0.03a (0.01)	1.43a (0.04)	0.13ba (0.01)
	3	1.23a (0.01)	0.21a (0.03)	0.11a (0.01)	0.03a (0.01)	1.44a (0.04)	0.14a (0.01)
Natural fallow	1	1.04c (0.03)	0.08b (0.01)	0.08b (0.01)	0.02b (0.01)	1.12c (0.04)	0.10c (0.01)
	2	1.12b (0.03)	0.15a (0.02)	0.08b (0.01)	0.02b (0.01)	1.27b (0.04)	0.11b (0.01)
	3	1.19a (0.02)	0.17a (0.03)	0.09a (0.01)	0.03a (0.01)	1.36a (0.04)	0.12a (0.01)
Continuous cultivation	1	1.04a (0.05)	0.14a (0.02)	0.08a (0.01)	0.02a (0.01)	1.18a (0.07)	0.10a (0.01)
	2	0.97b (0.06)	0.09b (0.01)	0.07b (0.01)	0.01b (0.01)	1.06b (0.07)	0.08b (0.01)
	3	0.81c (0.05)	0.07c (0.01)	0.06c (0.01)	0.01b (0.01)	0.88c (0.06)	0.07c (0.01)

¹ Mean of three replications followed by standard error in parenthesis. Means with the same letter in a column are not significantly ($P>0.05$) different.

Appendix 4b: Effect of the interaction of fallow period and fallow type on N and P uptake by above ground maize components at Gairo in Morogoro, Tanzania.

Fallow type	Fallow period (years)	N uptake (kg ha ⁻¹)		P uptake (kg ha ⁻¹)		Total uptake (kg ha ⁻¹)	
		Grain	Stover	Grain	Stover	N	P
<i>S. sesban</i>	1	26.27b ¹ (3.22)	11.57b (2.03)	1.59c (0.15)	1.17b (0.12)	37.84b (4.61)	2.76c (0.25)
	2	38.73a (3.49)	14.10ba (1.68)	2.46b (0.27)	1.38ba (0.19)	52.83a (5.11)	3.84 (0.47)
	3	41.32a (3.54)	15.55a (2.67)	3.34a (0.37)	1.61a (0.21)	56.87a (6.72)	4.95a (0.56)
<i>T. vogelii</i>	1	64.36b (9.72)	19.23a (2.56)	4.09b (0.56)	1.62b (0.22)	83.59b (12.53)	5.71c (0.77)
	2	75.40ba (5.68)	22.04a (2.61)	5.96a (0.63)	1.79b (0.16)	97.44b (7.62)	7.75b (0.77)
	3	89.62a (6.28)	28.94a (4.86)	6.77a (0.59)	2.63a (0.34)	118.56a (9.11)	9.40a (0.90)
<i>C. cajan</i>	1	24.96b (3.43)	4.43b (0.75)	2.09b (0.32)	0.98b (0.13)	29.39b (3.81)	3.07b (0.39)
	2	39.99ba (6.17)	12.49a (2.22)	3.54ba (1.53)	1.51a (0.20)	52.48ba (16.27)	5.05ba (1.66)
	3	65.77a (7.21)	13.19a (2.78)	5.68a (0.72)	1.75a (0.24)	78.98a (9.10)	7.43a (0.93)
Natural fallow	1	17.46b (2.58)	3.34c (0.30)	1.22b (0.15)	0.96b (0.07)	20.80b (2.81)	2.18b (0.19)
	2	19.66b (1.79)	5.99b (1.08)	1.47b (0.13)	0.99b (0.08)	25.65b (2.59)	2.46b (0.20)
	3	36.14a (2.40)	9.17a (1.79)	2.66a (0.19)	1.38a (0.11)	45.31a (4.14)	4.04a (0.30)
Continuous cultivation	1	28.61a (4.46)	7.28a (1.71)	2.09a (0.26)	0.85a (0.07)	35.89a (5.88)	2.94a (0.32)
	2	22.77a (3.07)	5.32a (0.89)	1.62b (0.16)	0.96ba (0.12)	28.09a (3.84)	2.58a (0.27)
	3	13.33b (2.22)	2.86b (0.51)	1.01c (0.12)	0.61b (0.05)	16.19b (2.72)	1.62b (0.17)

¹ as defined in appendix 4a.

Appendix 4c: Effect of the interaction of fallow type and fertilizer treatment on maize grain and stover N and P concentrations at Gairo in Morogoro, Tanzania.

Fallow type	Fertilizer treatment ²	N concentration (%)		P concentration (%)		Total concentration (%)	
		Grain	Stover	Grain	Stover	N	P
<i>S. sesban</i>	F ₁	1.00c ¹ (0.03)	0.20b (0.03)	0.06b (0.01)	0.02b (0.01)	1.20c (0.06)	0.08b (0.01)
	F ₂	1.12b (0.04)	0.31a (0.02)	0.06b (0.01)	0.02b (0.01)	1.43b (0.05)	0.08b (0.01)
	F ₃	0.99c (0.02)	0.19b (0.02)	0.08a (0.01)	0.03a (0.01)	1.18c (0.03)	0.11a (0.01)
	F ₄	1.19a (0.03)	0.34a (0.02)	0.08a (0.01)	0.03a (0.01)	1.53A (0.03)	0.11A (0.01)
<i>T. vogelii</i>	F ₁	1.25d (0.01)	0.33a (0.02)	0.08b (0.01)	0.03c (0.01)	1.58b (0.03)	0.11b (0.02)
	F ₂	1.41b (0.01)	0.42a (0.03)	0.08b (0.01)	0.03c (0.01)	1.83a (0.03)	0.11b (0.01)
	F ₃	1.26c (0.01)	0.36a (0.03)	0.11a (0.01)	0.04b (0.01)	1.62b (0.03)	0.15a (0.01)
	F ₄	1.42a (0.01)	0.41a (0.04)	0.11a (0.01)	0.05a (0.01)	1.83a (0.04)	0.16a (0.01)
<i>C. cajan</i>	F ₁	1.15c (0.01)	0.14b (0.03)	0.08b (0.01)	0.01d (0.01)	1.29c (0.04)	0.10b (0.01)
	F ₂	1.24b (0.01)	0.17b (0.04)	0.09b (0.01)	0.02c (0.01)	1.41b (0.04)	0.11b (0.01)
	F ₃	1.16c (0.01)	0.16b (0.03)	0.11a (0.01)	0.03b (0.01)	1.32c (0.03)	0.14a (0.01)
	F ₄	1.26a (0.01)	0.27a (0.04)	0.11a (0.01)	0.04a (0.01)	1.53a (0.04)	0.14a (0.01)
Natural fallow	F ₁	1.00c (0.03)	0.08c (0.01)	0.07b (0.01)	0.02c (0.01)	1.08d (0.04)	0.09b (0.01)
	F ₂	1.20a (0.02)	0.15b (0.02)	0.07b (0.01)	0.02c (0.01)	1.35b (0.03)	0.09b (0.02)
	F ₃	1.05b (0.02)	0.08c (0.01)	0.09a (0.01)	0.03a (0.01)	1.13c (0.02)	0.12a (0.01)
	F ₄	1.21a (0.01)	0.21a (0.03)	0.09a (0.01)	0.03a (0.01)	1.42a (0.04)	0.12a (0.02)
Continuous cultivation	F ₁	0.76b (0.03)	0.06c (0.01)	0.06b (0.01)	0.01c (0.01)	0.82b (0.03)	0.07b (0.01)
	F ₂	1.13a (0.04)	0.11b (0.01)	0.06b (0.02)	0.01c (0.04)	1.24a (0.05)	0.07b (0.03)
	F ₃	0.77b (0.04)	0.06c (0.02)	0.07a (0.02)	0.02b (0.01)	0.83b (0.04)	0.09a (0.03)
	F ₄	1.14a (0.04)	0.16a (0.03)	0.08a (0.01)	0.03a (0.01)	1.30a (0.06)	0.09a (0.04)

¹ as defined in appendix 4a. ² as defined in appendix 3a.

Appendix 4d: Effect of the interaction of fallow type and fertilizer treatment on N and P uptake by above ground maize components at Gairo in Morogoro, Tanzania.

Fallow type	Fertilizer treatment ²	N uptake (kg ha ⁻¹)		P uptake (kg ha ⁻¹)		Total uptake (kg ha ⁻¹)	
		Grain	Stover	Grain	Stover	N	P
<i>S. sesban</i>	F ₁	26.08b ¹ (3.01)	7.61c (1.41)	1.60c (0.17)	1.39d (0.05)	33.69c (3.55)	2.99d (0.22)
	F ₂	33.75b (3.24)	15.42b (1.82)	2.13bc (0.25)	3.11c (0.08)	49.17b (4.39)	5.24c (0.28)
	F ₃	32.22b (3.47)	9.93c (1.34)	2.75ba (0.47)	4.07b (0.14)	42.15cb (2.43)	6.82b (0.39)
	F ₄	49.69a (4.05)	21.21a (1.76)	3.40a (0.43)	5.55a (0.12)	70.90a (5.24)	8.95a (0.56)
<i>T. vogelii</i>	F ₁	55.21c (5.01)	15.48b (2.39)	3.57c (0.44)	1.20c (0.12)	70.69c (6.23)	4.77c (0.54)
	F ₂	79.84b (4.50)	28.61a (4.94)	4.93b (0.46)	1.74b (0.16)	107.45b (8.13)	6.67b (0.56)
	F ₃	64.46cb (6.23)	20.67ba (2.20)	5.74b (0.67)	2.11b (0.23)	85.13c (6.92)	7.85b (0.77)
	F ₄	106.34a (9.30)	29.92a (5.22)	8.20a (0.57)	3.02a (0.36)	136.26a (12.16)	11.22a (0.85)
<i>C. cajan</i>	F ₁	28.86b (6.31)	6.36b (2.48)	2.19b (0.45)	0.75b (0.11)	35.22b (6.21)	2.94b (0.47)
	F ₂	37.36b (7.40)	9.07b (2.32)	2.82b (0.60)	1.00b (0.12)	46.43b (7.63)	3.82b (0.68)
	F ₃	35.78b (8.91)	8.56b (2.22)	3.45ba (0.89)	1.85a (0.24)	44.34b (10.10)	5.30ba (1.10)
	F ₄	72.30a (10.54)	16.15a (2.98)	6.62a (1.93)	2.04a (0.18)	88.45a (11.43)	8.66a (2.07)
Natural fallow	F ₁	16.52c (3.12)	3.08c (0.47)	1.17c (0.20)	0.77c (0.06)	19.60d (3.29)	1.94d (0.22)
	F ₂	26.94b (3.48)	7.22b (1.60)	1.72b (0.23)	1.00b (0.10)	34.16b (4.92)	2.72c (0.33)
	F ₃	21.79cb (3.35)	3.93c (0.32)	1.84a (0.29)	1.23a (0.07)	25.72c (3.60)	3.07b (0.35)
	F ₄	32.43a (3.59)	10.23a (1.90)	2.41a (0.26)	1.39a (0.13)	42.66a (5.13)	3.80a (0.35)
Continuous cultivation	F ₁	14.26b (3.49)	2.61c (0.34)	1.18b (0.22)	0.58b (0.05)	16.87c (3.74)	1.76c (0.27)
	F ₂	25.99a (3.62)	5.75b (0.84)	1.54b (0.18)	0.79ba (0.09)	31.74b (4.30)	2.33bc (0.24)
	F ₃	17.69b (3.03)	3.49cb (0.71)	1.67a (0.23)	0.91a (0.14)	21.18c (3.55)	2.58ba (0.31)
	F ₄	32.45a (5.55)	9.91a (2.21)	2.21a (0.36)	1.04a (0.12)	42.36a (7.49)	3.25a (0.46)

¹ as defined in appendix 4a. ² as defined in appendix 3a.

Appendix 4c: Effect of the interaction of fallow period, fallow type and N and P fertilization on maize grain and stover N and P concentrations at Gairo in Morogoro, Tanzania.

Fallow type	Fert. t _r ¹	Fallow period (years)																	
		1				2				3									
		Grain	Stover	Grain	Stover	N conc. (%)	P conc. (%)	Total conc. (%)	N conc. (%)	P conc. (%)	Total conc. (%)	N conc. (%)	P conc. (%)	Total conc. (%)					
<i>S. sesban</i>	1	0.87 ² (0.01)	0.15 (0.01)	0.06 (0.03)	0.02 (0.03)	1.02 (0.01)	0.08 (0.05)	1.11 (0.01)	0.29 (0.06)	0.07 (0.01)	0.02 (0.01)	1.40 (0.06)	0.09 (0.01)	1.03 (0.03)	0.14 (0.01)	0.07 (0.04)	0.02 (0.01)	1.17 (0.01)	0.09 (0.03)
	2	1.04 (0.01)	0.27 (0.01)	0.06 (0.01)	0.02 (0.01)	1.31 (0.02)	0.08 (0.01)	1.27 (0.03)	0.31 (0.05)	0.07 (0.01)	0.01 (0.01)	1.59 (0.07)	0.10 (0.01)	1.04 (0.01)	0.04 (0.01)	0.08 (0.02)	0.02 (0.01)	1.39 (0.01)	0.09 (0.02)
	3	0.89 (0.03)	0.20 (0.05)	0.06 (0.01)	0.03 (0.01)	1.09 (0.05)	0.09 (0.01)	1.07 (0.03)	0.21 (0.03)	0.07 (0.04)	0.04 (0.01)	1.29 (0.01)	0.12 (0.02)	1.03 (0.02)	0.17 (0.03)	0.11 (0.03)	0.03 (0.01)	1.19 (0.03)	0.14 (0.01)
	4	1.25 (0.01)	0.33 (0.06)	0.07 (0.01)	0.03 (0.01)	1.57 (0.06)	0.09 (0.02)	1.28 (0.02)	0.35 (0.03)	0.08 (0.01)	0.05 (0.01)	1.61 (0.03)	0.13 (0.01)	1.06 (0.01)	0.36 (0.01)	0.09 (0.08)	0.03 (0.01)	1.42 (0.01)	0.13 (0.01)
<i>T. vogelii</i>	1	1.24 (0.03)	0.30 (0.01)	0.07 (0.04)	0.03 (0.03)	1.54 (0.01)	0.09 (0.01)	1.25 (0.03)	0.32 (0.05)	0.08 (0.01)	0.03 (0.01)	1.58 (0.05)	0.11 (0.01)	1.27 (0.01)	0.37 (0.08)	0.08 (0.04)	0.03 (0.01)	1.64 (0.08)	0.11 (0.01)
	2	1.38 (0.01)	0.42 (0.01)	0.08 (0.04)	0.03 (0.01)	1.80 (0.01)	0.11 (0.01)	1.42 (0.01)	0.39 (0.03)	0.09 (0.01)	0.03 (0.01)	1.81 (0.03)	0.12 (0.01)	1.43 (0.03)	0.45 (0.08)	0.09 (0.01)	0.03 (0.01)	1.88 (0.08)	0.12 (0.01)
	3	1.24 (0.03)	0.35 (0.01)	0.10 (0.01)	0.04 (0.01)	1.60 (0.03)	0.13 (0.01)	1.26 (0.01)	0.37 (0.06)	0.12 (0.04)	0.04 (0.01)	1.63 (0.06)	0.16 (0.01)	1.28 (0.03)	0.36 (0.08)	0.11 (0.03)	0.04 (0.01)	1.64 (0.09)	0.15 (0.01)
	4	1.40 (0.01)	0.47 (0.02)	0.10 (0.01)	0.04 (0.01)	1.87 (0.01)	0.14 (0.01)	1.42 (0.03)	0.45 (0.07)	0.12 (0.04)	0.04 (0.01)	1.87 (0.07)	0.16 (0.01)	1.44 (0.01)	0.31 (0.12)	0.12 (0.03)	0.04 (0.01)	1.75 (0.12)	0.16 (0.01)
<i>C. cajan</i>	1	1.13 (0.05)	0.08 (0.01)	0.09 (0.01)	0.02 (0.03)	1.21 (0.01)	0.11 (0.01)	1.16 (0.03)	0.22 (0.10)	0.09 (0.01)	0.02 (0.03)	1.38 (0.10)	0.11 (0.01)	1.18 (0.01)	0.13 (0.01)	0.09 (0.05)	0.02 (0.01)	1.31 (0.01)	0.11 (0.01)
	2	1.22 (0.01)	0.10 (0.02)	0.09 (0.01)	0.02 (0.03)	1.32 (0.01)	0.11 (0.01)	1.24 (0.01)	0.22 (0.03)	0.09 (0.06)	0.02 (0.01)	1.46 (0.03)	0.11 (0.01)	1.27 (0.01)	0.20 (0.15)	0.10 (0.12)	0.02 (0.01)	1.47 (0.09)	0.12 (0.01)
	3	1.13 (0.01)	0.10 (0.02)	0.10 (0.01)	0.03 (0.01)	1.24 (0.02)	0.13 (0.01)	1.16 (0.01)	0.22 (0.10)	0.12 (0.11)	0.04 (0.01)	1.38 (0.10)	0.15 (0.02)	1.20 (0.01)	0.15 (0.02)	0.12 (0.01)	0.04 (0.01)	1.34 (0.06)	0.15 (0.01)
	4	1.24 (0.01)	0.21 (0.07)	0.11 (0.03)	0.04 (0.01)	1.45 (0.06)	0.15 (0.01)	1.25 (0.01)	0.27 (0.07)	0.11 (0.08)	0.04 (0.01)	1.52 (0.07)	0.15 (0.01)	1.28 (0.01)	0.40 (0.06)	0.12 (0.01)	0.04 (0.01)	1.65 (0.06)	0.15 (0.01)
Natural fallow	1	0.86 (0.01)	0.07 (0.01)	0.07 (0.01)	0.02 (0.01)	0.93 (0.01)	0.09 (0.02)	1.01 (0.01)	0.09 (0.02)	0.08 (0.01)	0.02 (0.01)	1.11 (0.02)	0.10 (0.03)	1.13 (0.01)	0.10 (0.01)	0.08 (0.02)	0.02 (0.01)	1.23 (0.01)	0.10 (0.02)
	2	1.14 (0.01)	0.1 (0.01)	0.07 (0.03)	0.02 (0.01)	1.25 (0.01)	0.09 (0.01)	1.22 (0.01)	0.16 (0.01)	0.08 (0.01)	0.02 (0.01)	1.38 (0.01)	0.10 (0.02)	1.24 (0.01)	0.24 (0.01)	0.08 (0.07)	0.02 (0.01)	1.47 (0.01)	0.11 (0.02)
	3	1.02 (0.02)	0.07 (0.03)	0.08 (0.01)	0.03 (0.01)	1.09 (0.02)	0.11 (0.01)	1.02 (0.01)	0.10 (0.03)	0.09 (0.01)	0.03 (0.01)	1.12 (0.02)	0.12 (0.03)	1.14 (0.01)	0.09 (0.01)	0.10 (0.05)	0.03 (0.01)	1.23 (0.01)	0.13 (0.01)
	4	1.17 (0.01)	0.11 (0.01)	0.08 (0.01)	0.03 (0.01)	1.29 (0.02)	0.11 (0.01)	1.22 (0.02)	0.24 (0.04)	0.09 (0.01)	0.03 (0.01)	1.46 (0.04)	0.12 (0.01)	1.25 (0.02)	0.28 (0.02)	0.10 (0.01)	0.03 (0.01)	1.53 (0.03)	0.13 (0.01)

Appendix 4e continued

Fallow type	Fert. trt. ¹	Fallow period (years)																	
		1				2				3									
		Grain	Stover	Grain	P conc. (%)	Grain	Stover	Grain	P conc. (%)	Grain	Stover	Grain	P conc. (%)						
Continuous cultivation	1	0.84 (0.06)	0.07 (0.01)	0.07 (0.03)	0.02 (0.03)	0.91 (0.06)	0.09 (0.02)	0.09 (0.02)	0.75 (0.02)	0.07 (0.01)	0.07 (0.01)	0.01 (0.01)	0.82 (0.02)	0.08 (0.03)	0.08 (0.02)	0.05 (0.01)	0.06 (0.01)	0.72 (0.01)	0.07 (0.01)
	2	1.21 (0.01)	0.15 (0.02)	0.07 (0.01)	0.02 (0.01)	1.36 (0.02)	0.09 (0.01)	0.09 (0.01)	1.17 (0.02)	0.10 (0.01)	0.10 (0.01)	0.02 (0.01)	1.27 (0.01)	0.08 (0.03)	0.09 (0.02)	0.09 (0.02)	0.06 (0.01)	1.04 (0.04)	0.08 (0.02)
	3	0.87 (0.07)	0.08 (0.01)	0.08 (0.01)	0.02 (0.01)	0.95 (0.08)	0.10 (0.02)	0.10 (0.02)	0.76 (0.03)	0.06 (0.01)	0.06 (0.01)	0.02 (0.01)	0.82 (0.03)	0.09 (0.01)	0.09 (0.02)	0.05 (0.02)	0.07 (0.01)	0.71 (0.01)	0.08 (0.01)
	4	1.21 (0.02)	0.27 (0.01)	0.09 (0.01)	0.02 (0.01)	1.48 (0.03)	0.11 (0.02)	0.11 (0.02)	1.19 (0.02)	0.13 (0.01)	0.13 (0.01)	0.02 (0.01)	1.32 (0.02)	0.10 (0.01)	0.10 (0.01)	0.09 (0.01)	0.07 (0.01)	1.05 (0.04)	0.08 (0.01)

¹ as defined in appendix 4a. ² as defined in appendix 3.

Appendix 4f: Effect of the interaction of fallow period, fallow type and N and P fertilization on maize grain and stover N and P uptake at Gairo in Morogoro, Tanzania.

Fallow type	Fert. trt. ¹	Fallow period (years)																	
		1						2						3					
		N uptake (kg ha ⁻¹)		P uptake (kg ha ⁻¹)		Total uptake (kg ha ⁻¹)		N uptake (kg ha ⁻¹)		P uptake (kg ha ⁻¹)		Total uptake (kg ha ⁻¹)		N uptake (kg ha ⁻¹)		P uptake (kg ha ⁻¹)		Total uptake (kg ha ⁻¹)	
Grain	Stover	Grain	Stover	N	P	Grain	Stover	N	P	Grain	Stover	N	P	Grain	Stover	N	P		
<i>S. sesban</i>	1	17.16 (2.63)	4.97 (0.59)	1.15 (0.15)	0.64 (0.04)	22.13 (2.49)	1.79 (0.15)	27.59 (4.99)	10.73 (3.13)	1.69 (0.18)	0.78 (0.07)	38.32 (5.71)	2.47 (0.19)	33.51 (2.90)	2.27 (0.10)	0.99 (0.07)	37.53 (0.19)	0.99 (0.07)	37.53 (0.19)
	2	23.23 (5.39)	12.44 (2.64)	1.37 (0.32)	1.04 (0.15)	35.67 (7.30)	2.41 (0.38)	40.05 (3.01)	15.13 (3.05)	2.29 (0.39)	1.14 (0.13)	55.19 (0.15)	3.43 (0.27)	37.99 (1.93)	2.73 (0.21)	1.07 (0.30)	56.53 (0.03)	1.07 (0.30)	56.53 (0.03)
	3	23.88 (2.78)	9.71 (3.19)	1.72 (0.20)	1.35 (0.05)	33.59 (0.56)	3.07 (0.16)	32.76 (2.64)	11.09 (0.19)	2.30 (0.30)	1.85 (0.03)	46.47 (0.38)	4.45 (0.07)	40.03 (8.03)	4.25 (0.89)	1.82 (0.45)	49.22 (4.44)	1.82 (0.45)	49.22 (4.44)
	4	40.83 (5.49)	19.18 (4.55)	2.14 (0.23)	1.67 (0.11)	60.02 (5.29)	3.80 (0.29)	54.52 (4.67)	20.63 (0.24)	3.58 (0.63)	2.21 (0.23)	79.36 (3.26)	6.41 (0.22)	53.73 (9.28)	4.49 (0.62)	2.24 (0.07)	77.36 (11.0)	2.24 (0.07)	77.36 (11.0)
<i>T. vegetalis</i>	1	41.03 (0.14)	10.69 (1.21)	2.45 (0.15)	0.91 (0.13)	51.72 (1.18)	3.36 (0.27)	55.26 (3.69)	15.01 (0.930)	3.61 (0.67)	1.26 (0.12)	70.28 (2.78)	4.87 (0.76)	69.33 (9.37)	4.66 (0.82)	1.44 (0.28)	90.07 (9.43)	1.44 (0.28)	90.07 (9.43)
	2	69.66 (5.99)	20.27 (2.13)	3.78 (0.37)	1.25 (0.08)	89.93 (6.86)	5.37 (0.14)	78.81 (7.92)	25.49 (4.26)	5.14 (1.09)	1.71 (0.11)	104.3 (11.3)	6.85 (1.20)	91.05 (5.45)	5.86 (0.44)	2.09 (0.33)	128.3 (13.8)	2.09 (0.33)	128.3 (13.8)
	3	44.46 (3.48)	17.77 (4.33)	3.42 (0.49)	2.42 (0.44)	62.23 (3.79)	5.20 (0.32)	70.41 (10.7)	19.61 (7.91)	6.78 (0.56)	1.83 (0.43)	90.02 (15.8)	8.62 (0.99)	78.51 (4.76)	7.01 (0.59)	2.72 (0.27)	103.1 (6.29)	2.72 (0.27)	103.1 (6.29)
	4	102.3 (18.7)	28.55 (4.17)	6.71 (1.25)	2.42 (0.26)	130.8 (21.0)	9.13 (1.41)	97.12 (7.91)	28.05 (7.96)	8.33 (0.56)	2.37 (0.43)	125.2 (15.8)	10.71 (0.99)	119.5 (3.32)	9.56 (0.14)	4.25 (0.44)	152.7 (18.7)	4.25 (0.44)	152.7 (18.7)
<i>C. cajan</i>	1	18.80 (3.47)	2.23 (0.09)	1.49 (0.28)	0.52 (0.07)	21.04 (3.46)	2.01 (0.33)	27.05 (7.30)	11.19 (7.28)	1.30 (0.61)	0.86 (0.29)	28.24 (6.54)	2.16 (0.38)	50.72 (7.34)	3.79 (0.32)	0.89 (0.15)	56.39 (7.71)	0.89 (0.15)	56.39 (7.71)
	2	27.09 (6.83)	3.98 (1.26)	1.97 (0.47)	0.71 (0.11)	31.07 (5.58)	2.68 (0.47)	22.84 (5.32)	10.37 (1.37)	1.62 (0.45)	0.98 (0.14)	33.22 (5.03)	2.61 (0.74)	62.15 (10.8)	4.87 (0.93)	1.33 (0.16)	75.02 (5.35)	1.33 (0.16)	75.02 (5.35)
	3	18.23 (4.46)	3.71 (0.45)	1.60 (0.49)	1.30 (0.24)	21.94 (4.10)	2.91 (0.72)	26.21 (7.47)	12.09 (5.69)	2.62 (0.75)	1.90 (0.18)	38.29 (11.1)	4.53 (0.74)	62.91 (17.6)	6.14 (1.75)	2.37 (0.57)	72.80 (20.3)	2.37 (0.57)	72.80 (20.3)
	4	35.72 (8.90)	7.81 (1.54)	3.28 (0.88)	1.40 (0.11)	43.52 (9.80)	4.69 (0.83)	93.88 (6.50)	16.30 (3.26)	8.63 (5.74)	2.31 (0.24)	110.2 (5.82)	10.93 (5.36)	87.29 (17.5)	7.95 (1.65)	2.41 (0.20)	111.6 (22.5)	2.41 (0.20)	111.6 (22.5)
Natural fallow	1	8.84 (0.32)	2.03 (0.25)	0.69 (0.03)	0.68 (0.08)	10.87 (0.47)	1.36 (0.09)	12.71 (1.94)	3.31 (1.20)	0.96 (0.17)	0.74 (0.08)	16.02 (0.84)	1.71 (0.09)	28.01 (3.27)	1.87 (0.21)	0.89 (0.12)	31.92 (3.02)	0.89 (0.12)	31.92 (3.02)
	2	23.49 (6.08)	3.90 (0.28)	1.38 (0.35)	0.89 (0.07)	27.39 (6.08)	2.28 (0.37)	29.88 (3.76)	5.93 (1.00)	1.29 (0.29)	0.83 (0.11)	25.81 (3.67)	2.13 (0.29)	37.48 (2.89)	2.49 (0.09)	1.41 (0.14)	52.05 (6.38)	1.41 (0.14)	52.05 (6.38)
	3	12.17 (1.32)	2.97 (0.07)	1.00 (0.09)	1.09 (0.05)	15.14 (1.27)	2.10 (0.13)	19.11 (1.10)	4.20 (0.23)	1.65 (0.04)	1.13 (0.09)	23.31 (1.00)	2.78 (0.12)	34.11 (2.51)	2.87 (0.32)	1.47 (0.06)	38.73 (3.14)	1.47 (0.06)	38.73 (3.14)
	4	25.36 (2.85)	4.48 (0.37)	1.82 (0.20)	1.16 (0.13)	29.85 (2.65)	2.99 (0.07)	26.95 (0.88)	10.55 (2.83)	1.99 (0.06)	1.27 (0.21)	37.50 (3.70)	3.27 (0.25)	44.99 (5.18)	3.41 (0.19)	1.74 (0.21)	60.67 (6.16)	1.74 (0.21)	60.67 (6.16)

Appendix 4f continued

Fallow type	Fert. tr. ¹	Fallow period (years)																		
		1				2				3										
		Grain	Stover	N uptake (kg ha ⁻¹)	P uptake (kg ha ⁻¹)	Grain	Stover	N uptake (kg ha ⁻¹)	P uptake (kg ha ⁻¹)	Grain	Stover	N uptake (kg ha ⁻¹)	P uptake (kg ha ⁻¹)							
Continuous cultivation	1	19.16 (7.56)	2.73 (0.22)	13.81 (5.31)	3.13 (0.60)	16.93 (5.91)	1.82 (0.47)	1.65 (0.83)	0.66 (0.13)	9.28 (3.18)	1.08 (0.17)	1.52 (0.42)	0.64 (0.05)	1.18 (0.36)	0.64 (0.12)	1.82 (0.47)	1.65 (0.83)	0.66 (0.13)	9.28 (3.18)	1.08 (0.17)
	2	32.07 (7.07)	7.10 (1.41)	26.36 (4.30)	5.90 (0.22)	32.27 (5.07)	2.41 (0.35)	3.51 (0.95)	1.04 (0.13)	19.86 (4.58)	1.62 (0.16)	1.92 (0.35)	0.81 (0.06)	1.49 (0.16)	0.91 (0.22)	2.41 (0.35)	3.51 (0.95)	1.04 (0.13)	19.86 (4.58)	1.62 (0.16)
	3	23.72 (6.50)	3.96 (0.84)	16.54 (1.40)	3.87 (1.69)	20.41 (3.06)	2.67 (0.50)	2.24 (1.24)	1.02 (0.31)	12.61 (5.12)	1.66 (0.42)	2.21 (0.89)	0.89 (0.06)	1.55 (0.15)	1.11 (0.35)	2.67 (0.50)	2.24 (1.24)	1.02 (0.31)	12.61 (5.12)	1.66 (0.42)
	4	39.53 (12.9)	15.33 (3.73)	34.37 (5.14)	8.39 (2.10)	42.77 (6.81)	3.45 (0.57)	4.05 (0.68)	1.31 (0.26)	23.03 (5.40)	2.10 (1.59)	2.74 (1.08)	1.08 (0.21)	2.27 (0.35)	1.18 (0.22)	3.45 (0.57)	4.05 (0.68)	1.31 (0.26)	23.03 (5.40)	2.10 (1.59)

¹ as defined in appendix 4a. ² as defined in appendix 3.

Appendix 5a: Effect of the interaction of fallow period and fallow type on maize growth (84 DAS) and yield at Gairo in Morogoro, Tanzania.

Fallow type	Fallow period (years)	Maize height (m)	Grain yield (t ha ⁻¹)	Stover yield (t ha ⁻¹)
<i>S. sesban</i>	1	1.12b (3.73)	2.54c ¹ (0.23)	4.64b (0.34)
	2	1.14b (4.60)	3.24b (0.25)	4.99b (0.31)
	3	1.25a (4.74)	3.95a (0.25)	5.89a (0.28)
<i>T. vogelii</i>	1	1.23b (5.00)	4.80b (0.66)	4.83b (0.42)
	2	1.28ba (5.31)	5.60ba (0.37)	5.61b (0.39)
	3	1.33a (6.04)	6.55a (0.39)	7.59a (0.68)
<i>C. cajan</i>	1	1.12b (4.74)	2.09b (0.27)	3.59c (0.28)
	2	1.19ba (4.81)	3.27ba (1.30)	5.20b (0.34)
	3	1.24a (4.79)	5.43a (0.58)	6.11a (0.36)
Natural fallow	1	1.00c (3.76)	1.61b (0.19)	3.72b (0.21)
	2	1.07b (3.04)	1.74b (0.13)	3.82b (0.22)
	3	1.17a (3.20)	3.02a (0.17)	4.96a (0.32)
Continuous cultivation	1	1.14a (4.24)	2.66a (0.32)	4.77ba (0.35)
	2	1.01b (4.520)	2.27a (0.22)	5.78a (0.62)
	3	0.88c (3.52)	1.63b (0.24)	4.03b (0.29)

¹Means of three replications followed by standard error in parenthesis. Means with the same letter in a column are not significantly ($P>0.05$) different. DAS = As defined in appendix 3a.

Appendix 5b: Effect of the interaction of fallow type and fertilizer treatment on maize growth and yield at Gairo, Morogoro, Tanzania.

Fallow type	Fertilizer treatment ¹	Maize height (m)	Grain yield (t ha ⁻¹)	Stover yield (t ha ⁻¹)
<i>S. sesban</i>	F ₁	1.03c (3.72)	2.57b ² (0.25)	4.07c (0.35)
	F ₂	1.18b (3.18)	3.01b (0.27)	5.17b (0.38)
	F ₃	1.13cb (3.03)	3.20b (0.29)	5.24b (0.38)
	F ₄	1.33a (5.25)	4.20a (0.39)	6.22a (0.230)
<i>T. vogelii</i>	F ₁	1.07d (2.03)	4.37b (0.38)	4.55b (0.43)
	F ₂	1.32b (2.32)	5.66b (0.31)	6.29a (0.64)
	F ₃	1.18c (2.46)	5.09b (0.48)	5.86ba (0.59)
	F ₄	1.53a (3.74)	7.28a (0.65)	7.35a (0.83)
<i>C. cajan</i>	F ₁	1.01c (2.28)	2.64b (0.66)	3.98b (0.43)
	F ₂	1.18b (3.59)	2.98ba (0.57)	4.87ba (0.41)
	F ₃	1.15b (3.18)	3.04ba (0.73)	5.30a (0.56)
	F ₄	1.39a (4.38)	5.72a (1.65)	5.73a (0.480)
Natural fallow	F ₁	0.93c (3.53)	1.58c (0.24)	3.39b (0.26)
	F ₂	1.11b (2.97)	2.24ba (0.28)	4.24a (0.36)
	F ₃	1.07b (2.48)	2.02bc (0.27)	4.41a (0.21)
	F ₄	1.21a (2.79)	2.65a (0.26)	4.62a (0.39)
Continuous cultivation	F ₁	0.86d (3.02)	1.77c (0.34)	3.92c (0.36)
	F ₂	1.05b (4.35)	2.26b (0.26)	4.97b (0.54)
	F ₃	0.99c (4.68)	2.20cb (0.25)	5.24ba (0.73)
	F ₄	1.21a (4.60)	2.78a (0.40)	5.72a (0.58)

¹ and DAS as defined in Appendix 3a.

Appendix 5c: Effect of the interaction of fallow period, fallow type and fertilization on maize growth and yield at Gairo in Morogoro, Tanzania.

Fallow period (years)		Maize height (m)			Grain yield (t ha ⁻¹)			Stover yield (t ha ⁻¹)		
		1	2	3	1	2	3	1	2	3
Fallow type	Fertilizer treatment ¹									
<i>S. sesban</i>	F ₁	0.96 ² (1.05)	1.01 (0.79)	1.12 (9.01)	1.97 (0.27)	2.48 (0.45)	3.24 (0.26)	3.29 (0.17)	3.61 (0.27)	5.30 (0.42)
	F ₂	1.16 (7.05)	1.15 (4.69)	1.24 (4.99)	2.23 (0.50)	3.14 (0.28)	3.66 (0.18)	4.58 (0.80)	4.78 (0.28)	6.14 (0.52)
	F ₃	1.13 (5.35)	1.06 (3.24)	1.19 (5.52)	2.67 (0.30)	3.05 (0.24)	3.86 (0.70)	4.83 (0.19)	5.31 (0.06)	5.58 (0.80)
	F ₄	1.23 (6.25)	1.34 (6.04)	1.44 (7.40)	3.28 (0.44)	4.26 (0.42)	5.04 (0.85)	5.83 (0.50)	6.26 (0.39)	6.54 (0.33)
<i>T. vogelii</i>	F ₁	1.03 (1.31)	1.09 (3.18)	1.10 (4.83)	3.32 (0.01)	4.41 (0.30)	5.38 (0.80)	3.59 (0.53)	4.79 (0.46)	5.27 (0.96)
	F ₂	1.25 (4.34)	1.37 (1.56)	1.35 (1.71)	5.02 (0.42)	5.56 (0.59)	6.38 (0.39)	4.57 (0.38)	6.41 (0.48)	7.87 (1.34)
	F ₃	1.17 (4.54)	1.14 (1.55)	1.25 (4.25)	3.56 (0.28)	5.59 (0.87)	6.12 (0.37)	5.07 (1.23)	5.26 (0.90)	7.23 (0.73)
	F ₄	1.46 (5.78)	1.51 (3.89)	1.61 (7.58)	7.30 (2.05)	6.85 (0.56)	8.30 (0.21)	6.05 (0.62)	5.98 (1.18)	9.99 (1.11)
<i>C. cajan</i>	F ₁	0.94 (1.41)	1.01 (2.90)	1.08 (2.44)	1.66 (0.31)	2.47 (0.62)	4.78 (1.12)	2.85 (0.29)	4.20 (0.96)	4.88 (0.43)
	F ₂	1.09 (3.74)	1.22 (6.17)	1.22 (6.43)	2.21 (0.54)	2.83 (0.41)	4.90 (0.84)	3.64 (0.57)	4.73 (0.81)	6.23 (0.29)
	F ₃	1.10 (0.11)	1.16 (7.47)	1.19 (6.63)	1.60 (0.39)	2.25 (0.64)	5.25 (1.46)	3.83 (0.71)	5.44 (0.12)	6.60 (1.19)
	F ₄	1.34 (8.59)	1.36 (9.36)	1.46 (5.22)	2.87 (0.71)	7.53 (4.89)	6.79 (1.38)	4.04 (0.60)	6.41 (0.50)	6.71 (0.22)
Natural fallow	F ₁	0.81 (1.98)	0.95 (2.27)	1.04 (3.08)	1.02 (0.04)	1.25 (0.18)	2.47 (0.27)	2.89 (0.36)	3.37 (0.39)	3.90 (0.52)
	F ₂	1.04 (1.87)	1.08 (2.83)	1.21 (4.48)	2.05 (0.53)	1.63 (0.30)	3.02 (0.24)	3.90 (0.28)	3.67 (0.45)	5.15 (0.82)
	F ₃	1.01 (0.16)	1.05 (2.43)	1.16 (2.73)	1.19 (0.11)	1.87 (0.09)	2.99 (0.23)	6.06 (0.21)	4.08 (0.30)	5.09 (0.23)
	F ₄	1.15 (1.75)	1.22 (3.15)	1.26 (6.92)	2.16 (0.24)	2.21 (0.05)	3.59 (0.37)	4.03 (0.47)	4.14 (0.63)	5.68 (0.63)
Continuous cultivation	F ₁	0.95 (0.31)	0.84 (2.81)	0.75 (0.19)	2.16 (0.66)	1.80 (0.64)	1.16 (0.39)	3.89 (0.31)	4.47 (0.86)	3.15 (0.41)
	F ₂	1.18 (3.95)	1.01 (0.57)	0.91 (2.29)	2.63 (0.54)	2.24 (0.33)	1.75 (0.49)	4.65 (0.42)	5.91 (1.33)	4.06 (0.40)
	F ₃	1.11 (5.92)	0.96 (4.09)	0.84 (1.61)	2.64 (0.48)	2.18 (0.18)	1.61 (0.65)	4.85 (0.40)	6.36 (1.87)	4.14 (0.83)
	F ₄	1.31 (0.60)	1.24 (1.14)	1.01 (0.21)	3.21 (0.98)	2.87 (0.67)	2.01 (0.61)	5.66 (1.18)	6.41 (1.11)	4.77 (0.03)

¹ as defined in appendix 3a. ² Means of three replications followed by standard error in parenthesis.