SOIL MOISTURE DYNAMICS AND COMPONENTS PERFORMANCE IN RELAY INTERCROPPING OF *TEPHROSIA VOGELII* AND MAIZE IN SEMI ARID GAIRO, TANZANIA

BY

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ABSTRACT

A study investigating the effect of time of planting and spacing of *Tephrosia* on soil moisture and components performance in relay intercropping with maize were conducted at Gairo, Tanzania in three seasons. A split–plot design with main plot factor as time of planting having levels 0, 2 and 4 weeks after maize and spacing as minor plots factor with levels 30 x 90 (Tv30), 60 x 90 (Tv60) and 90 x 90 (Tv90) cm (intercrop and monoculture *Tephrosia vogelii*) plus control (Tv0), was laid in the first season. For second and third seasons, a split- split-plot design was laid, where spacing treatment was split to two levels of fertilizer (without and with half and full recommended doses of N and P respectively). In the first season, soil moisture was assessed within 100 cm soil depths using Profile Probe. Maize height and stover yield were assessed at tasselling while grain yield was assessed at maturity, and *Tephrosia* biomass yield was assessed at three, six and eleven months of growth. Soil bulk density, organic carbon and root biomass yield were assessed at 11 months. In the second and third seasons, field mineral nitrogen and maize yield were assessed. Highest soil moisture and maize yield were maintained with Wk2Tv60 in first season. At three months in intercrops, total shrub biomass was significantly higher ($P<0.05$) in Wk2Tv30 than the rest. Total shrub yields at eleven months in monoculture plots were 2-6 times higher than intercrops. Mean shrub biomass increment, mean shrub height increment and mean shrub diameter increment were significantly higher ($P<0.05$) in Wk0Tv90 than the rest between six and eleven month assessments for intercrops. Soil properties after eleven months did not consistently differ, but monoculture *Tephrosia* showed superiority in most cases over intercrops. Maize yield was maximized with fertilized monoculture *Tephrosia*, but unfertilized intercrops recorded 50 and 58 percent increase over unfertilized Tv0 in second and third seasons, respectively. The study concludes that *Tephrosia* relay-intercropped with maize can enhance sustainable maize production in land-scarce semi arid areas and recommends further study on continuous intercropping involving various provenances of *Tephrosia*.

DECLARATION

I, MOSES SAHR NGEGBA, do hereby declare to the Senate of Sokoine University of Agriculture that this thesis is my original work and that it has not been submitted for a degree award in any other University.

Signature:..

Date: 17/11/05

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There is one who gives strength to the weary, lifts the humble and provides a way where there may seem to be no way; God Almighty through Jesus Christ the Lord. The first and highest gratitude goes to Him for this accomplishment.

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DEDICATION

To God Almighty through Jesus Christ our Lord and Saviour who enabled me, I dedicate this work.

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LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS

AAS	African Academy of Sciences
AF	Agroforestry
Al	Aluminum
ANOVA	Analysis of variance
a. s. l.	Above sea level
avail-N	available nitrogen
avail-P	Available P
BD	Bulk density
DM	Dry matter
DMRT	Duncan's Multiple Range Test
E	East
EC	Electrical conductivity
e.g.	For example
Ed	Edition
Eds	Editors
esp	Especially
et al	And other people
FAO	Food and Agricultural Organization
g	Gramme
GLM	General linear models
ha	Hectare
ICRAF	International Centre for Research in Agroforestry
IF	Improved fallow
K	Potassium

kg	Kilogramme
L	Lignin
LSD	Least Significant Difference
m	Metre
mg	Milligramme
Mineral-N	Mineral nitrogen
msd	Mean shrub diameter
msdi	Mean shrub diameter increment
msh	Mean shrub height
mshi	Mean shrub height increment
msb	Mean shrub biomass
msbi	Mean shrub biomass increment
mm	Millimetre
MPR	Minjigu Phosphate Rock
mS	micro-siemen
N	nitrogen
nd	No data/not determined
NH4-N	Ammonium nitrogen
NO3-N	Nitrate nitrogen
OC	Organic carbon
OM	Organic matter
P	phosphorus
pH	Hydrogen ion concentration/soil reaction
PP	Polyphenol
S	South

SAS	Statistical Analysis Systems
SAT	Semiarid tropics
SUA	Sokoine University of Agriculture
SE	Standard error
SED	Standard error of the difference
t	Ton
TARP II	Tanzania Agricultural Research Project Phase Two
Tv	*Tephrosia vogelii*
UNDP	United Nations Development Programme
USA	United States of America
Vol	Volume
VSMC	Volume soil moisture content
Wk	Week
µg	micro-gramme

CHAPTER ONE

1.0 INTRODUCTION

Tropical Africa is widely known for its poor agricultural production and high growth of human population in the world (FAO, 1994; Buresh *et al.*, 1997). It is an indisputable fact that the causes of poor agricultural production are very closely related to the ever-rising population estimated to be over 6 percent in the 1980s and early 1990s for sub-Sahara Africa (FAO, 1994). Agriculture in this region largely depends on rain and the dominant practice has always been shifting cultivation, which inevitably demands extensive rather than intensive use of land, thus requiring large per capita landholdings. Increase in human population over the years has however greatly limited the size of per capita arable landholdings, thus rendering the practice virtually impracticable. Limited landholding has led to shortened fallow period, intensive use of land with little or no external input to restore fertility. The consequences of this are far-reaching, including land degradation, poor crop yields, food insecurity, low-income and the eventual vicious circle of poverty and poor standard of living in the region (Baumer, 1990; FAO, 1994; Brown and Gaston, 1996; Fleischhauer and Eger, 1998). This prevailing condition has necessitated change of practice or improvement in the traditional land use practices. Hence the advent of agroforestry (AF) brought great anticipation to not only farmers and agronomic researchers but also policy makers, as it was seen as the complete solution to the above-mentioned situation.

Not withstanding the above, an additional problem yet poses even greater obstacle to agricultural production in semi arid tropics (SAT) in particular. Generally, tropical soils are known for their inherently low fertility, a factor that greatly constrains agricultural production in the region (Rocheleau *et al.*, 1988; Buresh and Tian, 1998). In the face of rapid population growth, soil moisture deficiency poses an additional major obstacle to interventions that could successfully replace the now impracticable traditional shifting cultivation (Rao *et al.*, 1998), i.e., the application of many potential AF practices in semi arid areas of the tropics, including Tanzania.

Over the years, research has revealed that most of the highly advocated AF technologies are indeed site-specific; implying that they better suit certain localities than others. For example, hedgerow intercropping, a simultaneous system has been characterized with decline in crop yield after 2 to 3 years of continuous cropping in semi arid areas including Tanzania, where competition for belowground resources especially soil moisture was suggested as likely cause (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, Rao *et al.* 1998). Trials in India have shown that grain yield of millet grown in 3.6 m wide *Leucaena* alleys systematically decreased with increase in alley age from about 17 percent in the first year to over 80 percent by the fifth year (Singh *et al*, 1989). On the other hand, the adoption of sequential systems like improved fallow is seriously hampered by limited arable landholdings in many places because of the problem of having to skip at least a year of cultivation under the system. Under land-scarce condition, farmers find it extremely difficult to leave any portion (let alone all) of their land to lie in idle fallow even for a year (Rutunga *et al.*, 1999).

In light of the above-mentioned limitations of simultaneous and sequential systems of AF, a semi-simultaneous system is considered. Relay intercropping system is a semi-simultaneous system in which fast growing trees/shrubs or herbaceous perennials with soil fertility replenishing ability are inter-planted with fast maturing annual crops. The former is left to continue on the land during the dry season after the annual crops are harvested; and just before the next cropping season, all trees/shrubs are cut down and biomass that is not useful as fuel wood is returned to the soil (ICRAF, 1993). Relay intercropping in different trials has been found to increase crop yield considerably in Tanzania and elsewhere (Rocheleau *et al.*, 1988; Kwesiga and Coe 1994; Otsyina, *et al.*, 1994; ICRAF, 1995; Fasuluku, 1998).

The fundamental hypothesis of AF is that different plant life forms such as trees/shrubs and herbaceous crops or pastures occupy to some extent different soil strata with their root systems when grown in association, leading to a degree of complementarity in the use of soil resources (Schroth, 1999). In spite of this hypothesis, the general belief that there is always some level of competition in such association still remains. Hence, Ong *et al.* (1992) points out that the opportunity for complementarity in the use of soil moisture especially (which AF systems are known to possess over sole cropping systems), is likely to be limited unless the component species differ appreciably in rooting pattern and duration. Since soil moisture is most limiting factor in these areas (Ong *et al.*, 1996), such qualities as moderate growth vigour, deep rooting and drought resistance, are additional factors worthy of consideration in species selection.

Tephrosia vogelii among commonly available AF shrubs has exhibited satisfactory adaptation to dry conditions with reported survival rates of 97%, 94% and 72% in 1, 2, and 3 years fallows respectively, in an improved fallow trial at Gairo, Tanzania (Mgangamundo, 2000). In addition, despite its low foliage biomass yield compared to fallows of *Sesbania sesban* and *Gliricidia sepium*, maize grain yield was still highest in 1 and 2 year unfertilized *Tephrosia* fallows, recording 3.32 and 4.41 t ha^{-1}, which corresponded to 225 and 253% increase over natural fallows respectively (Chingonikaya, 1999; Mgangamundo, 2000). Its growth height hardly exceeds 2 m and attains maturity in one year in semi arid conditions (Mgangamundo, 2000).

Information on how *Tephrosia* and maize would interact to share soil moisture as a limited growth resource in relay intercropping system in Tanzania is hard to come by. It is hypothesized that competition for soil moisture would lead to reduction in crop yields. The degree of competition is a function of several factors including its effectiveness in capturing growth resources, which in turn is a function of *Tephrosia* vigour, rooting pattern and root mass (Ong *et al.*, 1996). *Tephrosia* vigour may be related to plant density as well as the time of planting in relation to the associated crop. It is therefore further hypothesized that with appropriate time of planting and spacing of *Tephrosia*, competition for soil moisture can be minimized, to optimize maize growth and yield during the intercropping phase.

Authors have commented on relay intercropping technology as a good soil management system, as well as the shrub *T. vogelii* (Rocheleau, 1988; Otsyina, *et al.*, 1994; Balasubramanian and Sekayange, 1994; ICRAF, 1995; Fasuluku, 1998; Chingonikaya, 1999; Mgangamundo, 2000), but there is generally no information on tree/shrub-crop moisture interaction under this system for semi arid conditions, particularly in Tanzania. Specifically, records on the effect of shrub density and time of planting on soil moisture and crop yield in relay intercropping are virtually unavailable. Understanding the tree/shrub-crop moisture interaction process under relay intercropping will help exploit the potentials of this promising AF system for land-scarce semi arid areas to enhance sustainable crop yield for the benefit of resource-poor farmers. Secondly understanding how best the tree component of the system can be manipulated to minimize competition and optimize complementarity (Singh, *et al.*, 1989), will help sustain increased arable crop production in already exhausted arable land. The overall objective of this study therefore was to utilize a less land-demanding and moisture-conserving AF technology to improve maize yield in land scarce semi arid Gairo, Tanzania. The specific objectives were:

- To determine the effect of time of planting and spacing of *Tephrosia vogelii* on soil moisture status
- To determine the effect of shrub spacing and time of planting on components performance in the intercropping season
- To determine the effect of shrub spacing and time of planting on selected soil properties and crop performance in first and second seasons following intercropping.

CHAPTER TWO

2.0 LITERATURE REVIEW

Many earlier research works in AF carried out especially in Gairo have more heavily focused on the aspect of soil fertility improvement (i.e., addition of nitrogen (N) especially to the soil), fodder for animals, wood for fuel and construction purposes, and other direct benefits (Chamshama *et al.*, 1998; Fasuluku, 1998; Chingonikaya, 1999; Mgangamundo, 2000). Though much has been accomplished in these areas however, little or no consideration has been given to the most critical prevailing social factor- arable land scarcity and the inherent environmental factor of low soil moisture availability in the design of technology for this semi arid area. This study investigated the shrub-crop-moisture interaction using an AF technology that has the potential to transcend the social problem of arable land-scarcity for the benefit of land-starved farmers in semi arid Gairo, Tanzania.

The scope of this review is to consider the effect of tree/shrub-crop-moisture interaction in AF systems for semi arid conditions as a land management intervention and its effect on crop yield and shrub performance as well as mineral-N availability in both intercropping and after intercropping phases. These are presented in the following major sections: Semi arid condition (2.1), sustainable land-use and human population (2.2) tree/shrub-crop interaction in AF (2.3), *Tephrosia vogelii*- study species (2.4), and residual effects of tree-crop interaction (2.5).

2.1 Semi arid Condition

Semi arid zone has been defined as an area with a growing period ranging from 75 to 197 days with Entisols, Alfisols and Vertisols as main soil types (Deckers, 1993). Soils in the zone generally have low organic carbon (OC) and total nitrogen (N) concentration due to low biomass production and high rate of decomposition, and though N and phosphorus (P) are limiting in the soil, the low activity-clay of these soils has relatively low capacity to fix added P (Mokwunye *et al.*, 1996, cited by Bekunda *et al.*, 1997). Entisols are mainly composed of quartz and have low water-holding capacity and nutrient content; weakly structured and prone to water and wind erosion as well as leaching problems. Alfisols on the other hand, have a clay accumulation horizon and have low capacity to store plant nutrients, while Vertisols are characterized by high content of swelling clay with usually high fertility, except that P availability is generally low and high N losses occur under water-logging conditions (Brady, 1994; Bekunda *et al.*, 1997).

High atmospheric water demand, with a high mean annual temperature (>18°C) and low variable annual rainfall (400 to 900 mm) further characterize semi arid zone (Swindale, 1982). In the dry semi arid tropics in particular, rainfall usually exceeds potential evapotranspiration for less than 4.5 months of the year. Under such conditions, except where the water-holding capacity is adequately good, water content would be most often inadequate in soil for effective plant performance. Hence, from plant physiology perspective, Taiz and Zeiger (1991) defined arid and semi arid zones as areas in which plant transpiration totals only 50% or less of the transpiration that would occur with unlimited water availability. Low plants transpiration in plant physiology is quickly and directly translated as low biomass production (Lefroy and Stirzaker 1999), hence low yield as the process of photosynthesis depends on transpiration.

Geographically, semi arid tropics cover most of West and East and part of central Africa, most of India, northeastern Myanmar, northeastern Thailand and northern Australia; most of Mexico, and large part of eastern and central South America (Vandenbeldt, 1990). Global wise, semi arid zone covers about 18% of the earth's surface (UNSO/UNDP, 1997), while semi arid tropics cover an area of 20 million km^2, carrying a population of over 700 million people (Vandenbeldt, 1990). In Africa, semi arid zone covers about 21% (6,100,000 km^2) of land-mass (Corbett *et al.*, 1996 and UNSO/UNDP, 1997), taking 26% of the continent's human population (172,964,000) (Corbett *et al.*, 1996 and Tobler *et al.*, 1995).

2.2 Sustainable Land-use and Human Population

2.2.1 The concept of sustainability

The term sustainability is popular where development issues are discussed in present day life. Although it has been variously defined, the definition of Food and Agricultural Organization (FAO) seems to have gained acceptance most. In its non-simplified form, 'Sustainable agriculture and rural development is the management and conservation of the natural resource base, and the orientation of technological and institutional changes, in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development conserves land, water, and plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable, and socially acceptable' (FAO, 1995). The simplified version is much convenient: Sustainability is a land use system that meets the needs for production of present land users, while conserving for future generations the basic resources on which that production depends; put in a simple equation as: **Sustainability =**

Production + Conservation (Young, 1997). Production is placed first in the equation with the consideration that the priority of farmers is to meet their present needs for food and cash income.

For land use system to be sustainable requires conservation not only of soil but of the whole range of natural resources, including water, forests and pasture, though in arable land use the most direct and primary requirement for sustainability is the maintenance of soil fertility (Young, 1997) together with all its components (physical, chemical, biological, water, etc).

2.2.2 Traditional land use practices

When human population was relatively small, land was never a scarce resource and probably was never thought to be; landholdings were big enough, and hence arable soils were naturally replenished in fertility without cost by subjecting the site to idle fallow for a considerable period of time. The duration of such idle fallows depended much on the amount of land owned by or accessible to the user, but usually ranged from ten years and above. The practice is referred to as shifting cultivation characterized by slash and burn with relatively short period of cultivation. The practice was also used to control diseases, pests and stubborn weeds on site, and high crop yields were maintained (Nair, 1984).

Currently, the sustainability of the practice is seriously threatened by rapid population growth in tropical Africa especially where population density goes up to more than 1000 people per square kilometer in some places (Figure 1). Arable land holdings have drastically dwindled, fallow period has consequently been shortened and soils are no longer given time to recover sufficiently under this condition. As a result crop yields have continued to drop at alarming rates. Where the situation is desperately serious, marginal lands and reserves are cultivated, leading to more serious land degradation and loss of forest and valuable plant species (Baumer, 1990; Nair, 1993; Rao, 1993). A study carried out in Kondoa, Central Tanzania, for example revealed the ratio of cultivation to fallow period as 5:2 (Mugasha and Nshubemuki, 1988). With over 16 years since that report came out, the situation must be expected to be even more critical by this time with the current rate of population increase of 3.36 percent (United Nations, 1993), hence the need to seek suitable alternative systems of land use especially for tropical Africa. In this situation, AF offers a chance for small income farmers of the tropics, especially Africa.

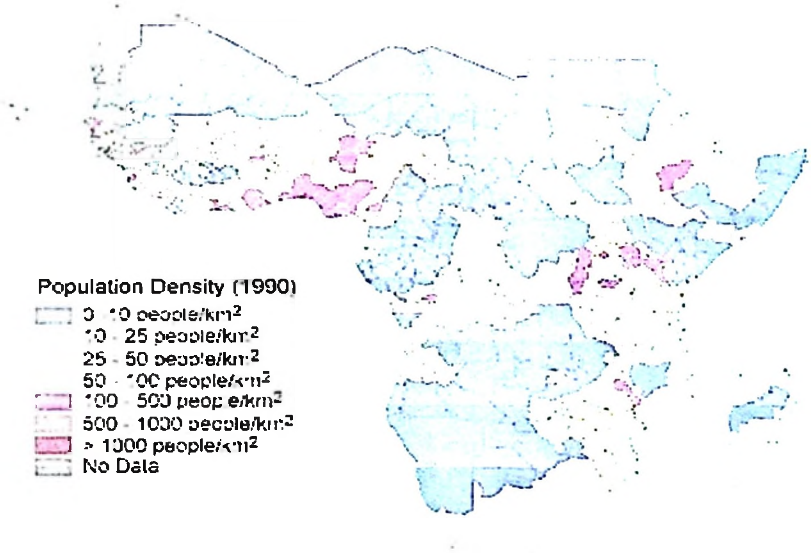

Figure 1: The distribution of population density in tropical Africa
Source: Brown and Gaston (1996)

2.2.3 Agroforestry as land use option

2.2.3.1 The concept of agroforestry

Agroforestry is defined as a dynamically, ecologically based, natural resources management system that, through the integration of trees in farmland and rangeland, diversifies and sustains production for increased social, economic and environmental benefits (Leakey, 1996, 1997) cited by Young (1997). This definition seems to have gained wide acceptance on the ground that it is more dynamic, in that it addresses in addition to sustainable crop yield, the three fundamental aspects of human life- social, economics and environmental.

The introduction of AF into farming systems was mainly aimed at providing a sustainable option to traditional shifting cultivation (Nair, 1993), which was then seen as losing ground in the face of growing human population. Although in practice AF is not new to farming system especially in the tropics, it however came into limelight of scientific research and discussions in the late 1970s (Bene *et al.*, 1977) cited by Young (1997). The design of AF technologies is strongly based on the hypothesis that trees with deep rooting systems can tap and transport nutrients upward from beyond the rooting zone of normal annual crops (Mekonen *et al.*, 1997). Hartemink *et al.* (1996) found lower subsoil nitrate and water in a *Sesbania* fallow than unfertilized maize monoculture and suggested that fast growing trees such as *S. sesban*, grown in rotation with annual crops can capture and recycle subsoil nitrate otherwise unavailable to shallow-rooted crops. Other studies have revealed that the presence of trees/shrubs on farm results in a better utilization of N and moisture in the soil, reducing the potential for nitrate leaching (Browaldh, 1995) and other ecological hazards. Owing to their deep and extensive rooting habit and N fixing ability too, many AF tree/shrub species can improve soil physical properties and increase fertility, thereby benefiting associated crops (Matta-Machado and Jordan, 1995). In improved fallow systems for example, trees are found to effectively increase soil organic matter (OM) content, recycle soil nutrients and improve both soil chemical and physical properties (Rocheleau *et al.*, 1988). Also by permitting the same piece of land to provide for food crop, wood and animal-based goods and services, maintain the productivity of farming systems, through soil erosion control and soil fertility enhancement (Young, 1986a, 1986b)

2.3 Tree-crop Interaction in Agroforestry

A better understanding and utilization of the outcome of the relationship (interaction) to both woody perennials (trees/shrub) and annuals (crops) and the relationship as a whole when they are grown whether in spatial or sequential arrangement is key to the success of all AF systems (Rao, *et al.*, 1998). Hence, interaction is defined as the effect of one component of the system on the performance of another component and/or the overall system (Nair, 1993).

2.3.1 Below ground tree-crop interaction in agroforestry

The fundamental hypothesis of AF stated earlier which often quickly stirs hope and excitement in interest groups is that the root systems of trees/shrubs and herbaceous crops or pastures occupy to some extent different soil strata when grown in association, leading to a degree of complementarity in the use of soil resources (Schroth, 1999). For this reason, rooting depth and the vertical distribution of root systems are of particular importance to AF. Most of the interactive processes that lead to competition or complementarity in AF systems are related to below ground interactions. It is in that regard Ong *et al.* (1992) points out that the opportunity for complementarity in the use of soil moisture especially, is likely to be limited unless the components species differ appreciably in rooting pattern and duration.

The above characteristic is much more crucial for spatial arrangements (Rao *et al.*, 1998; Ong and Leakey, 1999). Incidentally, the ability to form relatively deep root systems is not limited to woody perennials; annual crops such as maize do develop root systems of more than 1m deep in favourable conditions (Taylor, 1980). On the other hand, a study has shown that it is the rooting pattern beyond the tree canopy that is critical to the success of AF, suggesting that the ideal root morphology of species introduced for water management especially, would be a low root length density in the top soil with extensive lateral distribution below the rooting zone of annual plants (Lefroy and Stirzaker, 1999). The following are various environmentally influenced below ground plant orientations that may lead to successful tree-crop interaction in AF systems:

2.3.1.1 Compensatory root growth

Research has shown that the physical and chemical condition of the soil may largely influence the distribution of roots of component species (Schroth, 1999). Where there is dry, infertile or compacted soil zones restricting the growth of a portion of a root system, increased root branching may occur in the less restricted zones in the soil, a phenomenon referred to as 'compensatory root growth (Miller, 1986 In Schroth, 1999). Also through its water and nutrient uptake and possibly through allelopathic effect, one root system can cause restrictions to the development of another root system, thereby influencing its direction and distribution in the soil. A study involving apple trees (*Malus sylvestris*) in Britain shows that the closer the spacing of trees the more roots grew vertically into the soil instead of spreading horizontally near the soil surface indicating intra-specific competition in the top soil (Atkinson *et al.*, 1976). This was confirmed by Eastham *et al.* (1990) in Australia who observed that increasing tree density increased the subsoil water use in a silvopastural system, which may enhance increased nutrient uptake from the subsoil in other cases.

2.3.1.2 Vertical stratification of root systems

Vertical stratification is another form of root distribution between associated plant species in below ground interaction in AF system. This situation may be desirable in AF as it may result in reduction of overall root competition. The 'safety net' of tree roots below the root systems of associated crops refers to a situation of vertically stratified root systems, in which the tree roots absorb nutrients, which have not been taken up by the shallower-rooted crops and have therefore been leached out of the topsoil. In the coastal vegetation of California, root competition from an invading plant species with a very dense root system, *Carpobrotus edulis*, provoked the downward displacement of the root systems of two native shrubs, *Happlopappus ericoides* and *H. venetus* from 0-30 cm without competition from the invader to 20-50 cm with competition. Removal of the invader improved both the water relations and the growth of the shrubs (D'Antonio and Mashall, 1991).

From the above example and others, Schroth, (1999) suggests that for downward displacement of roots of associated species to occur four conditions must be fulfilled: 1) The root system of one species must be sufficiently competitive to be able to displace the root system of the other species, if not, the root systems will intermingle (this may be desirable though in leguminous cover crop-tree crop association); 2) the root system of the second (i.e., the displaced) species must be sufficiently flexible to respond to the restriction with compensatory root growth in depth; 3) root system of the first species must be sufficiently shallow so that the second species still exhibits lateral root spread below the root system of the first species and 4) the soil condition must permit root growth in depth, meaning that the subsoil must not be too compact, dry, infertile etc, in relation to the topsoil.

2.3.1.3 Spatial separation or segregation

Spatial separation or segregation is another mechanism used by associated plants to reduce competition and negative rhizospheric interactions between plants, but also the possibility of positive interactions. Spatial segregation or separation occurs when shallow-rooted crops take up water which has been hydraulically lifted into the topsoil by deeper-reaching tree root systems (Emerman and Dawson, 1996).

Other factors that influence interspecific root competition of associated plants include root length density, an important parameter in the acquisition of water and nutrients when the transport to the root other than the uptake into the root, is not the limiting step in resource acquisition (Eissenstat, 1992 In Schroth, 1999), root age, root diameter, presence of root hairs, physiological uptake characteristics, root exudates and root symbioses (Caldwell, 1994; Grayston *et al.*, 1996) cited by Schroth (1999).

From the foregone discussions, it goes without saying that the most important player in below ground tree/shrub-crop interaction is the root system of the component species. The various types of interaction are greatly influenced by the root system. Table 1 summarizes the types of below ground tree-crop interactions and tree desiderata.

2.3.2 Aboveground interaction

Aboveground interaction in AF is mainly related to sun light, growth space and air movement. A species which establishes an earlier advantage in light capture through more rapid initial shoot growth may also exhibit greater root growth and hence resource capture because of the increased availability of photosynthate. This may in turn improve shoot growth and light interception to the detriment of the less competitive species in the system (Ong, *et al.*, 1996). On non-acid soils where soil moisture deficiency is not a major limitation, competition between the woody component and the crop in intercropping system is mainly for light. In alley cropping with *Leucaena*, maize grown adjacent to hedgerows shows poorer performance than elsewhere in the plots because of the shading effect, especially where soil fertility is neither a limiting factor (Kang *et al.*, 1981).

If it happens that the annual crop exhibits such an advantage in an intercropping system, the whole purpose of the system will not be defeated; especially where the woody perennial component has the potential to recover considerably after the dominant annual crop is removed in relay intercropping for example. This is because for the farmer, increase in crop yield or at least maintaining it (if the woody component provides other benefits) is primary.

Table 1: Types of below ground tree-crop interactions and tree desiderata

Interaction process	Measure of effect	Tree desiderata for agroforestry systems	
		Sequential	Simultaneous
Competition for water	Positive crop response from tree root pruning especially in dry period, measurement of water flow in horizontally oriented proximal roots	-	Deep rooted trees
Modified water infiltration	Water infiltration rates with and without trees and/or tree mulch	-	Slowly decomposing tree mulch for erosion prevention
Hydraulic lift (water transfer to top soil)	Day-night cycles in soil water tension close to tree roots; water tracer movement	-	Deep rooted trees
Competition for N, P, K, etc.	Positive crop response from tree root pruning, esp. in dry periods	-	(Relatively) deep rooted trees
Vertical nutrient transfer to topsoil under the tree	Nutrient contents of pruning	Deep rooted trees	(Relatively) deep rooted trees
Horizontal nutrient transfer to topsoil under the tree	Nutrient contents of pruning	Efficiently scavenging trees	Rapid lateral spread; low root density, but large soil volume exploited
Arresting sediment flows (erosion control)	Biological terrace formation by contour plantings	Creating effective terraces as high fertility zones	-Non-competitive 'fertility traps'
Transfer of N etc. from root (nodule) turnover	Quantification of tree root nodules turnover	-	Rapid root decay (esp. after pruning)
Soil organic matter maintenance by root turnover, litterfall, etc.	Quantification of tree root turnover and litterfall, measurement of dead tree root decomposition rate	Abundant roots in topsoil rapid root turnover, high content of lignin/polyphenolics	-Rapid root turnover, high content of lignin/ polyphenolics
Facilitation of crop root growth in old tree root channels (overcoming constraints of soil density or Al toxicity)	Visual check of crop root positions in the soil profile	Deep rooted trees, slow decomposing tree exodermis	-
Stimulation of root symbionts such as VAM fungi	Crop root VAM infection percentages with or without trees	Common VAM fungal partners	Common VAM fungal partners
Stimulation of root pathogens and pests	Crop root damage with or without trees	Lack of common pathogens and pests	Lack of common pathogens and pests
Stimulation of soil fauna (e.g. earthworms)	Faunal activity in crop root zone with or without trees	Year round food supply, by high lignin/ polyphenolic content	

Source: Noordwijk *et al.*, (1996)

In general, effect of capture of growth resources by trees and crops in the tree-crop interaction, can be grouped into the broad categories of neutral, complementary or competitive interactions. In the neutral or trade-off category, trees and crops exploit the same pool of resources so that increase in capture by one species results in a proportional decrease in capture by the associated species. A complementary interaction results if for example the trees are able to tap resources unavailable to crops, resulting in an increase in the overall capture of the resources (Ong and Leakey, 1999). Where a serious reduction in the ability of one or both species to capture growth resources results from the interaction between associated species, it is competitive (or negative) interaction. In AF, the tree-crop interaction is liable to shift from one category to another depending on the age, size and population of the dominant species, as well as the supply and accessibility of the limiting growth resources (Ong and Leakey, 1999). The effect of tree-crop interactions in AF systems is often measured by: 1) the performance of component species (woody perennials and crops, in terms of biomass yield) and 2) changes in soil properties. For agrisilvicultural systems, increase in crop yield is the main priority. In other systems however, biomass yield of the woody perennial is equally important in influencing the yield of the associated crop. Table 2 shows how the aboveground biomass of both tree and crop are affected by the tree-crop interaction in two different systems (monoculture and intercropping) and varying management practices. From the table, it is noted that crop yields are higher in monoculture systems (i.e., absence of interspecies competition) than intercropped systems, while even within intercropped systems, where biomass yield of the perennial component was controlled (by pruning) annual crop component yields are higher than where it was not controlled. This demonstrates how the yield of one component affects the yield of the other in the association under low availability of limiting resource. Table 2 gives results of study conducted at Turkana, north-western Kenya, which is an arid area with Calcaric Fluvisols, as soil type and layer ranging from sandy to clayey in texture and soil pH between 8.2 and 9.2 (Lehmann *et al.*, 1998) cited by Droppelmann *et al.* (2000).

2.3.3 Agroforestry systems

An ecological analysis of the spread of various AF systems shows that the existence/adoption of an AF system in a given area is determined primarily by the ecological potential of the area, but socio-cultural and economic factors determine the complexity of the system and the degree of intensity of its management (Nair, 1989).

Depending on the main purpose to be served by a classification scheme, various criteria can be employed to classify the systems. The most common among these are the system's structure, functions, socio-economic scale and level of management and ecological (environmental) spread, and a classification scheme based on these approaches mentioned are summarized in Table 3. With respect to agrisilviculture in particular, two major categories distinguish the systems on the basis of components arrangement in time and space (Table 4), namely, simultaneous and sequential systems.

Table 1: Aboveground biomass yield of trees and annuals from the runoff agroforestry field trial in Turkana, NW Kenya

	Pruning of trees				No pruning of trees				Annuals as sole crop	One-Way-ANOVA	
	High density		Low density		High density		Low density			F-value	P-value
	Sole tree	Inter-cropped	Sole trees	Inter-cropped	Sole trees	Inter-cropped	Sole tree	Inter-cropped			
Fist pruning	5.0 (±1.6[1])	4.9 (±0.5)	3.4 (±1.2)	3.5 (±0.9)						1.75	0.234
Sorghum		5.3^a (±2.0)		5.7^a (±1.8)		0.7^b (±0.5)		1.4^b (±0.7)	6.6^a (±0.4)	13.30	0.001
Second pruning	3.7 (±1.8)	2.3 (± 0.9)	2.8 (±1.2)	1.8 (±0.4)						1.32	0.335
Cowpea		0.5 (±0.4)		0.6 (±0.3)		0.02 (±0.02)		0.2 (±0.3)	0.7 (±0.6)	4.10[2]	0.032[2]
Third pruning	1.2 (±0.9)	0.7 (±0.5)	0.8 (±0.2)	0.4 (±0.2)						0.84	0.508
Standing biomass yield of trees at final harvest	3.4^a (±2.1)	2.3^a (±1.5)	2.8^a (±0.8)	1.8^a (±0.6)	14.2^b (±3.3)	12.2^b (±1.2)	11.1^b (±2.5)	12.9^b (±5.5)		12.60	0.000
Total yield of trees	12.1 (±5.1)	9.6 (±2.9)	8.9 (±3.3)	7.1 (±1.8)	14.2 (±3.3)	12.2 (±1.2)	11.1 (±2.5)	12.9 (±5.5)		1.33	0.298
Total yield of annuals		5.8^a (±2.4)		6.3^a (±2.0)		0.7^b (±0.5)		1.5^b (±0.9)	7.3^a (0.9)	11.41	0.001
Total system yield (Trees and Annual where applicable)	**12.1** (±5.1)	**15.4** (±0.7)	**8.9** (±3.3)	**13.4** (±3.8)	**14.2** (±3.3)	**12.9** (±1.3)	**11.1** (±2.5)	**14.4** (±4.6)	**7.3** (±0.9)	**2.07**	**0.096**

Source: Droppelmann *et al.* (2000)

Note: Yields are in t ha^{-1}; same letters behind the values indicate no statistical difference between treatment means for Tukey (HSD) comparison of means at α=0.05 level after One-Way ANOVA; [1]± standard deviation; [2] On $\log_{10}$- transformed data

Table 3: Major approaches in classification of agroforestry systems and practices

Categorization Of Systems based on their structure and function			Grouping Of Systems based on their spread and management	
Structure		Function	Agro-Ecological	Socio-Economic And Management Level
Nature and arrangement of components especially woody ones		Role and/or output of components especially woody ones		
Nature of component	Arrangement of Components			
Agrisilviculture (crops and trees incl. Shrubs/trees and trees)	In space (Spatial) Mixed dense (e.g.: Home garden)	Productive Function Food	System in/for Lowland humid tropics	Based on level of technology input
Silvipastoral (pasture/animals and trees)	Mixed sparce (e.g.: Most systems of trees in pastures)	Fodder Fuelwood Other woods Other products	Highland humid tropics (above 1200 m a.s.l; e.g.; Andes, India, Malaysia)	Low input (marginal)
Agrosilvopastoral (crops. pasture/animals and trees)	Strip (width of strip to be more than one tree) Boundary (trees on edges of plots/fields)	Protective Function Windbreak Shelterbelt Soil conservation Moisture conservation Soil improvement	Lowland subhumid tropics (e.g.: savanna zone of Africa, Cerrdo of South America)	Medium input
Others (multipurpose tree lots, apiculture with trees, aquaculture with trees, etc)	In time (Temporal) Coincident Concomitant Overlapping Sequential (separate) Interpolated	Shade (for crops, animals and man)	Highland subhumid tropics (Tropical highlands) (e.g.: in Kenya, Ethiopia)	High input Based on cost/benefit Relations Commercial Intermediate Subsistence

Source: Nair, (1985) cited by Nair (1989)

2.3.3.1 Simultaneous agroforestry systems

From biophysical standpoint, simultaneous AF is a system in which the woody perennial component (tree/shrub) and the annual (crop) component both occupy the same piece of land at the same time; the spatial arrangement mentioned in the definition above, include systems like trees on cropland, hedgerow intercropping, intercropping in perennial-tree-crop stands and multistrata systems (Rao *et al.*, 1998). Probably the most popular example of simultaneous AF system is hedgerow intercropping in tropical AF, or alley cropping. The system was initially promoted in the 1980s for improving soil fertility in the humid and sub-humid tropics, where bush fallowing had been traditionally practiced for the same purpose (Rao *et al.*, 1998). It later attracted researchers and development organizations in other parts of the tropics for its combined benefit of tree fallow and continuous cropping characteristics. Other benefits of the technology were later realized to include fodder production and erosion control on sloping lands. Like other simultaneous systems however, hedgerow intercropping exhibits tree-crop interaction effects, especially those that affect crop yields and related to soil fertility, competition for growth resources, soil conservation and weed control. Nevertheless, it was found that the nature and extent of interaction varies greatly with climatic conditions from semi arid to sub-humid and humid (Rao *et al.*, 1998) (Table 4).

The narrow hedgerows spaced at distances recommended for the humid and sub-humid tropics (i.e., 4 m), have been particularly found to be competitive with crops in the SAT. Ignoring yield increase of less than 15 percent as unattractive to farmers, Rao, *et al.* (1998) found that only two out of ten studies in semi arid sites (<1000mm rainfall) gave substantial yield increases confirming location-specificity of system performance.

Systematic decrease in grain yields of millet with age of hedgerow from 17% in first year of *Leucaena* hedgerow to 80% in the fifth year has been reported in semi arid India (Singh *et al.*, 1989a). Competition for soil water was the main suggested cause for the drop in yield of millet. Outside the tropics, a study of competition for water in an alley cropping system consisting of pecan (*Carya illinoensis*) and cotton (*Gossypium hirsutum*) in Florida, USA, yield of 677 kg ha^{-1} from root barrier treatment (similar to yield in sole crop stand) and 502 kg ha^{-1} from non-root barrier treatment have been reported (Wanvesttraut *et al.*, 2004); thus suggesting competition for soil water as cause of loss in yield in alley cropping.

Table 4: Net effect on crop yield of tree-soil-crop interactions in hedgerow intercropping systems in different climates, assuming a moderately fertile soil

Processes	Semiarid	Subhumid	Humid
Nutrient availability to alley crops	Positive (S-L)	Positive (L)	Positive (L)
Soil chemical changes	Positive (S)	Positive (S)	Positive (L)
Soil physical changes	Positive (S-L)	Positive (S-L)	Positive (S-L)
Soil biological changes	Neutral	Positive (S-L)	Positive (L)
Soil conservation	Positive (S-L)	Positive (L)	Positive (L)
Water availability to alley crops	Negative (L)	Neutral/negative (S)	Neutral
Shading	Neutral	Negative (S)	Negative (L)
Microclimate changes	Positive (S/neutral)	Neutral	Neutral
Weed suppression	Positive (S)	Positive (L)	Positive (L)
Crop yield	Negative (S-L)	Positive (S-L)	Positive (S-L)

Source: Rao *et al.* (1998).
S= small, L= large

2.3.3.2 Sequential agroforestry systems

In sequential arrangements of AF system, the component species follow one another in time on the cultivated land, the most popular example being improved fallows (IF). In IF selected tree (or herbaceous perennial) species are planted or retained from natural regeneration with some level of management (Rao, *et al.*, 1998).

With regards to planted fallows, two categories can be distinguished: 1) short-duration fallows with fast growing, leguminous trees or shrubs established primarily to replenish soil fertility that supports food crop production, the category that this review addresses. 2) Medium- to long-duration fallows with diverse species established for amelioration of degraded and abandoned lands as well as for utilization of tree products. Planted fallows are an improvement to natural fallows in that the objectives for which natural fallows have traditionally been practiced are to be attained in a shorter time through manipulation of management operations including choice of tree species, spacing, establishment and cultural practices like weeding and pruning.

Based on the changes that occur in the rotation system of tree/shrub fallows followed by crops, three main phases can be distinguished; these include: 1) restoration (or fallow) phase in which the fallow accumulates nutrient in its standing biomass through biological gains from processes such as biological N fixation and recovery of lost nutrients from depths beyond the reach of annual crops roots, suppress weeds and pathogens, and improves other soil properties. 2) Nutrient transfer (or fallow clearing) phase in which nutrient stocks in biomass are added to the soil through fallow clearing and incorporation, and 3) biomass degradation (or cropping) phase in which nutrients are depleted through crop harvests, weeds and pests may also increase and general soil condition deteriorate (Rao, *et al.*, 1998). Whether the fallows are cleared by slash-and-burn or slash-and-mulch (most commonly recommended by researchers) methods, this system has been widely reported to have improved soil fertility and crop yield, as well as supply most needed forest products in many parts of the tropics (Onim *et al.*, 1990; Torquebiau and Kwesiga, 1996; Mgangamundo, 2000). In eastern Zambia, Phiri *et al.*, (2003) reported 265 and 201 percent increase in maize grain yield in first and second cropping seasons respectively following two year *S. sesban* fallow (Table 5).

Table 5: Stover, grain, and total aboveground biomass yields of maize in the different cropping systems during two cropping seasons at Msekera in eastern Zambia

Cropping systems	1998 – 1999 season			1999 – 2000 season		
	..............................($t\ ha^{-1}$)					
	Stover	Grain	Total biomass	Stover	Grain	Total biomass
2ss/M	4.86	3.07	8.50	6.51	2.98	9.49
M+F	6.93	6.14	13.07	9.14	6.01	15.16
M-F	2.55	1.16	3.97	4.82	1.48	6.30
'F' Probability	≤0.01	≤0.01	≤0.01	≤0.05	≤0.05	≤0.01
$LSD_{(0.05)}$	1.27	1.58	3.06	3.29	1.54	4.40

Source: Phiri *et al.*, (2003)

2ss/M=maize after 2 years *Sesbania* fallow, M+F= Continuous maize with fertilizer, M-F= Continuous maize without fertilizer.

In the absence of severe arable land scarcity, sequential AF systems offer an opportunity for exploiting the potential soil ameliorative attributes of trees for enhancing crop production (Rao, *et al.*, 1998). Hence all things being equal it is safe to say that planted fallow systems suit the semiarid tropics most, owing to the inherent problem of soil moisture deficiency that seems to hinder the success of hedgerow intercropping systems in the region.

However, all things are never always equal, as in areas where arable land is in short supply either due to high population density or due to expansion of cultivated land resulting from increases in market demand for agricultural produce or the desire to increase cash income with cash crops, the adoption of the practice is seriously constrained, thus necessitating the need for less land-demanding and moisture-conserving AF systems for land-scarce semiarid areas.

2.3.3.3 Semi-simultaneous systems

Two AF systems most ideally fit the category of semi-simultaneous systems. These are rotational woodlot and relay intercropping. Rotational woodlot technology involves growing trees and crops on farms in three inter-related phases: 1) an initial tree establishment phase in which trees are intercropped with annual crops (similar to hedgerow system), 2) a tree fallow phase (the idle fallow phase similar to planted fallow system) and 3) a cropping phase after harvest of trees (Nyadzi, 2004). Since the former shares in very large extent the features of both simultaneous and sequential AF systems, which have already been discussed, the latter is instead discussed in this review.

There are two forms of relay intercropping. In the first, the trees are planted at the same time with the last crop in the cropping cycle, giving a 'flying start' to the fallow. In the second, the trees are planted annually, with no loss of crop space or time at all; after crop harvest, the trees continue to grow through the dry season, making use of resources of groundwater and radiation, and are then cut and non-woody residues left on the soil prior to the next cropping season (ICRAF, 1993; Young, 1997).

Relay intercropping technology may not be as popular as hedgerow intercropping and IF especially in semi arid tropical Africa nevertheless; it is in research and practice. Relay intercropping combines features of both simultaneous and sequential systems though to a lesser extent than rotational woodlot does. Therefore it does not transcend the problem of competition (a feature of simultaneous systems). Depending on the rooting pattern and vigour of the tree/shrub component of the system, interaction may result in competition or complementarity for available resources, especially moisture in semiarid areas (McIntyre *et al.*, 1997). Therefore the careful selection of the tree/shrub component (with respect to the above properties), and proper management techniques (which take into account appropriate time of planting and density or spacing of tree component) are extremely important for the success of relay intercropping in semi arid areas like all other intercropping systems (Rao *et al.*, 1990).

Careful selection and management of trees/shrubs to meet the desired qualities in turn depends on the proper understanding of the rooting pattern of the species concerned. The duration of the crop component is also of great importance, as short-duration crops relative to the tree component are required for successful interactions in relay intercropping.

The positive effects of relay intercropping as an AF system have been documented by a number of authors. Fasuluku (1998) reported that relay intercropping of *S. sesban* and maize resulted in fire wood production of 2.53 t ha^{-1}. Soil N mineralization too tends to increase in soils under relay intercropping (ICRAF, 1995; Fasuluku, 1998). An increase by 10.2% in soil mineral-N under relay intercropping of *S. sesban* and maize has also been reported (Fasuluku 1998). Relay intercropping in different trials has been found to increase maize grain yields (Table 6) in tropical Africa including Tanzania (Otsyina *et al*, 1994; ICRAF, 1995; Fasuluku, 1998).

Table 6: Some results of the effect of tree/shrub-crop intercropping on maize grain yield

Tree/shrub species	Yield (t ha^{-1} year^{-1}) 1	2	3	Source
S. sesban	0.53	2.73	-	Fasuluku (1998)
A. nilotica	1.0	1.5	0.4	Otsyina *et al.* (1996)
A. polyacantha	1.2	1.5	0.4	"
F. albida	1.9	0.5	-	Chamshama *et al.* (1994)
L. leucocephala	1.5	1.10	0.40	Otsyina *et al.* (1996)
T. candida	3.42	2.84	4.86	Chilimba *et al.* (2004)
T. vogelii	1.73	3.22	3.62	"
G. sepium	0.99	-	5.27	"

2.4 Study Species - *Tephrosia vogelii* (F) Hook

Tephrosia vogelii is a soft-woody nitrogen-fixing legume 1-4 m tall, belonging to the family Fabaceae (Milne-Redhead and Polhill, 1971). It is short-lived, slow growing and frost susceptible perennial shrub. It is widely distributed and adapted to dry and moist tropics (500-2500 mm rainfall), and altitude up to 2100 m a.s.l, temperatures ranging from 12.5 to 26^{0}C (Milne-Redhead and Polhill, 1971). In East Africa it is widely used as fish poison, but elsewhere it has been discovered to be a potential source of rotenone, an important non-residual insecticide (Ibrahim *et al.*, 2000). In some farming communities in Tanzania, it is already been used for control of storage pests in maize and beans. However, because of its high N fixing ability, slow growing, high biomass production and efficient nutrient uptake, the species is being also planted in fallow land (Rocheleau, *et al.*, 1988).

The flower is typically papilionaceous, about 2 cm across, and purple with white markings or white. The flowers are borne on compact racemes that bloom over a 3- to 4- week period and there may be 20 to 30 flowers per raceme with up 200 flowers per plant (Gaskins *et al.* 1972). The flowers have a faint but definite pleasant aroma and bees are common quests to them for both necta and pllon. Pods usually contain 8 to 16 seeds and seed yield per plant ranges from 1.0 to 9.0g depending on plant density (Barnes and Freyre, 1969).

In observation plots at Kagasa, Rwanda, a 1-year *Tephrosia* fallow produced 2.6 t ha^{-1} of foliage and 9.5 t ha^{-1} of woody stems at harvest (Balasubramanian and Sekayange, 1994). In Kenya, maize grain yield of 4.16 - 4.85 t ha^{-1} was obtained following 12 months fallow with *Tephrosia* (Niang *et al.*, 1996). In a decomposition experiment at SUA Farm in Morogoro, Tanzania, Fasuluku (1998) recorded highest initial concentration of P and second highest concentration of N in *T. vogelii* compared with *Albizia lebbeck*, *Gliricidia sepium*, *Senna siamea* and *S. sesban*. The same trend was revealed in N and P released from decomposing biomass in the same experiment. In an improved fallow trial of 1, 2 and 3 years at Gairo, Tanzania, with three shrub species (*S. sesban*, *C. cajan* and *T. vogelii*), *Tephrosia* showed the least total biomass yield, but highest maize yield (Mgangamundo, 2000). The same study also revealed that yield can be maximized with half recommended dose of N fertilizer and full dose of P fertilizer following *Tephrosia* fallow. Relay intercropping involving *Tephrosia vogelii* may have a unique advantage over many other species for semiarid conditions in that it is less vigorous in growth, hence its competitive ability may not pose serious threat to associated crop as others would. The performance of the shrub in terms of biomass yield under various trials is documented (Table 7).

Table 7: *Tephrosia* performance in improved fallow trials of different durations and places

Place	Duration (years)	Survival (%)	Foliar/ above -ground biomass (t ha^{-1})	Small root biomass (t ha^{-1})	Surface litter (t ha^{-1})	Total biomass (t ha^{-1})	Source
Zambia (mean of 14 provenances)	1.5	73	0.52[1]	nd	2.45	10.04	Mafongoya *et al.* (2003)
Kenya	0.5	nd	5.30[2]	0.336	1.0	9.5	Rutunga *et al.* (1999)
Tanzania	1.0	97	2.11	nd	nd	5.44	Mgangamundo (2000)
Tanzania	2.0	94	4.11[1]	nd	nd	8.9	"

[1]Foliar biomass; [2]Aboveground biomass

2.5 Residual Effect of Tree-crop Interaction

With either sequential system or a semi-simultaneous system, the expectation is always on how the system would affect the subsequent crops, which is usually a reflection of how it affects the soil. For sequential systems like IF, the success of the system is only measured from the performance of the crop that follows the harvest of trees and the changes in soil properties. On other hand the success of simultaneous and semi-simultaneous systems is measured first in the intercropping season, when the performances of the component species are assessed, and then in the season(s) that follow after removal of trees, when soil properties and crop performance are assessed. The performance of the system after the removal of the tree component of either sequential or semi-simultaneous system is the residual effect (Young, 1997).

The primary purpose of AF interventions is the speedy attainment of the objectives of traditional shifting cultivation and bush fallow, in which the farmer benefits from all the positive effects of tree on farmland. Usually also, the residual effect of the system will depend very much on the performance of the system especially with respect to the tree/shrub component during fallow or intercropping phase as depicted in Table 8. The foliar and root biomass yield and quality of the biomass of the woody perennial component is what largely determines the extent of residual effect (Young, 1997; Mafongoya *et al.*, 1998 and Mafongoya, *et al.*, 2003).

Table 8: Shrub performance and soil nutrient status and maize grain yield in two subsequent seasons to two-year fallow of *Tephrosia* provenances in Zambia

Provenances	Survival (%)	Leaf + twig	Stems	Surface litter	Total biomass	NO_3-N	NO_3 + NH_4-N	Grain 2000-2001	Grain 2001-2002
		......................t ha^{-1}			....	.... ($\mu g\ g^{-1}$)......		......t ha^{-1}.....	
T. vogelii 98/04	81	0.6	9.1	1.5	11.2	1.8	6.9	0.5	0.8
T. vogelii 02977	83	0.7	5.5	0.5	6.7	1.2	5.5	0.4	1.0
T. candida 02970	83	0.9	13.4	3.3	17.6	4.9	14.1	0.6	1.4
T. candida 02971	85	1.4	10.4	3.3	15.1	2.9	11.8	0.7	1.2
T. candida 02972	73	1.3	18.0	3.4	22.7	2.7	12.6	1.0	1.6
T. vogelii 02973	85	0.3	5.3	2.9	8.5	1.6	7.6	0.7	1.0
T. vogelii 02974	65	0.3	6.0	3.2	9.4	2.0	10.2	0.4	1.3
T. vogelii 02976	65	0.4	4.3	1.4	6.1	1.8	6.6	0.6	1.3
T. vogelii 02975	69	0.3	6.5	2.0	8.8	1.1	7.1	0.6	0.8
T. vogelii 98/03	56	0.2	6.1	1.5	7.8	2.1	6.8	0.5	1.2
T. vogelii 98/01	56	0.2	5.5	1.6	7.3	2.3	10.7	0.6	0.8
T. vogelii 00031	83	0.4	6.2	2.5	9.1	1.0	6.5	0.6	0.8
T. vogelii 98/02	58	0.1	2.5	1.6	4.1	1.0	5.2	0.2	0.7
T. vogelii 98/05	79	0.2	4.5	1.4	6.2	0.9	6.6	0.3	0.6
SED	11.6	0.3	2.7	1.2	3.4	1.0	3.5	0.4	0.4

Source: Mafongoya *et al.*, (2003)

SED= Standard error of difference between means.

2.5.1 Decomposition of biomass and nutrient release in residual phase

Organic materials are made of elements and substances, which form plant nutrients. These elements and substances are often released into available forms in the soil upon decomposition of the organic materials. The process of decomposition is complex, and it is often regulated by interactions between organisms (fauna and microorganisms), physical environmental factors (particularly temperature and moisture) and the resource quality (defined by lignin, N and condensed and soluble polyphenol concentrations) (Swift *et al.*, 1979). The major constituent of plant material include cellulose (15-60% of dry weight), hemicellulose (10-30%), water solubles (i.e. simple sugars, amino acids and aliphatic acids range between 5 and 30% of tissue weight), ether and alcohol solubles containing fats, oils, waxes, resins and a number of pigments and proteins having in their structures much of the plant N and P (Alexander, 1961). Among these constituents, N is the key nutrient substance for microbial growth and activity, hence organic matter breakdown (Alexander, 1961; *Tisdale et al.*, 1990). Microbial action may either lead to mineralization or immobilization depending on the C/N ratio of the decomposing material (Handayanto *et al.*, 1995). The critical C/N ratio and initial N concentration were found to be 20:1 and 1.5-1.7% respectively (Tisdale *et al.*, 1990; Handayanto *et al.*, 1995).

Generally, high quality organic material (litter) refers to those having high N (protein) and low C (carbon) contents and fast decomposing. Whereas woody residues and other lignified (i.e. of high lignin content) materials and those having high C/N ratio, high fat and wax contents and slow decomposing, are referred to as low quality litter (Constantinides and Fownes, 1993; Nair, 1993). However, in addition to these common factors known to be influencing rate of decomposition, lignin plus polyphenol (PP):N ratio has been found to affect the quality of biomass (Mafongoya *et al.*, 1998). The critical level of lignin plus PP:N ratio for good N release is 3.5, above which immobilization of N is expected (Palm *et al.*, 2001). Nevertheless, N release may still proceed rapidly with higher than critical level depending on the quality of PP, which is a measure of their protein-binding capacity (Palm *et al.*, 2001, Mafongoya *et al.*, 2003). In a trial involving N release in *Tephrosia vogelii* and *Tephrosia candida* provenances in Zambia, Mafongoya *et al.*, (2003) reported rapid N release between second and sixth weeks of incubation while lignin + PP: N ratios were still above the critical 3.5 level (Table 9).

Although fast decomposition is a desirable quality according to the above definition, it is however undesirable when considered in the context of effective nutrient utilization from green manure in areas where climatic factors already favour rapid decomposition. Rapid decomposition and nutrient release in AF systems often results in nutrient leaching and inefficient utilization by crops (Browaldh, 1995), if release and uptake are not properly synchronized. Therefore, AF tree/shrub species that exhibit good N fixing and other soil improvement qualities will be superior if their litter decomposition process proceeds less rapidly especially in high humid tropical regions.

Table 9: Quality characteristics of biomass from *Tephrosia vogelii*, *Tithonia diversifolia* and natural fallow

Quality grouping	Plant parts	N (g kg^{-1})	Lignin (L)(g kg^{-1})^3/ (%)^4	Polyphenol (PP) (g kg^{-1})	PP:N Ratio	(PP+L):N ratio	Source
High quality materials	Ti^5 leaves	27-30	170	15.6	0.5	5.6	Rutunga *et al.* (2001)
	Te^6 leaves	23-29	125	26.2	1.0	5.8	
	Te roots	25-30	114	7.1	0.2	4.2	
Medium quality materials	Ti mixture	19-23	164	11.2	0.5	8.2	"
	Te mixture	19-22	150	21.1	1.0	8.3	
	Ti stems	19-24	145	10.9	0.5	7.1	
Low quality Material	NF^7 leaves	9-15	85	10.2	0.7	7.0	"
	Ti roots	11-13	136	23.9	2.0	13.5	
	NF roots	11-15	115	5.1	0.4	9.7	
	Te stem	10-15	120	8.0	0.7	11.3	
-	Te leaves	3.01	8.5	5.38	nd	nd	Mafongoya *et al.*, (2003)
-	Te whole plant	2.85	8.3	2.37	nd	nd	Hagedorn *et al.*, (1997)
-	So^8 leaves	2.25	5.3	0.41	nd	nd	"
-	So stems	0.35	6.4	0.53	nd	nd	"

^{3}Unit of first ten data; ^{4}Unit of last two data; ^{5}*Tithonia diversifolia*; ^{6}*Tephrosia vogelii*; ^{7}Natural Fallow; ^{8}Sorghun; nd= no data

In a decomposition study carried out at SUA farm, in Morogoro, Tanzania, using green manure from, *S. sesban, T. vogelii* and *G. sepium,* the least decomposition rate was recorded for *T. vogelii (*Fasuluku, 1998*)*. At Gairo, Tanzania, highest maize was obtained from *T. vogelii* plots in the second residual season following the clearing of 1, 2, and 3 year improved fallows of *S. sesban, G. sepiun, C. cajan* and *T. vogelii* (Mgangamundo, 2000).

CHAPTER THREE

3.0 MATERIALS AND METHODS

This chapter is presented in two main sections, namely: Description of study site (3.1) and experimental procedures (3.2).

3.1 Study site description

3.1.1 Location

This study was carried out at Gairo village ($36^0 45'$E, $6^0 30'$S; 1200 m. a.s.l.), in Kilosa District, Morogoro Region, Tanzania. Gairo is located nearly halfway along the Morogoro-Dodoma Highway (140 km from Morogoro Municipality and 130 km from Dodoma) (Chamshama *et al.*, 1994).

3.1.2 Vegetation

The original vegetation of the study area as indicated by the remaining vegetation was miombo woodland consisting mainly of shrubs and few scattered trees dominated by species such as *Acacia, Brachystegia, Julbernadia* and *Isoberlinia* (Chamshama *et al.*, 1994).

Figure 2: Arable landscape during cropping season in semiarid Gairo, Tanzania

Note: Besides the few remaining scattered shrubs and trees in this figure, the rest of the vegetation is crop, mostly maize, except on the very top of hills and cliffs.

The remaining vegetation clearly shows sign of severe pressure from human activities and exploitation, as the entire landscape is over 90 percent arable land actively under cultivation (Fig. 2). The only uncultivated areas are truly marginal and unsuitable for profitable crop production, as they appear mostly rocky hills and cliffs with very steep slopes. These are primarily used to graze animals. This is not surprising since the main occupation of the local population is arable farming, cultivating predominantly maize and sweet potatoes, and is among the main suppliers of these produce to the towns and cities in the country and even abroad.

3.1.3 Soils

The experimental site acquired from local farmers had been under long period of maize cultivation without any deliberate external inputs of any form of fertilizer and hence yields are generally reported to be low. The soil is generally classified as Haplic Lixisols (Msanya and Msaky, 1994). The initial site status with respect to selected physical and chemical properties as revealed by initial characterization preceding the experiment is summarized in Table 10. The data shows that the soil is largely sandy loam to sandy clay down to the depth of 120 cm and the pH indicates moderately acidic with very low organic matter content and very low available N and P, and bulk density is between 1.34 and 1.41 g cm^{-3} indicating some compaction. Based on the general soil fertility standard of characterization, the site can be described as very poor in fertility, especially with respect to some chemical properties such as total nitrogen, available phosphorus and organic carbon (Table 11).

Table 10: Initial soil properties of experimental site, Gairo, Tanzania

Soil Properties	Soil depths (cm) 0-10	10-20	20-30	30-50	50-80	80-120
Total nitrogen (%)	0.17* (0.05)	0.15 (0.03)	0.13 (0.04)	0.12 (0.04)	0.11 (0.04)	0.10 (0.06)
Total organic Carbon (%)	0.84 (0.07)	0.73 (0.03)	0.63 (0.09)	0.50 (0.06)	0.33 (0.09)	0.24 (0.05)
Available P (ppm)	3.90 (0.77)	2.46 (0.71)	2.26 (1.13)	0.875 (0.46)	1.08 (0.34)	1.00 (0.58)
E/conductivity (mS cm^{-1})	0.05 (0.01)	0.04 (0.01)	0.03 (0.00)	0.04 (0.01)	0.04 (0.00)	0.04 (0.00)
pH	5.88 (0.04)	5.69 (0.11)	5.57 (0.09)	5.59 (0.05)	5.58 (0.11)	5.47 (0.10)
Bulk density (g cm^{-3})	1.34 (0.05)	1.36 (0.04)	1.38 (0.02)	1.40 (0.39)	1.43 (0.07)	1.41 (0.07)
Sand (%)	74.35 (2.48)	73.35 (2.62)	74.407 (1.91)	63.80 (5.35)	59.54 (4.08)	55.37 (0.91)
Silt (%)	5.86 (0.67)	4.79 (0.32)	4.62 (1.16)	6.94 (3.35)	4.91 (0.98)	4.59 (1.39)
Clay (%)	19.79 (1.62)	21.86 (2.64)	23.99 (1.91)	30.19 (0.75)	35.54 (3.37)	40.04 (1.97)
Texture	Sandy loam	Sandy loam	Sandy loam	Sandy clay loam	Sandy clay	Sandy clay

* Mean of three replicates with standard deviation in parenthesis

Table 11: Selected soil chemical and physical properties for characterizing soil fertility status

Soil properties	Range of value	Comments	Soil properties	Range of value	Comments
N (%)	> 1.0	Very high	OC (%)	> 20	Very high
	0 5 – 1.0	High		10 – 20	High
	0.2 – 0 5	Medium		4 – 10	Medium
	0.1 – 0.2	Low		2 – 4	Low
	< 0.1	Very low		< 2	Very low
AVP (ppm) by resin			CEC (me/100g		
extraction	13 - 22	Adequate	of soil)	> 40	Very high
	6 5 – 13	Marginal		25 – 40	High
	3 – 6 5	Deficient		15 – 25	Medium
	< 3	Acutely deficient		5 – 15	Low
				< 5	Very high
Infiltration rate					
(cm h^{-1})	< 0.1	Too slow	pH (H_2o)	4 0 – 4.5	Extremely acidic
	0.1 – 0.3	Unstable		4.5 – 5.0	Very strongly acidic
	0 3 – 6 5	Main stable range		5.0 – 5.5	Strongly acidic
	6.5 – 12 5	Marginal		5 5 – 6.0	Moderately acidic
	12.5- 25.0	SSC		6.0 – 6.5	Slightly acidic
	>25	OHI		7.0	Neutral

Source: Metson (1961), FAO (1979) in Landon, J. R. (1991).

OHI = Overhead irrigation, suitable for special case, SSC =Suitable in special case

3.1.4 Rainfall

Generally, rainfall is erratic and poorly distributed in this area, varying from year to year, most often interspersed with long periods of droughts ranging from a couple of days to several weeks; even a month and more has been reported.

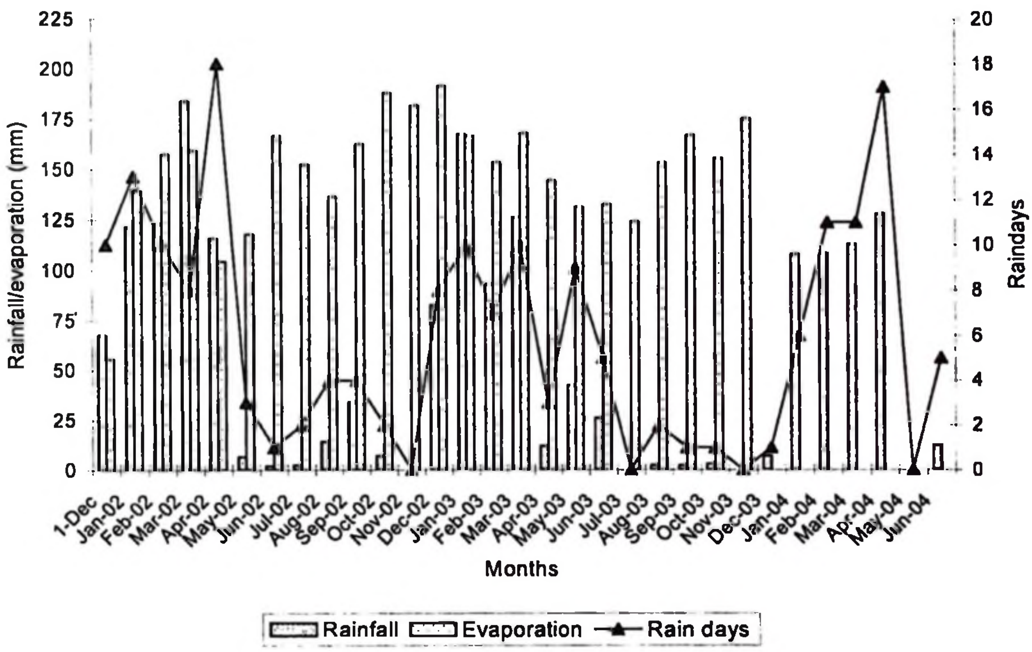

Figure 3: Rainfall distribution along with evaporation for three cropping seasons (2001/2002 – 2003/2004) at experimental site in Gairo, Tanzania.

Note: data collection ceased after harvesting crop in June 2004 and the last season evaporation data was not obtained.

Recent rainfall data before this experiment is unavailable, however, annual average rainfall up to the year 1994 is around 449 mm, most of which fell between November and May (Chamshama *et al.*, 1994). A mini weather station set up along with this experiment provided current rainfall data from 2001/2002 to 2003/2004 (Fig. 3).

The period January – April is considered the main growth period for the maize crop at Gairo as most of the rain falls within this period. Most maize varieties grown in this area are harvested within five months, and are usually planted between December and January depending on the promptness of the rains. In the first year of this study, i.e., 2001/2002 cropping season, fairly good amount of rain was received with a total of 617 mm and fairly well distributed with no month receiving less than eight rain days between December 2001 and April 2002 (Fig. 3). The second and third seasons did not receive good amount of rain, and distribution was equally poor with totals of 469 and 454 respectively, interspersed with long drought periods.

3.2 Experimental Procedures

3.2.1 Effect of relay intercropping on soil water content and maize and *Tephrosia* biomass yields in intercropping season

3.2.1.1 Experimental design and treatments

The experiment was established in December 2001 in split plot layout with three replications. The major plot treatments were time of planting *T. vogelii* in relation to time of planting maize crop, which had three levels, and minor plot was spacing of *Tephrosia* also with three levels plus control (sole maize).

The treatments were designated as follows:

i) Main plot treatments (3 levels of time of planting shrub)

- T1 = Week0 (wk0) i.e. shrub planted at the same time of sowing maize
- T2 = Week2 (wk2) i.e. shrub planted two weeks after sowing maize
- T3 = Week4 (wk4) i.e. shrub planted four weeks after sowing maize

ii) Minor plot treatments (3 levels of spacing of shrub + control)

- S0 =Tv0 (sole maize) i.e. maize without interplanting with shrub or control
- S1 = Tv30 (shrub planted at 30 x 90 cm) intra- and inter-rows spacing
- S2 = Tv60 (shrub planted at 60 x 90 cm) "
- S3 = Tv90 (shrub planted at 90 x 90 cm) "

Adjacent and concurrently with the above layout was laid additional plots as an extension of minor plots for *Tephrosia* monoculture stands, designated as follows:

- S4 = Tvm30 (shrub planted at 30 x 90 cm) intra- and inter-row spacing
- S5 = Tvm60 (shrub planted at 60 x 90 cm) "
- S6 = Tvm90 (shrub planted at 90 x 90 cm) "

3.2.1.2 Establishment and management of experiment

The installation of a mini meteorological station at the experimental site preceded closely the establishment of the experiment. The aim was to capture such weather parameters as rainfall, temperature, relative humidity and evaporation rate, as the nearest weather station is located 50 km away from the experimental site in an area where the annual average rainfall sometimes varies from that of the experimental site. Weather data were collected on daily basis since its installation in December 2001 up to the end of the experiment in June 2004.

The experimental site was ploughed and harrowed, followed by layout and subsequent planting of crop and shrub at the on-set of rains in December 2001. Three major plots were laid in each block; each major plot measured 14.8 x 17.5 m, length by breadth respectively, laid along contours. Distance between major plots within block was 4 m and between blocks 4 m (Fig. 4). Each main plot was split into four minor plots separated by 2 m distance. The minor plots measured 9.2 x 4.5 m each.

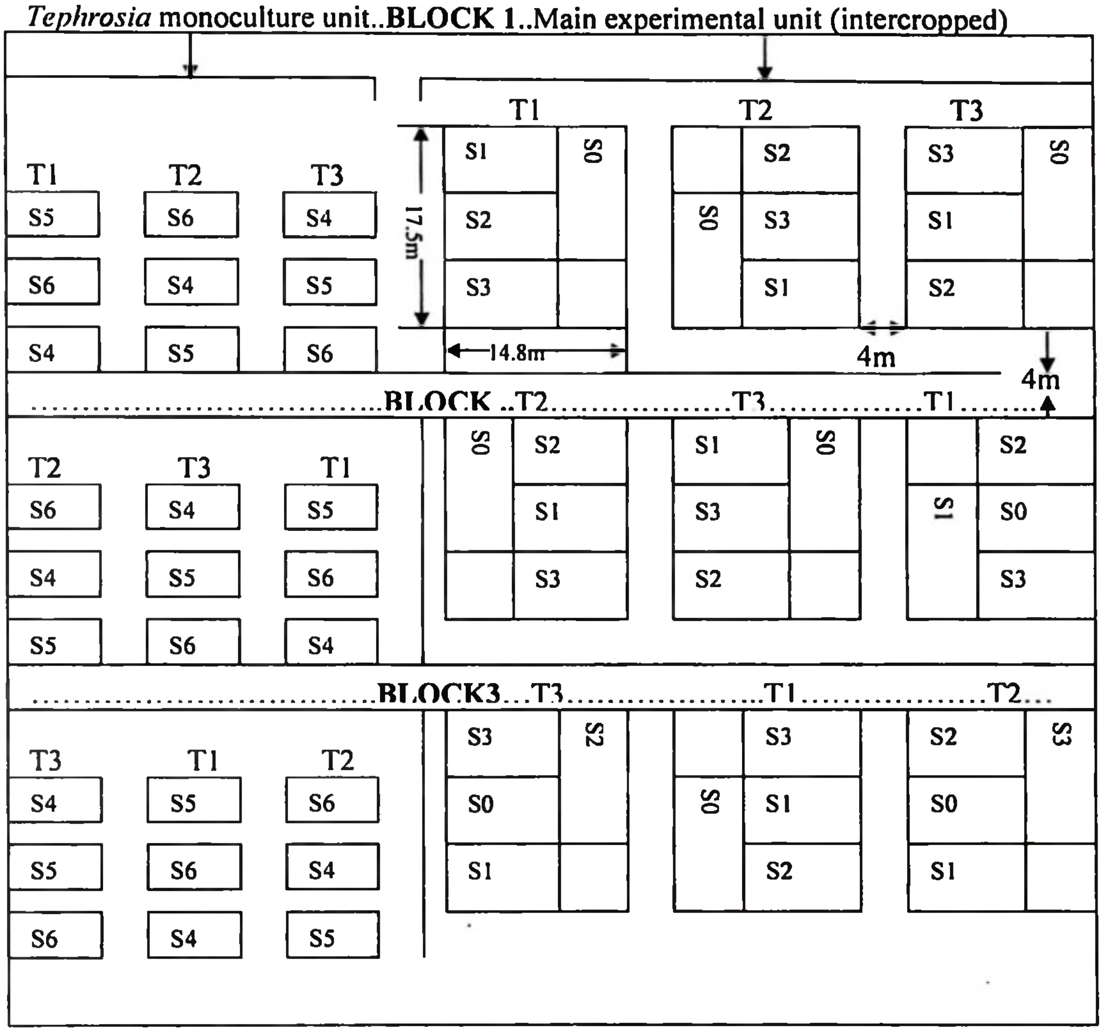

Figure 4: Schematic layout of experimental site showing main unit and sub-unit

Note: Distance between main plots is 4m and between minor plots 2m for both main experimental unit and monoculture *Tephrosia* plots, and minor plot size is the same in both units

Along side this layout, about 10 m away, the exact replica of the above experimental design was laid out. This served for destructive sampling purposes in order to avoid serious disturbances in the main experimental unit, meant for long period assessments. All destructive sampling in the first cropping season were done in this unit. Treatments were allocated systematically ensuring that no treatment occurs more than once in a row or column.

Maize was planted in 6 rows in each minor plot planted at fixed spacing of 90 x 45 cm between and within row spacing respectively. Three maize seeds of variety Kilima were sown in each planting hole, but later reduced to two where all three seeds germinated and established. All plots of maize were planted the same day. The T1 plots were planted with *Tephrosia* seeds the same day as maize. *Tephrosia* seeds from local source (Shinyanga Provenance) were directly sown in rows between rows of maize. Six seeds were sown in each planting hole with spacing varied according to spacing treatment levels of minor plots, but later thinned to three plants after germination and establishment. The other two major plots (T2 and T3) were planted two and four weeks after sowing of maize with the same spacing variation as above. *Tephrosia* was planted the same day in both intercrop and monoculture plots for each time of planting. All plots were weeded twice during the rainy season, at 3 and 6 weeks of planting maize, and once during dry season. *Tephrosia* remained on site up to November 2002 after harvesting maize in May 2002.

3.2.1.3 Soil sampling for site characterization

Following lay out of experiment, four sampling pits were randomly dug in each experimental block but outside experimental plots and soil samples were collected for selected parameters including total N, available P, organic carbon (OC), pH, electrical conductivity (EC), texture and bulk density (BD). From each pit soil samples were collected at 0-10, 10-20, 20-30, 30-50, 50-80 and 80-120 cm, bulked by depth, thoroughly mixed, sub-sampled and taken to laboratory where they were air-dried for analysis. For BD, core cylinders of 5 x 5 cm (height x diameter) were used, collecting two cores from each pit depth and cores from pits were bulked by depth divided by the number of cores to obtain mean core weight after oven drying at 105°C for 48 hours (Anderson and Ingram, 1993).

3.2.1.4 Assessment of soil water content

Immediately after the experiment was laid out, access tubes for Profile Probe instrument were installed for the assessment of soil water content, two in each minor plot to the depth of 1 m, in the shrub-maize intercrop and sole maize (control) plots. Profile Probe type PR1/6 of length 110 cm was used with moisture meter type HH2 that measures soil moisture content directly making use of the dielectric properties of water. The 1.1 m long probe consists of a sealed composite rod of 25 mm diameter, with electronic sensors (in the form of pairs of stainless steel rings arranged at fixed intervals along its length, from which it gives readings). The output from each sensor is a simple analogue dc voltage. This output is easily converted into soil moisture using the supplied general soil calibrations for mineral and organic soil, or the probe can be calibrated where the condition is different using a ThetaProbe. The metre gives reading in the unit of choice out of options including %Vol, and $m^3.m^{-3}$. The fixed intervals are 0-10, 10-20, 20-30, 30-40, 40-60 and 60-100 cm. The thin wall access tubes made of fibreglass were inserted in the soil with 0.05 m of the tube left above ground capped with black plastic cover.

With the probe connected to the moisture meter, from each tube readings were taken three times from each depth interval while rotating the probe 120° clockwise each time inside the access tube. Initially, readings were taken once weekly starting five weeks after maize sowing till April 2002, and thereafter at two-week intervals with the aim of monitoring soil moisture status as affected by treatments. The mean reading for each month was determined and used as working data. Thus the first batch of probe readings were taken when T1 plots were five weeks old, T2 three weeks and T3 one week. Measurements were continued up to when the shrub was cleared at the end of November 2002.

3.2.1.5 Assessment of *Tephrosia* and maize biomass yield at maize tasselling and laboratory procedures

At maize tasselling (about eight week old), six plants of *Tephrosia* were randomly selected from the middle two rows of each minor plot in both intercrop and monoculture plots of the destructive sampling unit. The six plants were carefully dug out with most of their roots (hardly more than 20 cm deep by then) intact and taken to the laboratory for determination of oven-dried weight. Similarly six maize plants were randomly selected from the two middle rows, separated into root, leaf and stem and taken to the laboratory for oven-dry weight determination. All plant materials were oven-dried at 60°C to constant weight (Anderson and Ingram, 1993).

3.2.1.6 Assessment of *Tephrosia* and maize biomass yield at maize harvesting and laboratory procedures

At maize maturity, all maize plants in the two middle rows were harvested, the stems cut at ground level, weighed fresh in the field and sub-sampled for determination of dry weight and moisture content in the laboratory. Similarly, maize cobs were harvested, shelled and both shaft and grain were weighed fresh both bulk and sub-samples, and sub-samples taken to the laboratory for determination of dry weight and moisture content. For *Tephrosia*, the heights and root collar diameters of all shrubs in the two middle rows of each minor plot in the main experimental unit were measured from both intercrop and monoculture plots. These data were later entered into allometric equations to estimate standing biomass yield on dry weight basis. All plant samples were oven-dried at 60° C to constant weight (Anderson and Ingram, 1993). The moisture content from sub-samples was used to calculate dry weight of bulk samples, which was converted to a hectare basis.

3.2.1.7 Development of allometric equations

At flowering stage of *Tephrosia* about the eighth month of growth, 40 plants including varying sizes were randomly selected from the destructive sampling experimental unit with 20 plants each from intercrop and monoculture plots. Heights and root collar diameter of each selected shrub were measured, cut down from ground level and biomass partitioned into foliar and wood components. These were taken to the laboratory where they were oven-dried at 60°C to constant weight to obtain oven-dried weights. With the oven-dried weights of the 40 plants, 30 were used to develop allometric equations and 10 used to validate the equations. Equations were developed for foliar, wood and total biomass, from a general model for shrubs as suggested by Elliott and Cliton (1993):

$Y = a+b_1D^2+b_2H$..(1)

$Ln(Y) = a + b\ln D$..(2)

$\ln(Y) = a + b_1\ln D+b_2\ln H$..(3)

Where: ln = base of natural logarithm

Y = dependent variable (biomass of foliage, wood or total biomass)

D = root collar diameter

H = total shrub height

The model number three was selected for predicting standing biomass on the basis of best fit as determined from coefficient of determination (r^2) and low standard error (Table 12); all models selected had R-squares above 0.8. Foliar biomass was made of leaf, soft twig, floral and pod components as some plants were in flower, others had already developed pods, while others had not yet flowered.

Table 12: Equations for predicting biomass for the various components of *Tephrosia* standing biomass at Gairo, Tanzania

Dependent variable	Model	r^2	SE	Pr>F-ratio	n
Foliar biomass					
	ln(Y)=5,282981+3.218182lnD-0.57337lnH	0.842	1.489	0.0000	30
Wood biomass					
Total biomass	ln(Y)=0.27056+2.376042lnD+0.705035lnH	0.882	1.341	0.0000	30
	ln(Y)=2.724015+2.701026lnD+0.215463lnH	0.895	1.336	0.0000	30

3.2.1.8 Assessment of *Tephrosia* growth and biomass yield at clearing and laboratory procedures

At eleventh month of *Tephrosia* growth, November 2002, the heights and root collar diameters of shrubs in the two middle rows of each minor intercrop and monoculture plots in the main experimental unit were measured. These were used to predict the standing biomass of *Tephrosia* with respect to foliar, woody and total above ground biomass.

3.2.1.9 Determination of soil bulk density and root biomass at 11th month of *Tephrosia* growth

Closely preceding the clearing of shrub in the 11th month of growth, two narrow pits measuring 30 x 30 x 50 cm were carefully dug at two diagonals between the two outer *Tephrosia* rows on both sides of each minor plot of the main experimental unit. With a core cylinder of 5 x 5 cm (height x diameter), soil samples were taken from 0-10, 10-20, 20-30 and 30-50 cm soil depths. Cores at each depth were bulked together and taken to the laboratory to obtain average mass after oven drying, according to procedure outlined in Anderson and Ingram (1993). At the other two opposite ends of the two outer *Tephrosia* rows in each minor plot, using root corer of dimensions 15 x 7 cm (height and diameter respectively) samples were taken from four randomly selected points between and within

Tephrosia rows at 0 -15, 15 -30 and 30 -50 cm soil depths in both intercrop and monoculture plots of the main unit. Core samples were bulked by depth for each plot and samples were processed at the end of each sampling day to obtain root biomass (without the main taproot), using procedures outlined in Anderson and Ingram (1993). *Tephrosia* roots were distinguished from maize and other plant roots by using fresh root samples of the two plants prepared in advance. All sampling points for both bulk density and root biomass were located 45 cm from outside on either side of plot border (Fig. 5).

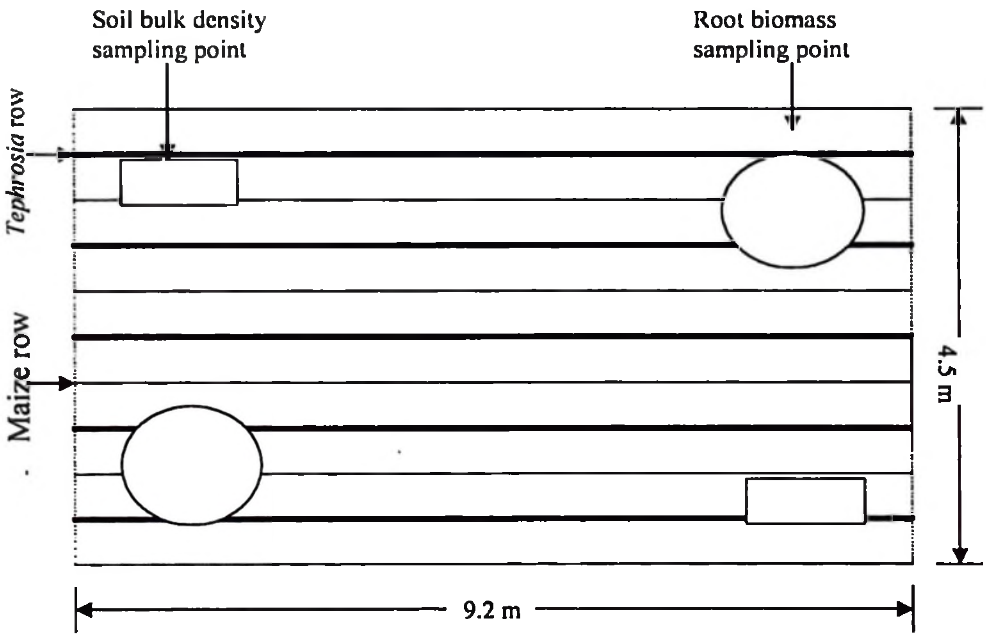

Figure 5: Minor plot showing sampling points for soil bulk density and root biomass of *Tephrosia,* in *Tephrosia* - maize relay intercropping experiment at Gairo, Tanzania

3.2.1.10 Laboratory procedures for site characterization samples

Total N was analysed using the semi-microKjeldahl procedure described in Bremner and Mulvaney (1982) after digesting samples in concentrated sulphuric acid and hydrogen peroxide as oxidising agent. Available P was analyzed by Bray1 test using 0.05M HCL and 0.03M NH_4F as acid extractants (Bremner and Mulvaney, 1982). Organic carbon was determined by the Walkey and Black wet oxidation method using concentrated sulphuric acid and aqueous potassium dichromate (Okalebo *et al.*, 1993). Electrical conductivity and pH were determined in 1:2.5 ratio of soil:distilled water paste (Anderson and Ingram, 1993) using electrical conductivity and pH meters respectively. Soil texture was done according to improved Bouyoucus (1962) hydrometer method and International classification of diameter classes (Okalebo *et al.*, 1993).

3.2.1.11 Statistical analysis

Data for site characterization were summarized in Microsoft Excel to generate means and standard deviation. Soil moisture data were summarized and means for each month sorted by soil depths in SAS and subjected to analysis of variance (ANOVA) using general linear model (GLM) for split plot design, with time of planting as main plot and spacing as minor plot factors (equation 4).

$Y_{ijk} = \mu + B_i + A_j + BA_{ij} + S_k + BS_{ik} + AS_{jk} + BAS_{ijk}$ ....(4)

$i = 1,2,3;\ j = 1,2,3;\ k = 1,2,3,4$

Where: Y_{ijk} = variable to be analyzed (dependent variable)

μ = Overall mean

B_i = effect due to i^{th} block

A_j = effect of the j^{th} time of planting (random) in i^{th} block

BA_{ij} = first restriction error (error I)

S_k = effect of the k^{th} spacing level

BS_{ik} = effect of the interaction of block with spacing

AS_{jk} = effect of the interaction of time of planting with spacing

BAS_{ijk} = second restriction error (error II)

Significant means were separated by Duncan Multiple Range Test (DMRT) in SAS.

To test the hypothesis that time of planting and spacing of *Tephrosia* has effect on maize height, stover and grain yield per hectare for the first cropping season (intercropping phase); *Tephrosia* mean shrub total biomass and shrub total biomass per hectare at maize tasselling were subjected to analysis of variance (ANOVA) using a fixed model as in equation 4 above for split plot design in SAS.

For *Tephrosia* mean height and mean diameter per plot, mean shrub total biomass, foliar, wood and total biomass per hectare at sixth and eleventh months of growth were subjected to ANOVA using a fixed model (equation 5) for split plot design in SAS. Significant means were separated by DMRT in SAS.

$Y_{ijk} = \mu + B_i + A_j + BA_{ij} + S_k + BS_{ik} + AS_{jk} + BAS_{ijk}$ ....(5)

$i = 1,2,3; j = 1,2,3; k = 1,2,3,4,5,6$

Where: Y_{ijk} = variable to be analyzed (dependent variable)

μ = Overall mean

R_i = effect due to i^{th} block

A_j = effect of the j^{th} time of planting (random) in i^{th} block

BA_{ij} = first restriction error (error I)

S_k = effect of the k^{th} spacing level

BS_{ik} = effect of the interaction of block with spacing

AS_{jk} = effect of the interaction of time of planting with spacing

BAS_{ijk} = second restriction error (error II)

Similarly, the effect of treatments on root biomass and soil bulk density at *Tephrosia* clearing (11th month) was tested by ANOVA in general linear model for split plot in SAS as equation 4 above, and significant means separated by DMRT in SAS.

3.2.2 Residual effect of trial

3.2.2.1 Experimental design and layout

Immediately following the assessment of *Tephrosia* biomass yield at the 11th month, shrubs were cut down at ground level and all non-woody biomass were left on the plot for ploughing into the soil and the woody components taken away by women as fuelwood. Thereafter a split-split plot design was used to layout the experiment. The same plots in the first season layout were used for the second season experiment. In the second season, major plot (time of planting) size remained the same (14.8 x 17.5 m); what was minor plot in the first season became sub-major plots still measuring 9.2 x 4.5 m but split to give two minor plots (fertilizer treatment with two levels) measuring 3.6 x 4.5 m length and breadth respectively, separated by 2 m distance. Fertilizer treatment involved no fertilizer as level 1 (F0) and half recommended dose of N (40 kg N ha^{-1}) plus full-recommended dose of P (40 kg P ha^{-1}) as level 2 (F1).

3.2.2.2 Establishment and management of experiment

Following hand hoe ploughing and layout of the field, planting holes for maize were dug in all plots including *Tephrosia* monoculture plots with dimensions of about 15 x 15 x 15 cm (length x breadth x depth respectively). In all F1 plots (i.e. with fertilizer application), the full dose of recommended P fertilizer in the form of Minjingu Phosphate Rock (MPR) was evenly deposited in each hole and mixed with soil thoroughly within the hole. Three maize seeds of variety Kilima were sown in all dugout holes in both F0 and F1 minor plots on the same day. Nitrogen fertilizer in the form of urea was applied to F1 plots in two split-applications, i.e. at 4th and 6th weeks after maize sowing by evenly depositing around each planting spot of maize and later carefully mixed with soil using hand hoe. Fertilizer was applied in both first and second cropping seasons after intercropping phase. All plots were weeded twice in the growing season and once in the dry season, as plots were required to be kept free of weeds throughout experimental period.

3.2.2.3 Soil sampling for field mineral nitrogen and organic carbon

Preceding the planting of maize and immediately following layout of experiment before planting rains were ensured, the first soil samples for determination of available or mineral N were collected from all unfertilized (i.e., F0) plots using soil auger at 0-15 cm depth from four randomly selected spots between the two outer maize rows while leaving 45 cm from plot border (Fig. 6). These were thoroughly mixed together and sub-samples taken in cool containers to the laboratory for analysis. For the first cropping season following the intercropping season, the same soil samples collected for analysis of available N collected before maize planting were also used for the determination of OC content. Soil samples for available N were further collected at 2nd, 4th and 6th weeks after planting maize in first and second cropping seasons after intercropping season with the aim of assessing the effect of *Tephrosia* in intercrop and monoculture systems on field mineral N. A distance of 45 cm from plot borders was left at each sampling spot.

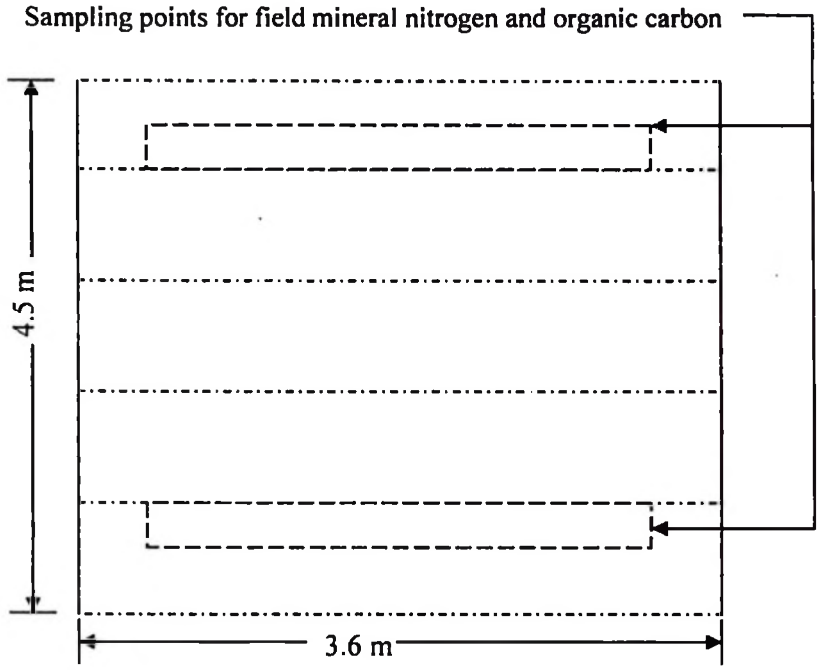

Figure 6: Minor plot showing dimensions and soil sampling points for field mineral nitrogen and organic carbon in first and second residual seasons

3.2.2.4 Assessment for maize growth and yield and laboratory procedures

In the first season following intercropping season (first residual season), at maize tasselling, four maize plants in the two second rows from outside (Fig. 7) were randomly selected, cut at ground level and partitioned into leaf and stem, and taken to the laboratory for determination of oven dry weight biomass. At maturity, all maize in the middle two rows in all minor plots of the main experimental unit was harvested. The stovers were weighed fresh in the field and sub-samples of leaf and stem taken to the laboratory to determine dry weight and moisture content. Maize cobs were shelled and fresh bulk and sub-sample weights of grain and shaft were taken and oven dried at 60°C to constant weight.

In the second season following *Tephrosia* removal (second residual season), maize grain and biomass yields were assessed at maize maturity. All maize in the middle two rows (Fig. 7) of each minor plot in the main experimental unit was harvested. Stover was weighed fresh and sub-samples of leaf and stem were taken to the laboratory for determination of oven-dry weight. Maize cobs were processed as in the first residual season. All plant samples were oven-dried at 60° C to constant weight.

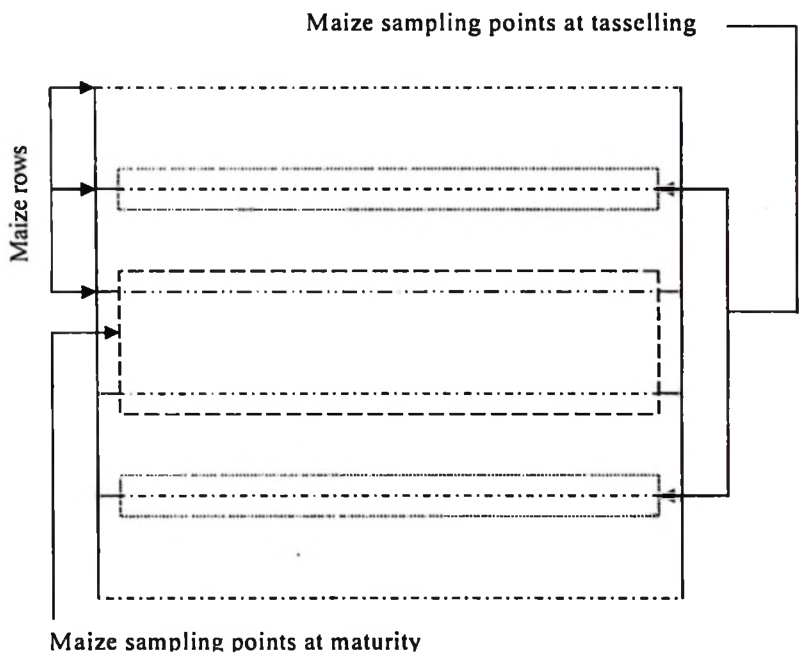

Figure 7: Minor plot showing maize sampling points in first and second residual seasons

3.2.2.5 Laboratory procedures for soil samples

Soil samples for field available N (i.e. nitrate-N and ammonium-N) were analyzed by calorimetric method outlined in Anderson and Ingram (1993) after extraction with potassium sulphate solution, and colour read by spectrophotometer at 410 and 655 nm wave lengths respectively.

3.2.2.6 Statistical analysis

For nitrate-N, ammonium-N, total mineral-N and OC, the same model for split plot design (equation 4) was used, and means separated by DMRT in SAS. For root biomass and soil bulk density, data were sorted by depths in SAS and subjected to ANOVA using a fixed model as equation 5, and significant means separated by DMRT in SAS.

To test the hypothesis that *Tephrosia* time of planting, spacing and fertilization treatments have effect on maize height, stover biomass, shaft and grain yield for first and second residual season, data were subjected to ANOVA in GLM for split-split plot in SAS (equation 6) and significant means separated by DMRT in SAS.

$Y_{ijk} = \mu + B_i + A_j + BA_{ij} + S_k + Bb_{ik} + AS_{jk} + BAS_{ijk} + C_l + BC_{il} + AC_{jl} + SC_{kl} + BSC_{ikl} + ASC_{jkl} + BSAC_{ijkl}$..(6)

$i = 1,2,3; j = 1,2,3; k = 1,2,3,4,5,6,7; l = 1,2.$

Where: Y_{ijk} = variable to be analyzed (dependent variable)

μ = Overall mean

B_i = effect due to i^{th} block

$A_{(i)j}$ = effect of the j^{th} time of planting (random) in i^{th} block

BA_{ij} = First restriction error (error I)

S_k = effect of the k^{th} spacing level

BS_{ik}	=	effect of the interaction of the i^{th} block with k^{th} spacing
AS_{jk}	=	effect of the interaction of time of planting and spacing
$BAS_{(ijk)}$	=	second restriction error (error II)
C_l	=	effect of the l^{th} fertilizer level
BC_{il}	=	effect of the interaction of block with fertilization
AC_{jl}	=	effect of interaction of the time of planting and fertilization
SC_{kl}	=	interaction of spacing and fertilization
BSC_{ikl}	=	effect of the interaction of spacing and fertilization
ASC_{jkl}	=	interaction of time of planting, spacing and fertilization
$BSAC_{ijkl}$	=	Experimental error

CHAPTER FOUR

4.0 RESULTS

This chapter gives the results of three specific objectives of the experiment: the effect of time planting and spacing of *Tephrosia vogelii* on soil moisture status and components performance during intercropping period (4.1), the effect of time of planting and spacing of *Tephrosia* on the performance of the shrub following maize removal (4.2) and the effect of time of planting and spacing of *Tephrosia* on selected soil properties and crop performance in first and second residual seasons (4.3). Appropriate subsections detail each major section accordingly.

4.1 Effect of Time of Planting and Spacing of *Tephrosia* on Soil Moisture Status During Intercropping Season (January- November 2002)

4.1.1 Effect of time of planting on soil moisture content during growing period (January- April 2002)

The effect of time of planting *Tephrosia vogelii* on mean monthly soil water content for the months of January to April 2002 is given in Figure 8. Soil moisture content was significantly higher ($P<0.05$) in plots planted four weeks after maize planting (Wk4), at soil depth 10-20 cm than plots planted at the same time with maize (Wk0). The treatments Wk0 and Wk2 were not significantly different ($P>0.05$) in all four months except February, where all three levels of time of planting differ significantly ($P<0.05$) from each other, with week4 being the highest and week0 the lowest.

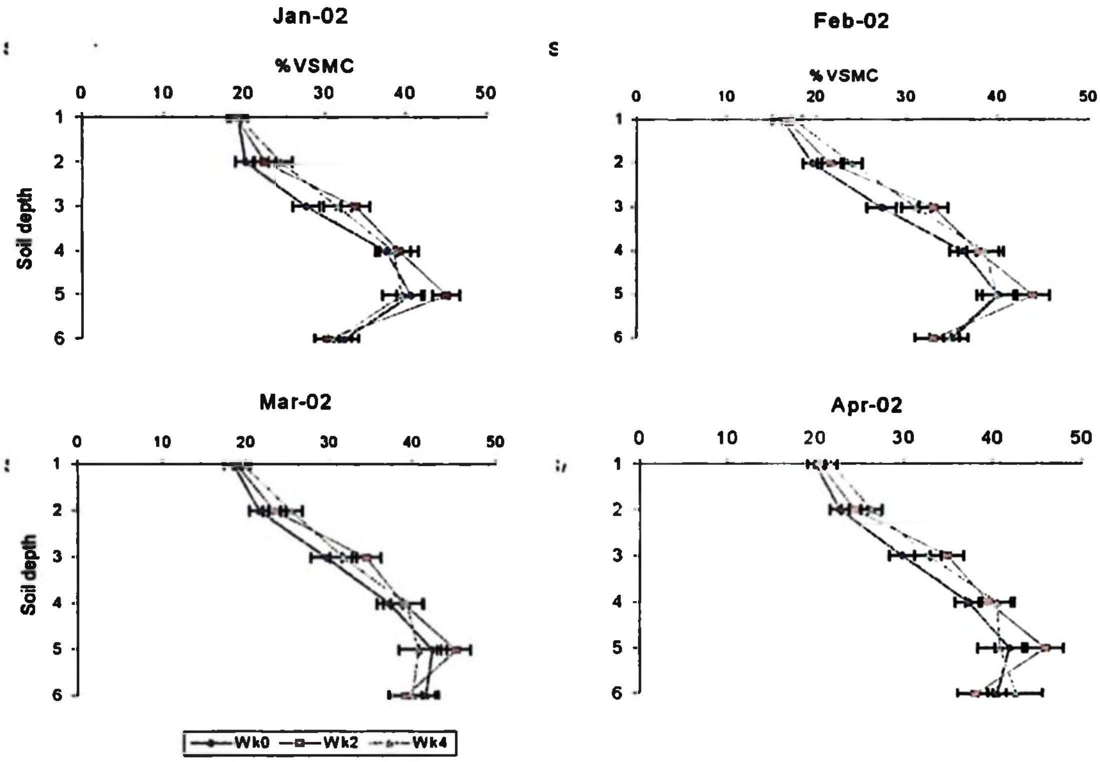

Figure 8: Mean soil moisture content as affected by time of planting *T. vogelii* during maize growing period - January – April 2002 at Gairo, Tanzania (±standard error, n = 12)

Note: the numbers 1-6 on the vertical axis represents soil depths 0-10, 10-20, 20-30, 30-40 40-60 and 60-100cm respectively and the acronym %VSMC on the horizontal axis represents percent by volume soil moisture content.

At soil depth 40-60 cm, soil moisture content in week2 time of planting was also significantly higher (P<0.05) than in week0 and week4. At the remaining soil depths, 0-10, 20-30, 30-40 and 60-100 cm in all four months of assessment soil moisture content did not differ significantly (P>0.05) within levels of time of planting. However, a more consistent trend is that soil moisture was highest in week4 time of planting at depths 1 and 2 and lowest in week0 at soil depths 1 - 4.

4.1.2 Effect of time of planting on moisture content during the non-growing period (May – November 2002)

The effect of time of planting on soil moisture content during the months of May – November 2002 are given in Figures 9 and 10. Significant differences were observed at the same soil depths (10-20 cm) as was in growing period in all months of the non-growing period except July and November. In all cases of significant ($P<0.05$) difference, week4 maintained higher soil moisture over week0 while week0 and week2, and week2 and week4 were not significantly ($P>0.05$) different, except in May where all three levels differed significantly ($P<0.05$) from each other at that soil depth. Significant differences among treatments were also observed at soil depth 40-60 cm with consistence in all seven months, and in all cases, week2 moisture content was significantly higher ($P<0.05$) than both week0 and week4 except in October where week2 was not significantly different ($P>0.05$) from week4 (Figures 9 and 10). At other depths, there were neither significant differences nor any particularly consistent trends observed.

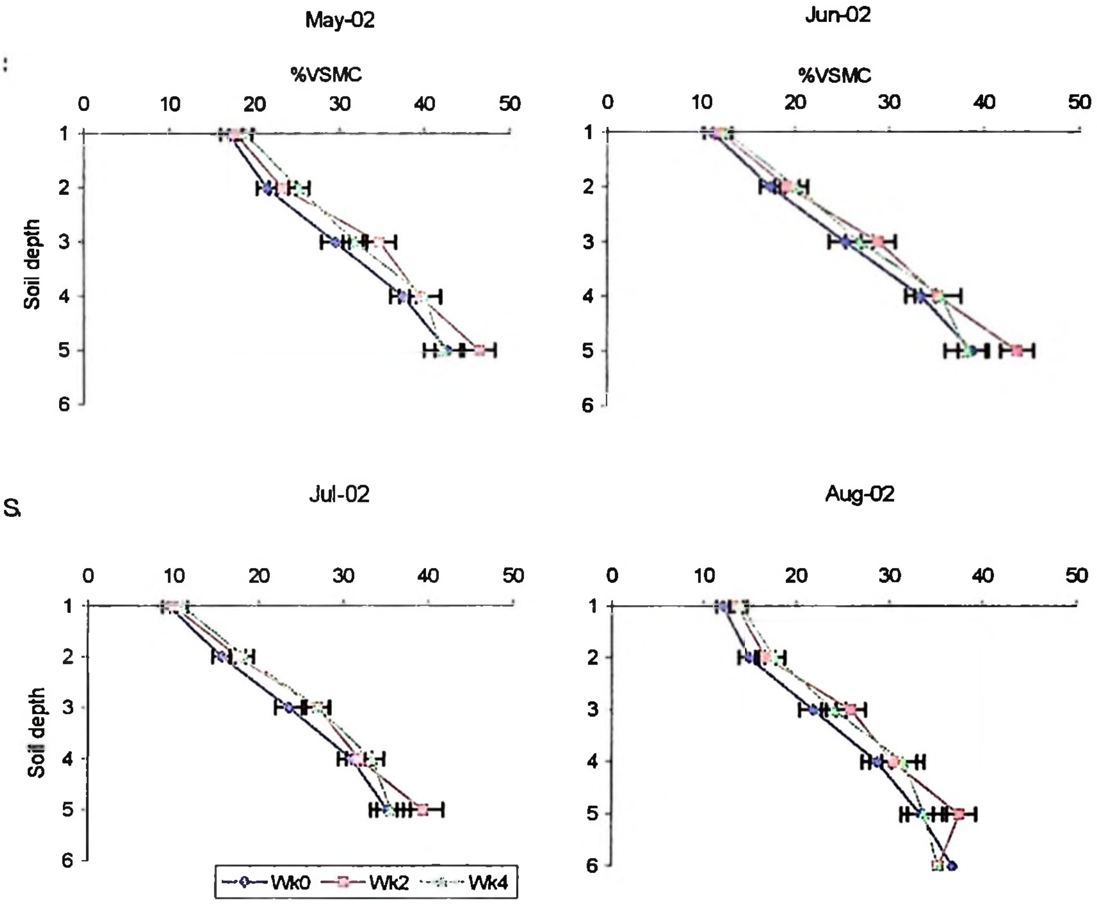

Figure 9: Mean soil moisture content as affected by time of planting *T. vogelii* for the period May – August 2002 at Gairo, Tanzania (± standard error, n = 12).

Note: the numbers 1-6 on the vertical axis represents soil depths 0-10, 10-20, 20-30, 30-40 40-60 and 60-100cm respectively and the acronym %VSMC on the horizontal axis represents percent by volume soil moisture content

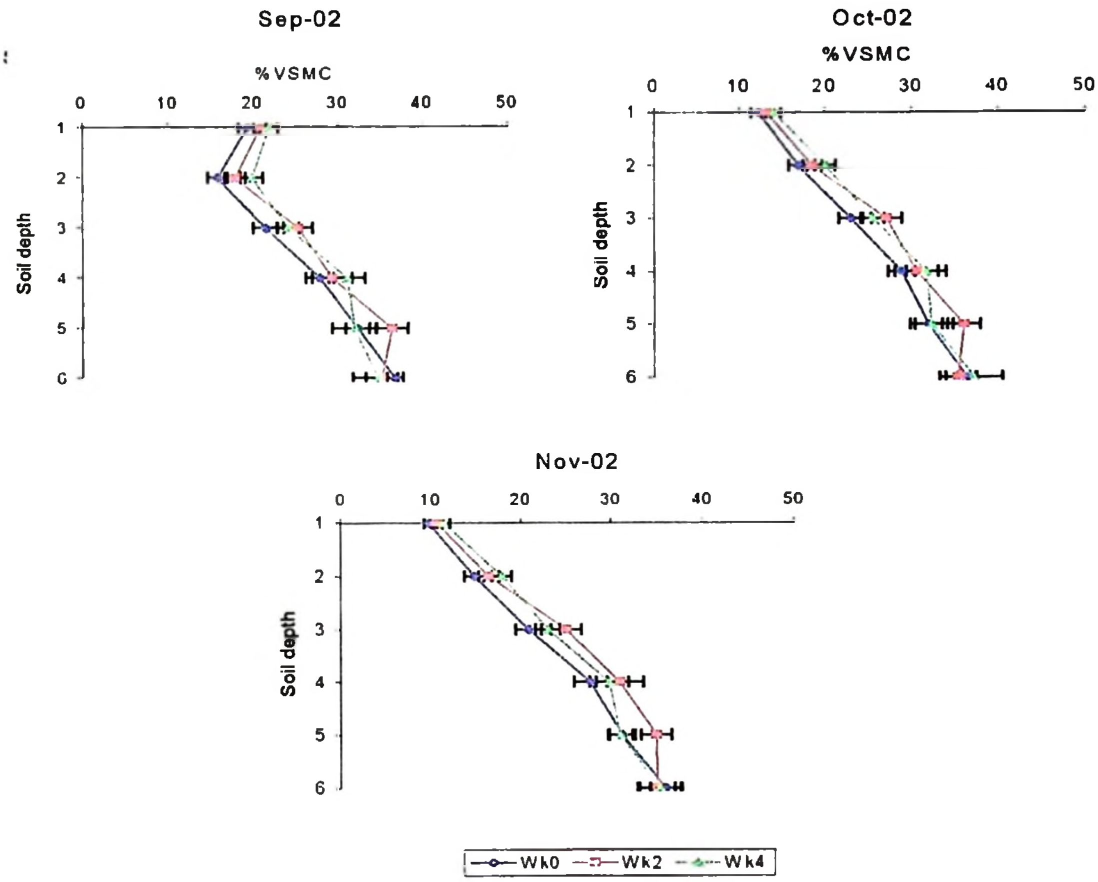

Figure 10: Mean soil moisture content as affected by time of planting *T. vogelii* for the period September – November 2002 at Gairo, Tanzania (± standard error, n = 12).

Note: the numbers 1-6 on the vertical axis represents soil depths 0-10, 10-20, 20-30, 30-40 40-60 and 60-100cm respectively and the acronym %VSMC on the horizontal axis represents percent by volume soil moisture content

4.1.3 Effect of time of planting *Tephrosia* on annual soil moisture cycle

The effect of time of planting on annual soil moisture cycle for each soil depth measured within the profile is given in Figure 11. At soil depth 0-10 cm there were no significant differences (P>0.05), only very slight differences between treatments, which showed no specific consistence especially in January. Generally, soil moisture content at this depth was low for all the months and for all treatments. Distinct differences and some consistence were generally observed at depths 10-20 and 20-30 cm and to some extent at depths 30-40 and 40-60 cm. Week4 time of planting maintained superiority in soil moisture for most time of the year at soil depth 0-10, 10-20 and 30-40 cm while week2 maintained superiority at depths 20-30 and 40-60 cm, while the least soil moisture content was maintained by week0 for most of the 11 months of assessment. Data were missing for soil depth 60-100 cm in the months of May, June, July and August. This was due to malfunction of device when the sensor at that depth failed to read, but was restored again by September. Overall, the responses of soil moisture to the treatments of time of planting were very similar for both growing and non-growing periods. A further noticeable trend observed is that lowest soil moisture content was recorded at soil depth 0-10 cm, which gradually increased down the soil profile to depth 40-60 cm thereafter declining a little sharply for the first four months, but increasing again at 60-100 cm.

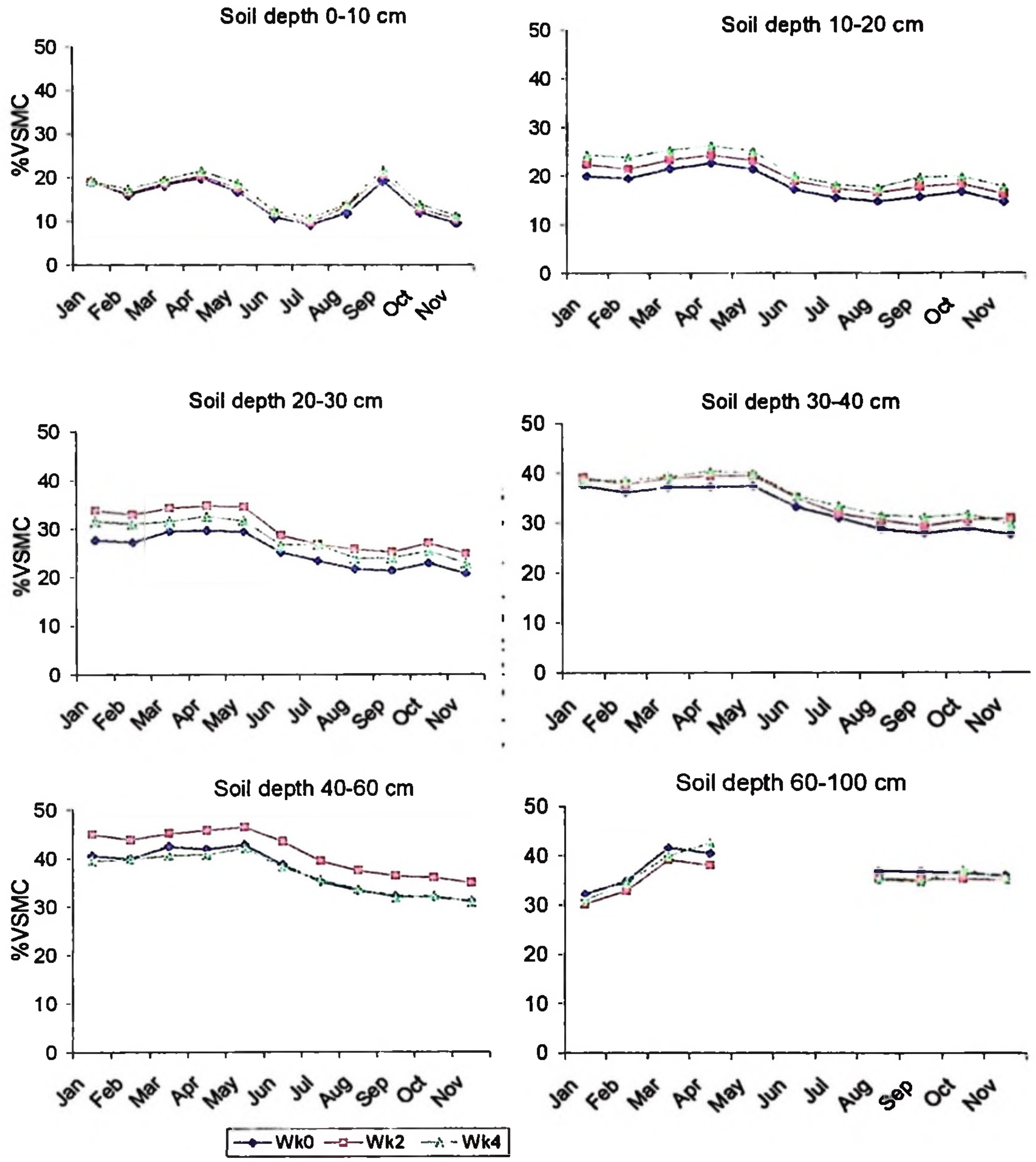

Figure 11: Annual soil moisture cycle for the year 2002 as affected by time of planting *Tephrosia vogelii* intercropped with maize at Gairo, Tanzania.

Note: The acronym %VSMC on the vertical axis represents percent by volume soil moisture content.

4.1.4 Effect of spacing of *T. vogelii* on soil moisture content

Soil moisture content as affected by spacing of *Tephrosia* for cropping and non-cropping periods are presented in Figures 12, 13, 14 and 15. Soil moisture content for all levels of spacing of shrub and control (Tv0) did not significantly differ (P>0.05) throughout the year at all soil depths, and there is no consistent trend except at soil depth 0-10 cm, where Tv0 treatment showed a slight increase over the intercropped plots and soil moisture steadily declined as shrub spacing increased with Tv90 most frequently maintaining the lowest moisture content throughout the season, but especially in the growing period, i.e. January – April 2002 (Figure 12). In the overall seasonal moisture cycle (Figure 15), 30 x 90 spacing (Tv30) distinctly maintained highest soil moisture content for most of the time at soil depths 20-30 and 40-60 cm.

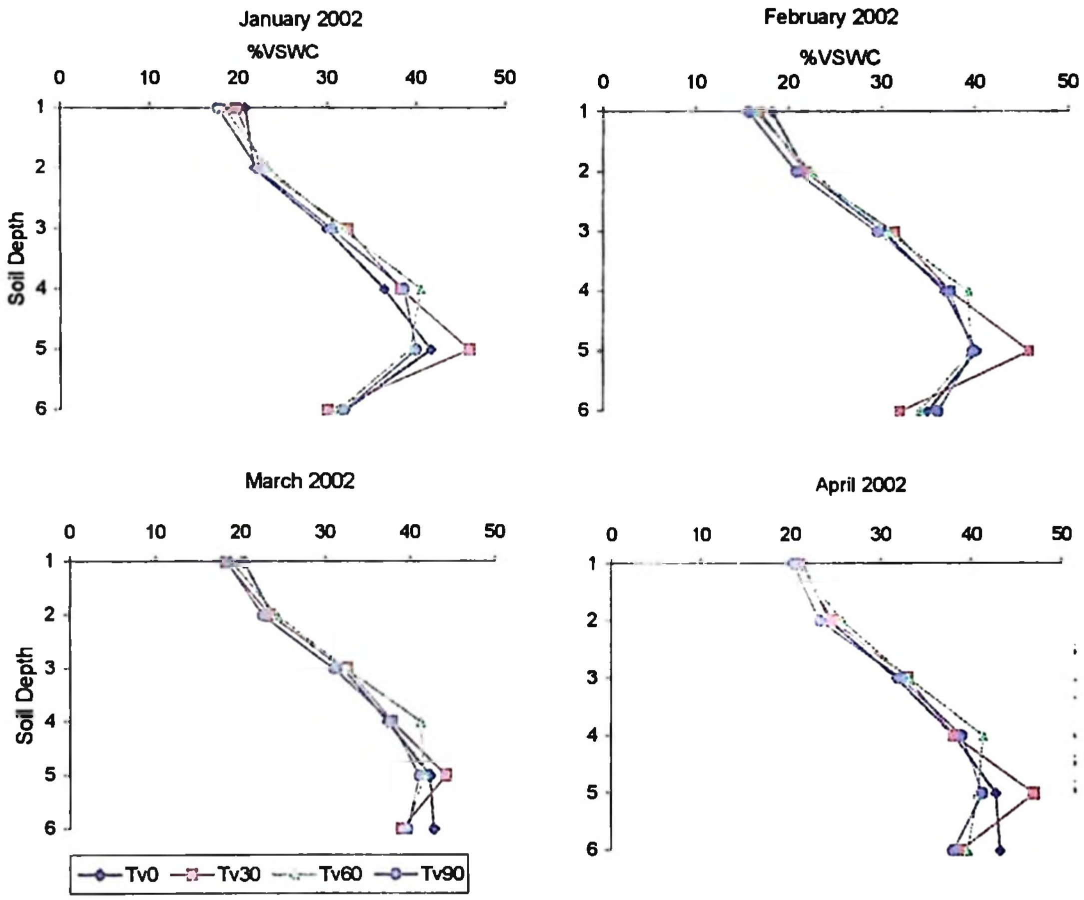

Figure 12: Effect of Spacing of *T. vogelii* on mean monthly soil moisture content for the growing period of 2002 at Gairo, Tanzania.

Note: the numbers 1-6 on the vertical axis represents soil depths 0-10, 10-20, 20-30, 30-40 40-60 and 60-100cm respectively and the acronym %VSMC on the horizontal axis represents percent by volume soil moisture content

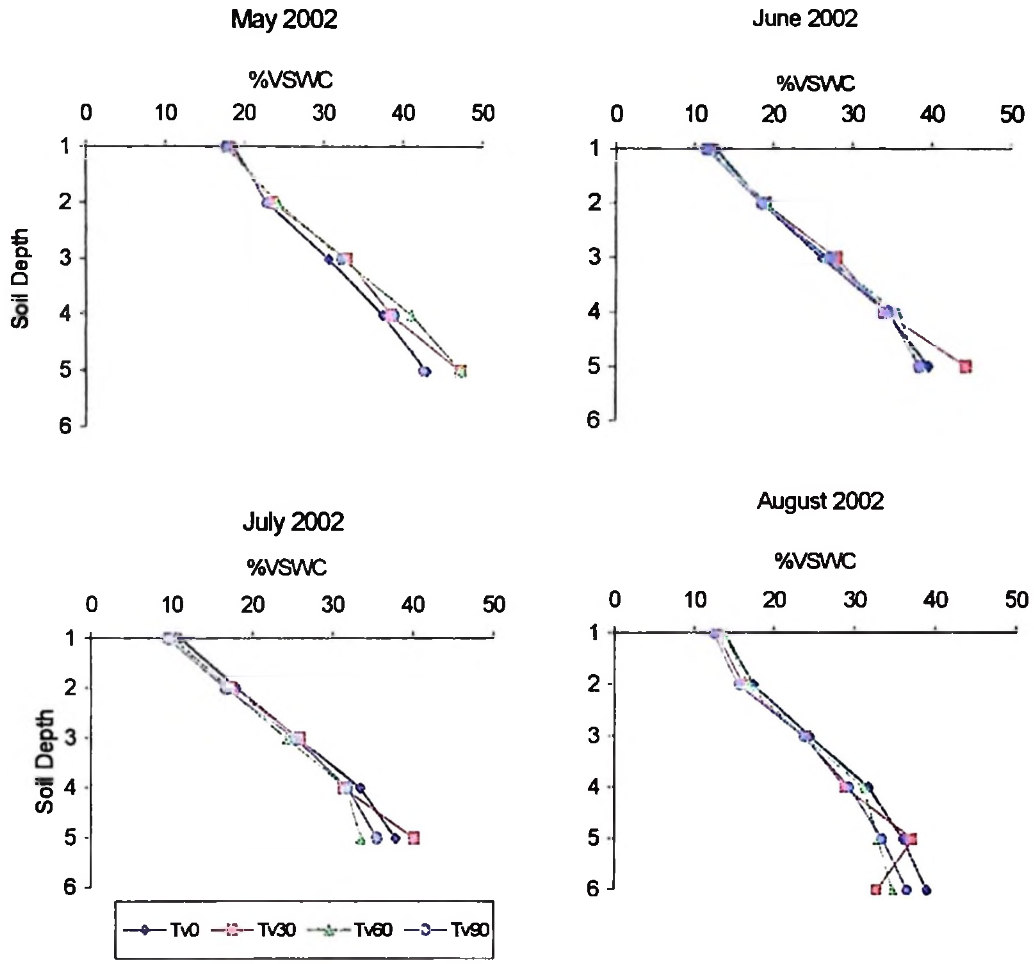

Figure 13: Effect of spacing of *T. vogelii* on mean monthly soil moisture content for the first four months of the dry season of 2002 at Gairo, Tanzania.

Note: the numbers 1-6 on the vertical axis represents soil depths 0-10, 10-20, 20-30, 30-40 40-60 and 60-100cm respectively and the acronym %VSMC on the horizontal axis represents percent by volume soil moisture content

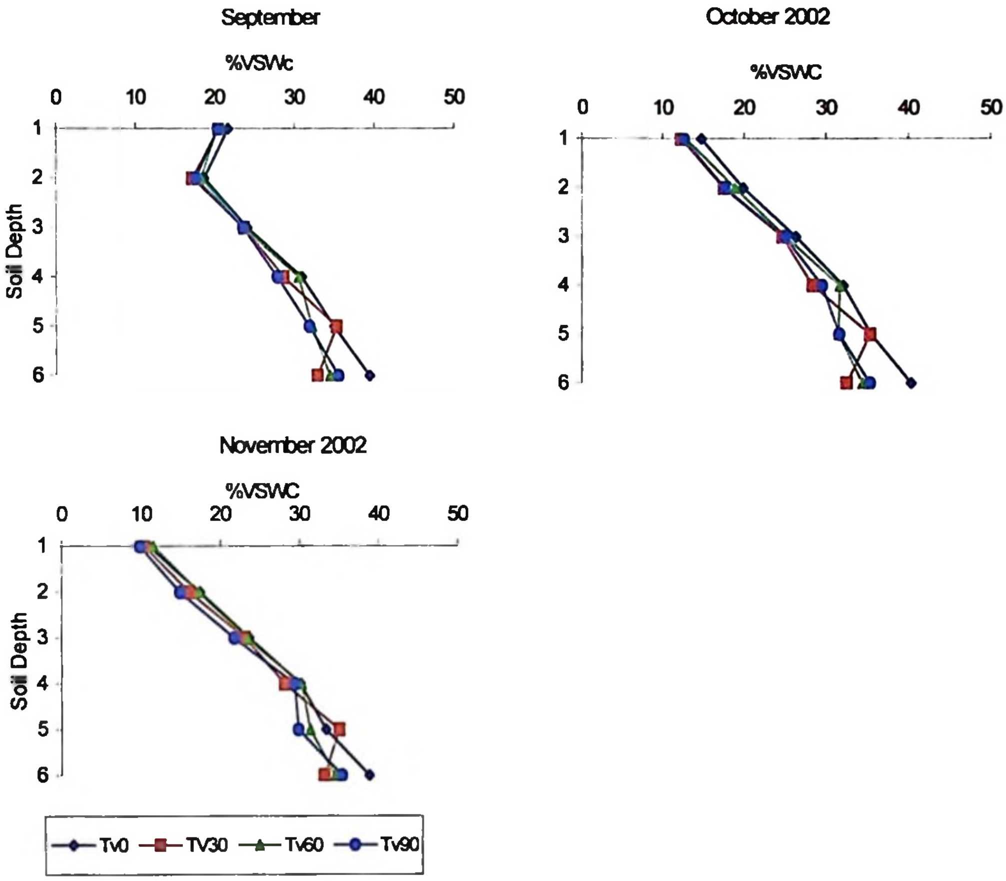

Figure 14: Effect of Spacing of *T. vogelii* on mean monthly soil moisture content for the period September to November, 2002 at Gairo, Tanzania.

Note: the numbers 1-6 on the vertical axis represents soil depths 0-10, 10-20, 20-30, 30-40 40-60 and 60-100cm respectively and the acronym %VSMC on the horizontal axis represents percent by volume soil moisture content

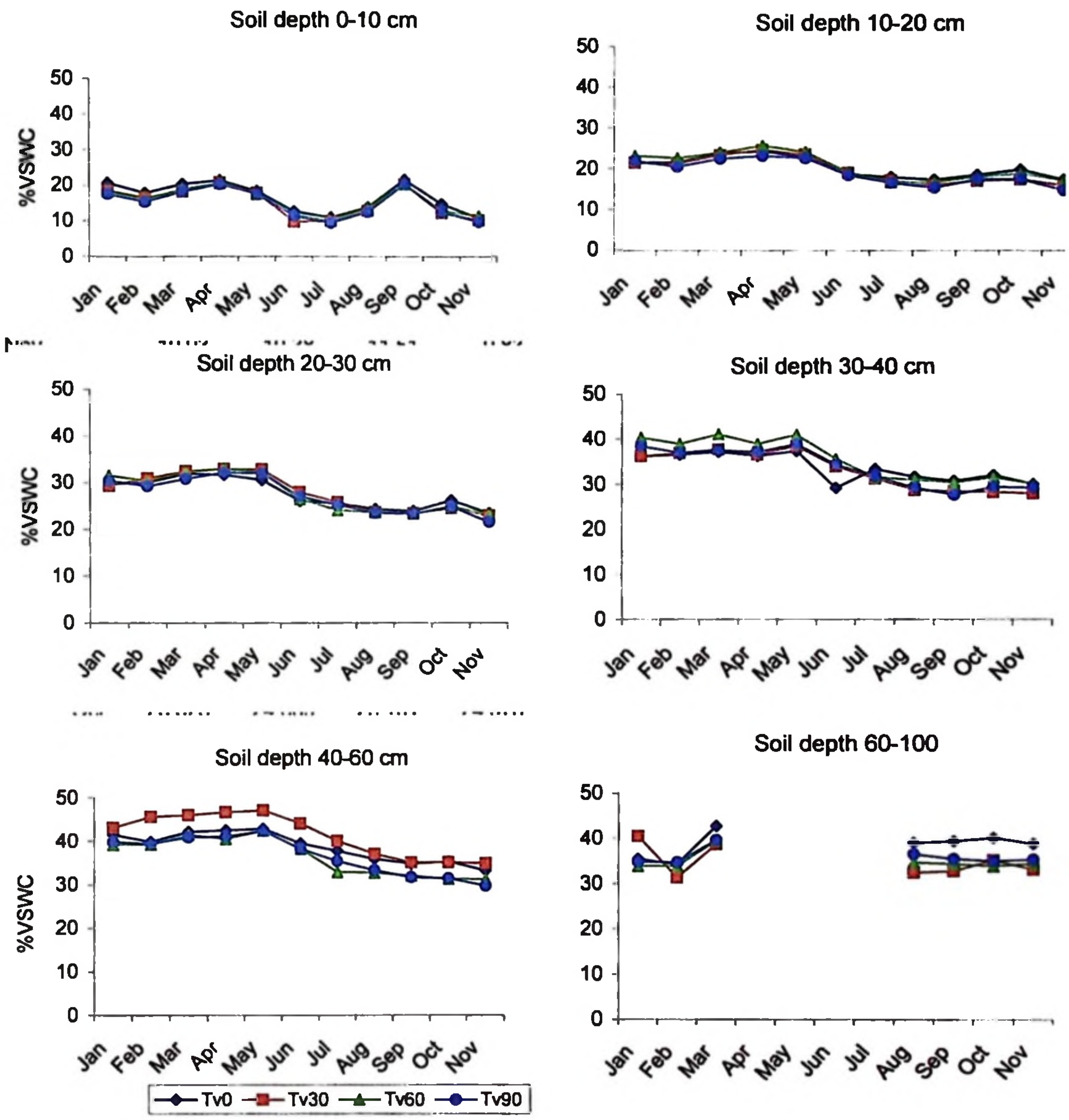

Figure 15: Annual soil moisture cycle for the year 2002 as affected by spacing of *Tephrosia vogelii* intercropped with maize at Gairo, Tanzania

Note: The acronym %VSMC on the vertical axis represents percent by volume soil moisture content

4.1.5 Effect of the interaction of time of planting and spacing of *Tephrosia* on soil moisture content

The effects of the interaction of time of planting and planting space of *T. vogelii* for the whole season are summarized in Table 13, and the three major growing months are presented in Figures 16, 17 and 18. Overall, significant differences ($P<0.05$) have been recorded at some soil depths in nearly all 11 months of assessment.

For the months of January, February and March, which were the peak months of maize growth period in Gairo area (the months in which most of the rain falls), soil moisture was significantly higher ($P<0.05$) for the interaction of Wk2 time of planting and planting space Tv60 than the rest of the treatment combinations at soil depths 2, 3 and 4 (Fig. 16). The significant differences obtained for the rest of the months were also all in favour of the same treatment combination mentioned above compared to the others. The general consistent trend for the entire assessment period is that apart from Tv0 (no-*Tephrosia* or control) plots, highest soil moisture was most frequently recorded in the treatment combination of Wk2 time of planting and Tv60 spacing at soil depths 1, 2, 3 and 4, while the least soil moisture was most frequently recorded in the treatment combination of Week0 time of planting and Tv60 spacing at soil depths 1, 2 and 3.

Another familiar trend observed in the above results for all 11 months of assessment is that, most of the significant differences were recorded within depths 2 - 3, with a few at depths 1 and 5.

Table 13: Probability of F-ratio for significant differences for the effects of interaction of time of planting and spacing of *T. vogelii* on soil moisture content in relay intercropping experiment at Gairo, Tanzania

	Soil depth (cm)					
Month	**0-10**	**10-20**	**20-30**	**30-40**	**40-60**	**60-100**
January	0.84	0.11	*0.02*	0.11	0.36	0.58
February	0.55	0.05	*0.01*	*0.02*	0.34	0.74
March	0.68	0.05	*0.01*	0.09	0.15	0.55
April	0.61	*0.01*	0.05	0.08	0.18	0.06
May	0.30	*0.03*	0.08	0.08	0.10	nd
June	*0.04*	*0.04*	0.07	*0.02*	0.08	nd
July	*0.02*	0.09	0.13	*0.03*	0.33	nd
August	0.12	*0.04*	0.11	*0.04*	0.20	0.43
September	0.39	0.16	0.10	0.06	0.22	0.35
October	0.24	0.05	0.25	0.12	0.25	0.32
November	0.22	*0.02*	0.17	0.13	0.21	0.44

Note: nd = no data

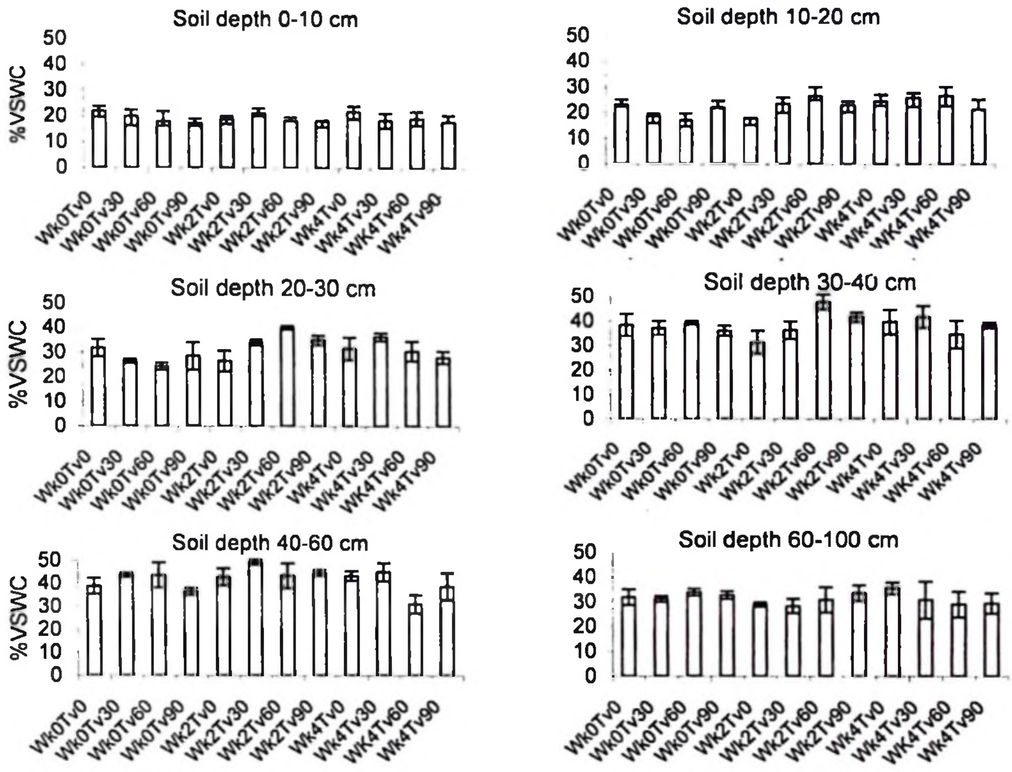

Figure 16: The effect of the interaction of time of planting and spacing of *T. vogelii* on soil moisture content for the month of January 2002 in relay intercropping experiment at Gairo, Tanzania (±=standard error)

Note: The acronym %VSMC on the vertical axis represents percent by volume soil moisture content

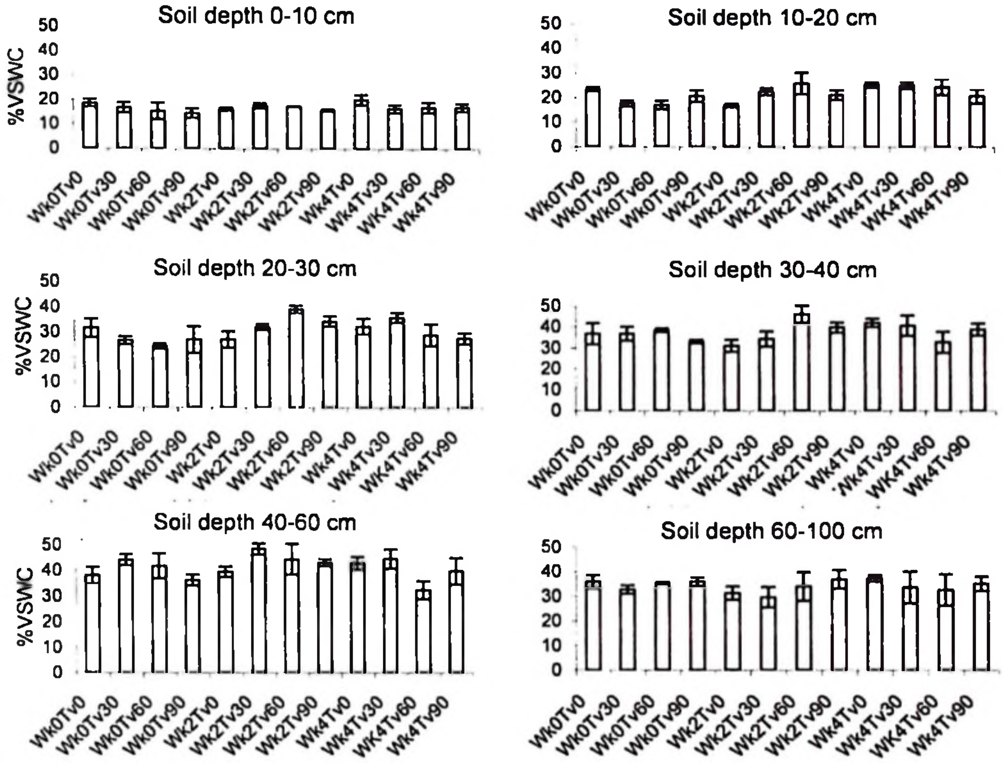

Figure 17: The effect of interaction of time of planting and spacing of *T. vogelii* on soil moisture content for the month of February 2002 in relay intercropping experiment at Gairo, Tanzania (±=standard error).

Note: The acronym %VSMC on the vertical axis represents percent by volume soil moisture content

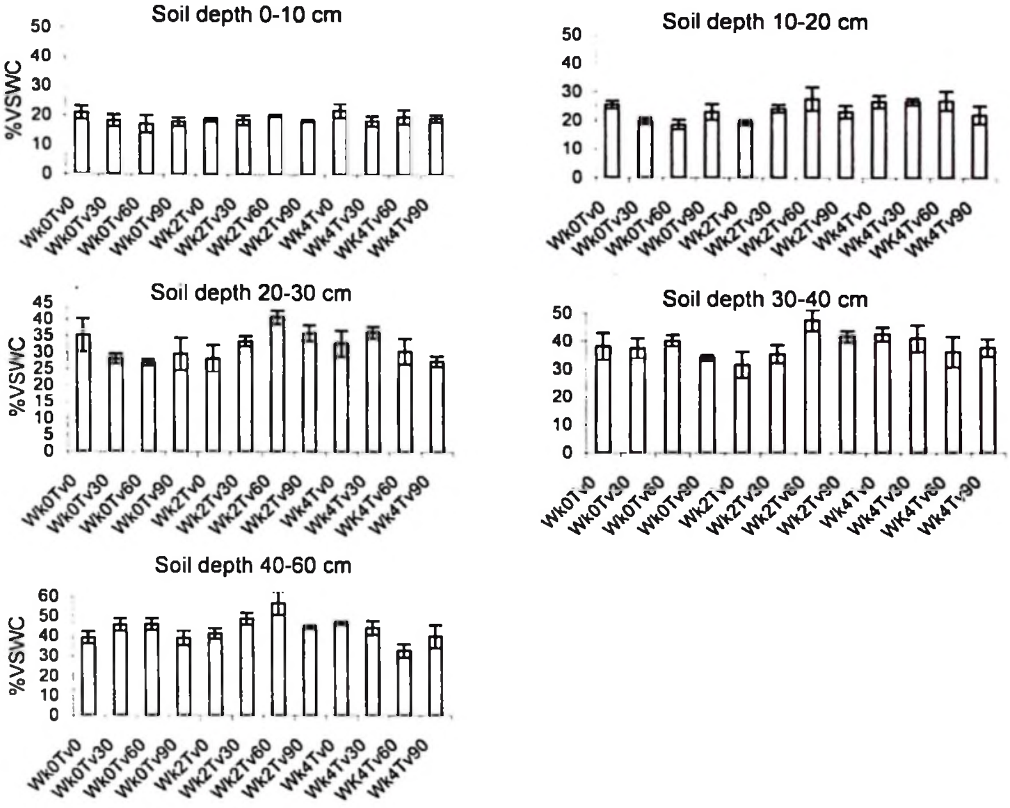

Figure 18: The effect of interaction of time of planting and spacing of *T. vogelii* on soil moisture content for the month of March 2002 in relay intercropping experiment at Gairo, Tanzania (±=standard error).

Note: The acronym %VSMC on the vertical axis represents percent by volume soil moisture content

4.1.6 Effect of time of planting and spacing of shrub on components performance in intercropping period.

4.1.6.1 Effect of time of planting and spacing on *Tephrosia* performance at three months of growth

The individual effects of time of planting and spacing of *Tephrosia* on average shrub yield and total yield per unit area are given in Table 14. Within time of planting, there were no significant differences (P>0.05) in mean plant total biomass and total biomass per unit area. Week0 however, had the highest mean plant total biomass and the second highest total shrub biomass after Wk2, while Wk4 had the least mean plant total biomass and least total shrub biomass. Within spacing, total biomass was significantly higher (P<0.05) in Tv30 than Tv60 and Tv90, while Tv60 and Tv90 did not differ significantly. There were no significant (P<0.05) differences in mean shrub total biomass.

The effect of the interaction of time of planting and spacing of *Tephrosia* is given in Figure 19. Mean plant total biomass did not differ, but total shrub biomass was significantly (P<0.05) higher in Wk2Tv30 plots than the rest of the treatments. The same treatment also maintained highest mean plant and total biomass, while Wk2Tv90 had the least of the two parameters.

Table 14: Individual effects of time of planting and spacing of *T. vogelii* on shrub performance during intercropping phase (three months) in relay intercropping experiment at Gairo, Tanzania

Treatment	Plant parameter: Mean plant total biomass (g/plant)	Total shrub biomass (Kg ha^{-1})	N
	Effect of time of planting		
Week0	0.636^a (0.139)[1]	40.03^a (11.8)	9
Week2	0.574^a (0.139)	43.53^a (16.9)	9
Week4	0.512^a (0.120)	35.67^a (11.0)	9
P< 0.05	0.698	0.876	
	Effect of spacing		
Tv30	0.602^a (0.168)	66.83^a (18.6)	9
Tv60	0.588^a (0.111)	32.67^b (6.1)	9
Tv90	0.533^a (0.116)	19.73^b (4.3)	9
P< 0.05	0.880	0.024	

[1]Standard error; Means in the same column within each factor followed by the same letter are not significantly different (P=0.05) by DMRT.

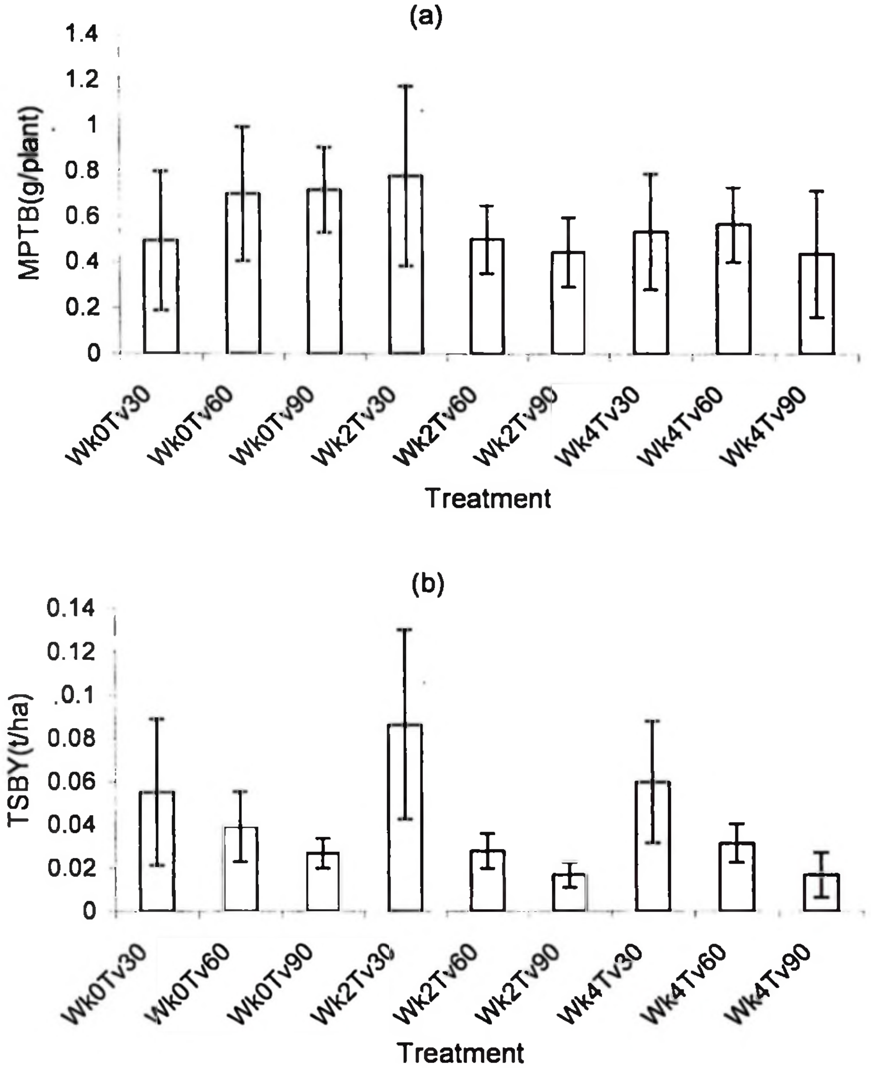

Figure 19: Mean *T. vogelii* total biomass (a) and total shrub biomass yield (b) as affected by the interaction of time of planting and spacing at three month of growth in relay intercropping experimented at Gairo, Tanzania (±=standard error, n=3).

Note: MPTB=mean plant total biomass, TSBY=total shrub biomass yield

4.1.6.2 Effect of time of planting and spacing of *Tephrosia* on maize performance during intercropping phase

Maize grain and stover yield as well as height growth did not differ significantly (P>0.05) within time of planting and spacing of *Tephrosia* (Figures 20 and 21). However, week2 time of planting and Tv60 spacing maintained highest grain yield. Week2 time of planting maintained six and seven percent increase over week0 and week4 respectively, while Tv60 spacing recorded up to 11 percent increase over Tv0 plots. The same two treatments maintained highest maize height within both time of planting and spacing. From Table 13 and Figures 20 and 21, at maize tasselling, biomass accumulated by maize in the form of stover was by far greater than that by *Tephrosia*, with 0.067 t ha^{-1} and 6.218 t ha^{-1} of *Tephrosia* and maize biomass respectively.

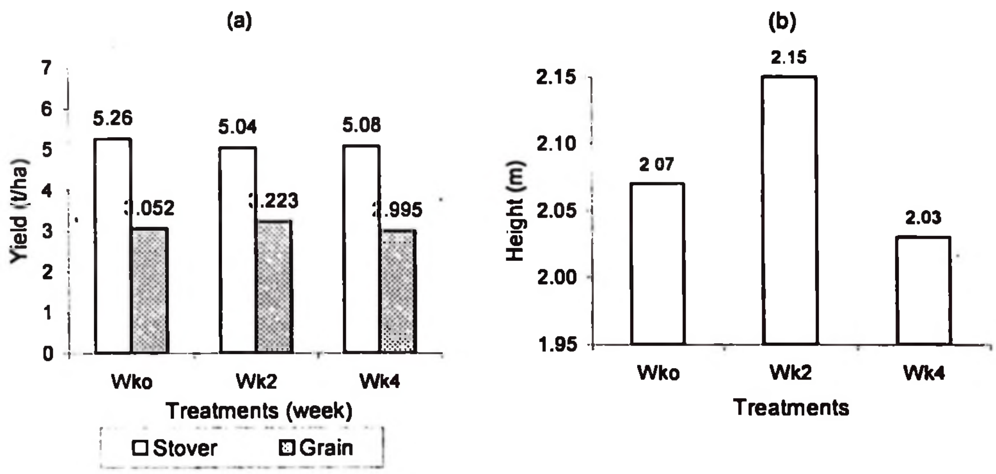

Figure 20: Effect of time of planting *T. vogelii* on maize yield (a) and height (b) during intercropping phase in relay intercropping experiment at Gairo, Tanzania

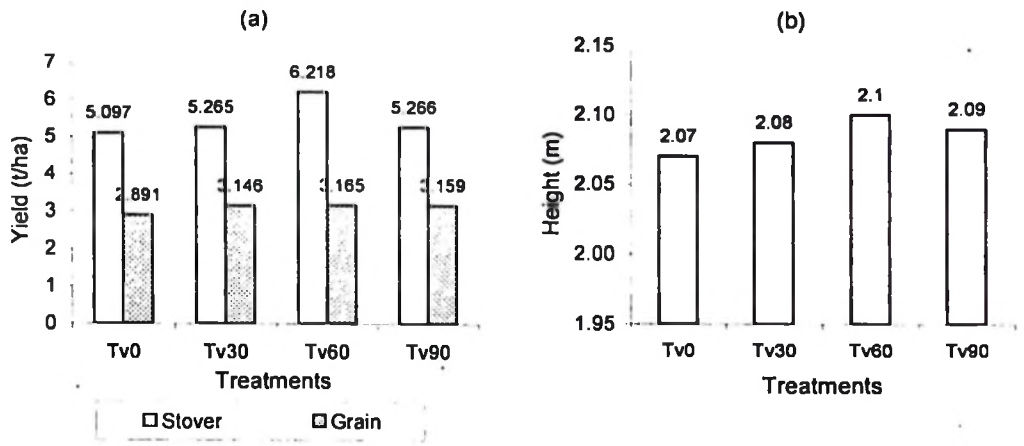

Figure 21: Effect of spacing *T. vogelii* on maize yield (a) and height (b) during intercropping phase in relay intercropping experiment at Gairo, Tanzania

The effect of the interaction on time of planting and spacing of *Tephrosia* on maize yield and height growth is given in Figure 22. There were still no significant (P>0.05) differences among treatments in grain yield, except that the interaction of Wk2 time of planting and spacing Tv60 recorded highest maize grain yield (3.54 t ha^{-1}) and Wk0Tv0 (control) had the lowest grain yield (2.77 t ha^{-1}). Stover yield however was significantly (P<0.05) higher in Wk2Tv60 than most treatments. The effect of interaction of time of planting and spacing on height growth was not significant (P>0.05).

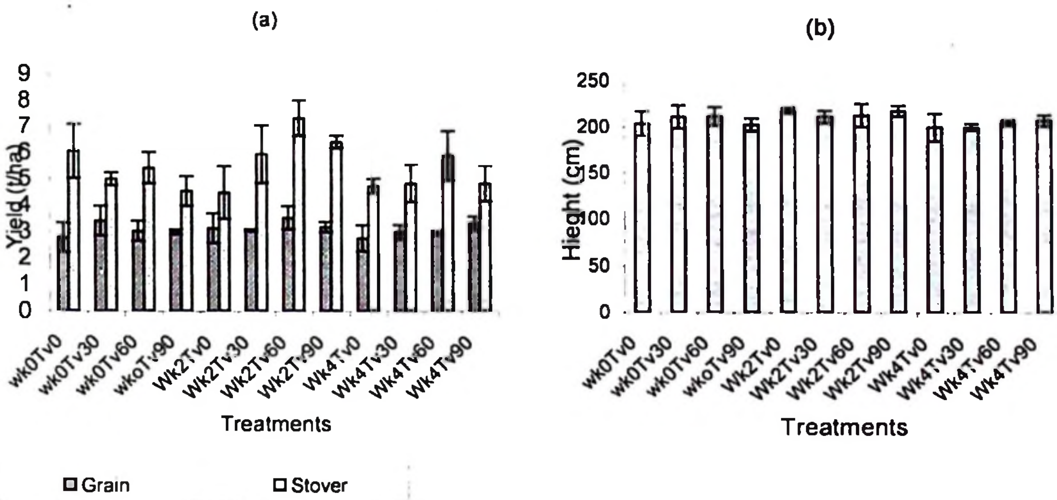

Figure 22: The effect of the interaction of time of planting and spacing of *T. vogelii* on maize yield and height growth during intercropping phase in relay intercropping experiment at Gairo, Tanzania (±standard error, n=3)

4.2 Effect of Time of Planting and Spacing of *Tephrosia* on the Performance of Shrub Following the Removal of Maize

4.2.1 Effect of time of planting and spacing of *Tephrosia* on average plant performance at six and eleven months

Mean shrub performance in the form of mean shrub biomass, mean shrub diameter and mean shrub height as affected by individual time of planting and spacing at six and eleven months of growth are given in Table 15. Within time of planting, significant (P<0.05) differences were recorded at six months but none at eleven months. At six months, Wk2 time of planting was significantly (P<0.05) higher in mean plant total biomass, mean shrub diameter and mean shrub height than Wk4, but not significantly higher (P<0.05) than Wk0, and Wk0 and Wk4 did not differ (P>0.05) significantly. At eleven months, Wk0 maintained highest mean plant performance in all cases.

Table 15: Effect of individual factors of time of planting and spacing of *T. vogelii* on mean shrub performance at six and eleven months of growth in relay intercropping experiment at Gairo, Tanzania

Treatment	*Tephrosia* at six months				*Tephrosia* at eleven months			
	msb[2] (g/plant)	msd[3] (cm)	msh[4] (cm)	N	msb (g/plant)	msd (cm)	msh (cm)	N
			Effect of time of planting					
Wk0	113.07^{ab} (25.73)	0.44^{ab} (0.04)	44.96^{a} (4.23)	9	249.18^{a} (31.43)	1.74^{a} (0.09)	128.62^{a} (6.06)	18
Wk2	123.61^{a} (10.79)	0.484^{a} (0.02)	51.77^{a} (1.33)	9	224.30^{a} (36.38)	1.66^{a} (0.11)	121.75^{a} (6.21)	18
Wk4	42.54^{b} (7.71)	0.33^{b} (0.03)	30.68^{b} (1.46)	9	232.04^{a} (36.26)	1.68^{a} (0.11)	116.51^{a} (7.66)	18
			Effect of spacing					
Tv30	92.90^{a} (25.21)	0.40^{a} (0.04)	43.50^{a} (4.77)	9	102.15^{c} (16.62)	1.25^{c} (0.08)	97.04^{b} (6.03)	9
Tv60	106.12^{a} (21.64)	0.45^{a} (0.03)	45.17^{a} (3.98)	9	128.29^{c} (17.42)	1.40^{c} (0.07)	100.80^{b} (3.67)	9
Tv90	80.21^{a} (13.34)	0.41^{a} (0.03)	38.74^{a} (3.06)	9	128.92^{c} (23.69)	1.39^{c} (0.10)	97.64^{b} (6.94)	9
Tvm30	nd	nd	nd		287.59b (32.76)	1.87^{b} (0.10)	147.62^{a} (4.31)	9
Tvm60	nd	nd	nd		373.30^{a} (34.16)	2.11^{a} (0.07)	145.49^{a} (5.32)	9
Tvm90	nd	nd	nd		390.79^{a} (36.11)	2.13^{a} (0.07)	145.16^{a} (4.06)	9

Note: [2]mean shrub biomass, [3] mean shrub diameter, [4]mean shrub height; Means in the same column within each factor followed by the same letter are not significantly different (P=0.05) by DMRT; nd stands for no data

Within spacing there were no significant (P>0.05) differences in all cases of mean shrub performance at six months, but significant (P<0.05) differences were recorded at eleven months, where monoculture plots maintained superiority in all cases of mean shrub performance over intercropped plots. Intercropped plots did not differ significantly either among themselves, though Tv60 maintained superiority over others. Within monoculture plots, Tvm60 also maintained superiority over others at eleven months.

4.2.2 Effect of time of planting and spacing of *Tephrosia* on total shrub performance (above ground) at six and eleven months

The individual effects of time of planting and spacing of *Tephrosia* on shrub foliar, wood and total biomass yield and survival at sixth and eleventh months of assessment are given in Table 16. There was significant (P<0.05) difference within time of planting in foliar, wood and total biomass at six month, but not at eleven months. Week2 time of planting was significantly (P<0.05) higher in foliar, wood and total biomass than Wk4, but Wk2 and Wk0, and Wk0 and Wk4 did not differ significantly (P>0.05). There was also no significant (P>0.05) difference in survival rate within time of planting at both six and eleven months.

At six months, there were significant (P<0.05) differences within spacing in foliar, wood and total biomass and survival rate. The spacing Tv30 was significantly (P<0.05) higher in foliar and total biomass than the rest, while with regard to wood biomass, Tv30 was significantly (P<0.05) higher than Tv90 only, and Tv30 and Tv90 were significantly (P<0.06) higher (82% and 83% respectively) in survival rate than Tv60 (63%) at six months. All four parameters (foliar, wood, total biomass and survival rate) were not determined at six months for monoculture plots (i.e., Tvm30, Tvm60, and Tvm90).

At eleven months, significant differences were recorded within spacing. The spacing of Tvm30 and Tvm60 were significantly ($P<0.05$) higher in foliar, wood and total biomass than the rest, while Tvm90 (monoculture plot) was significantly ($P<0.05$) higher for the same parameters than all intercropped plots, hence monoculture plots were significantly ($P<0.05$) higher in foliar, wood and total biomass than intercropped plots.

Within intercropped plots, Tv30 was significantly higher in all three forms of biomass than Tv90; but Tv30 and Tv60, and Tv60 and Tv90 did not differ significantly ($P>0.05$). Among the six treatments in the eleventh months of assessment, the highest total biomass was maintained by Tvm30 (13.407 t ha^{-1}), followed by Tvm60 (12.248 t ha^{-1}) and Tvm90 (8.845 t ha^{-1}), all of which were monoculture plots, while the least was Tv90 (2.929 t ha^{-1}), an intercropped plot. Foliar and wood biomass yield were in the same order.

Table 16: Effect of individual factors of time of planting and spacing of *T. vogelii* on shrub performance per unit area in relay intercropping experiment at Gairo, Tanzania

Treatment	*Tephrosia* at six months				*Tephrosia* at eleven months			
	Foliar (t ha^{-1})	Wood (t ha^{-1})	TotB[5] (t ha^{-1})	Survival (%)	Foliar (t ha^{-1})	Wood (t ha^{-1})	TotB (t ha^{-1})	Survival (%)
				Effect of time of planting				
Wk0	0.74^{ab} (0.20)	5.33^{ab} (1.69)	6.36^{ab} (1.92)	72.25^{a} (4.44)	3.41^{a} (0.41)	5.50^{a} (0.76)	9.04^{a} (1.18)	59.87^{a} (3.18)
Wk2	0.93^{a} (0.19)	6.35^{a} (1.39)	7.76^{a} (1.67)	81.67^{a} (4.65)	2.56^{a} (0.32)	4.03^{a} (0.56)	6.59^{a} (0.89)	56.92^{a} (3.55)
Wk4	0.33^{b} (0.05)	1.64^{b} (0.27)	2.19^{b} (0.36)	75.18^{a} (4.15)	3.24^{a} (0.51)	4.85^{a} (0.81)	8.21^{a} (1.35)	58.30^{a} (3.47)
				Effect of spacing				
Tv30	1.03^{a} (0.24)	6.97^{a} (1.98)	8.51^{a} (2.28)	82.62^{a} (3.65)	2.31^{c} (0.43)	3.47^{c} (0.68)	5.85^{c} (1.12)	55.13^{a} (4.56)
Tv60	0.64^{b} (0.10)	4.33^{ab} (0.89)	5.29^{b} (1.01)	63.15^{b} (1.85)	1.87^{cd} (0.20)	2.66^{cd} (0.30)	4.42^{cd} (0.47)	62.35^{a} (2.35)
Tv90	0.32^{b} (0.05)	2.02^{b} (0.40)	2.53^{b} (0.47)	83.33^{a} (3.85)	1.20^{d} (0.25)	1.69^{d} (0.35)	2.93^{d} (0.60)	62.59^{a} (6.57)
Tvm30	nd	nd	nd	nd	4.83^{a} (0.51)	8.38^{a} (0.93)	13.41^{a} (1.45)	47.97a (5.54)
Tvm60	nd	nd	nd	nd	4.73^{a} (0.49)	7.31^{a} (0.74)	12.25^{a} (1.25)	59.63^{a} (3.07)
Tvm90	nd	nd	nd	nd	3.46^{b} (0.36)	5.25^{b} (0.58)	8.84^{b} (0.94)	62.50^{a} (4.22)

Note: [5]Total biomass; Means in the same column within each factor followed by the same letter are not significantly different (P=0.05) with standard error in parentheses; nd stands for no data

There was no significant (P>0.05) difference in survival rate within spacing at the eleven months, but the highest was Tv60 (62%) and the least was Tvm30 (48%).

4.2.3 Effect of interaction of time of planting and spacing of *Tephrosia* on shrub performance (above ground) at six and eleven months of growth

The effect of the interaction of time of planting and spacing of *Tephrosia* on the performance of shrub at six months is given in Figure 23. With regard to mean plant parameters (i.e., mean plant biomass, height and diameter), Wk2 in combination with all levels of spacing were significantly higher than other treatments except Wk0Tv30 and Wk0Tv60, which in some cases were also significantly higher than the rest. Within each level of time of planting in combination with spacing there were no significant differences, except that within Wk2, the treatment Wk2Tv30 maintained highest position while Wk2Tv90 had the lowest; and within Wk4, Wk4Tv90 recorded highest followed by Wk4Tv60.

With total biomass yield per unit area (i.e., foliar, wood and total biomass), Wk2Tv30 maintained highest level over others, and was significantly higher than all except Wk0Tv30. Within Wk2 combinations, the same treatment Wk2Tv30 maintained significantly higher level over others with the least being Wk2Tv90. All Wk4 combinations were low and the lowest of all Wk4 was Wk4Tv90. In general, performance of shrub with regard to shrub yield per plant and total shrub yield per unit area, showed opposite trends. Within Wk4 combinations especially, mean shrub performance was increasing with increasing spacing while total shrub performance was decreasing with increasing spacing.

The average shrub performance as affected by the interaction of time of planting and spacing at eleven months are given in Figures 24 and 25 while total shrub performance as affected by the interaction of time of planting and spacing at eleven months is presented in figures 26, 27 and 28. The results, which included *Tephrosia* monoculture and intercrop plots generally showed all monoculture plots to be significantly higher in nearly all cases. With respect to average shrub parameters, performance of shrub was distinctly increasing with increasing spacing in nearly all cases, especially for monoculture plots. Within intercropped plots, the treatment Wk0Tv90 maintained the highest level in all cases and in most cases significantly higher, while within monoculture plots, Wk0Tvm90 was highest in most cases. With regard to mean shrub biomass, monoculture plots were two to five times higher than intercrop plots. With mean shrub growth increment, mean shrub biomass increment and mean shrub diameter increment were significantly higher in Wk0Tv90 treatment than others (Fig. 25). With respect to total, foliar and wood biomass yield per unit area at eleven months, the trend was almost completely opposite that of average plant performance. While the latter was increasing with increase in spacing, the former was decreasing with increase in spacing, for both intercrop and monoculture plots. Like with average shrub performance, monoculture plots were in all cases significantly higher than intercrop plots, and the highest biomass yield was attained by the treatment Wk0Tvm30, which in most cases was also significantly higher than the rest, while Wk2Tv90 recorded the least. Within intercropped plots there were no significant differences in most cases, but Tv30 combinations attained the highest biomass, while Tv90 combinations recorded the least biomass at all planting times.

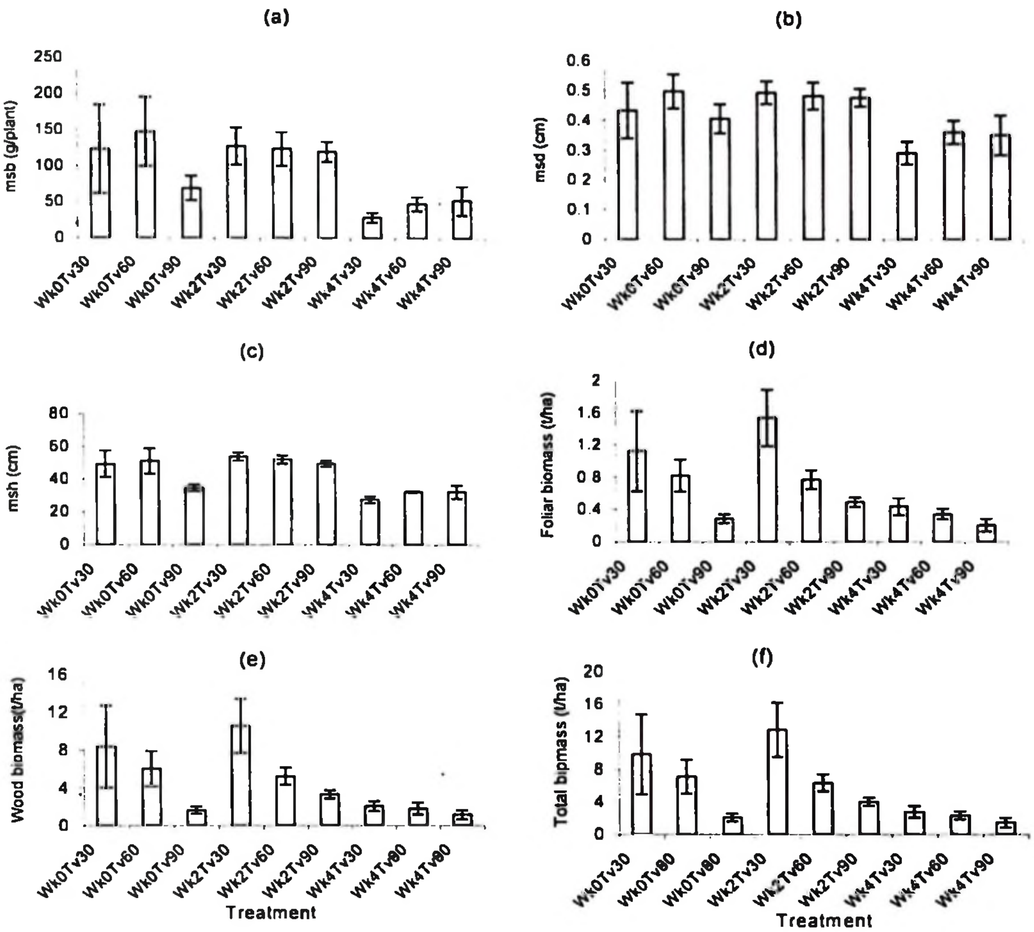

Figure 23: Effect of the interaction of time of planting and spacing on mean shrub biomass (a), mean shrub diameter (b), mean shrub height (c), foliar biomass (d), wood biomass (e) and total biomass (f) of *T. vogelii* at six months of growth in relay intercrpping at Gairo, Tanzania (± standard error, n=3)

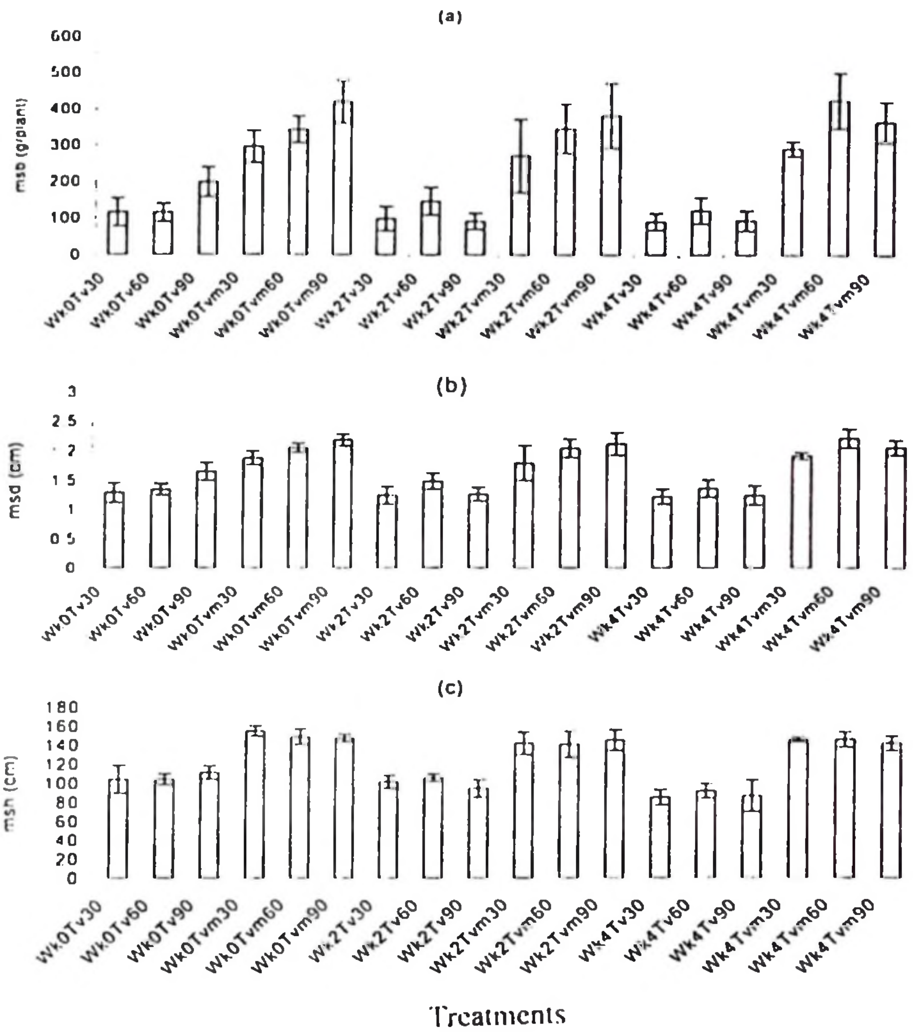

Figure 24: The effect of the interaction of time of planting and spacing on mean shrub biomass (a), mean shrub diameter (b) and mean shrub height (c) of *T. vogelii* at eleven months growth in relay intercropping experiment at Gairo, Tanzania (± standard error, n=3)

Note: The acronyms msb= mean plant biomass, msd= mean plant diameter and msh= mean plant height

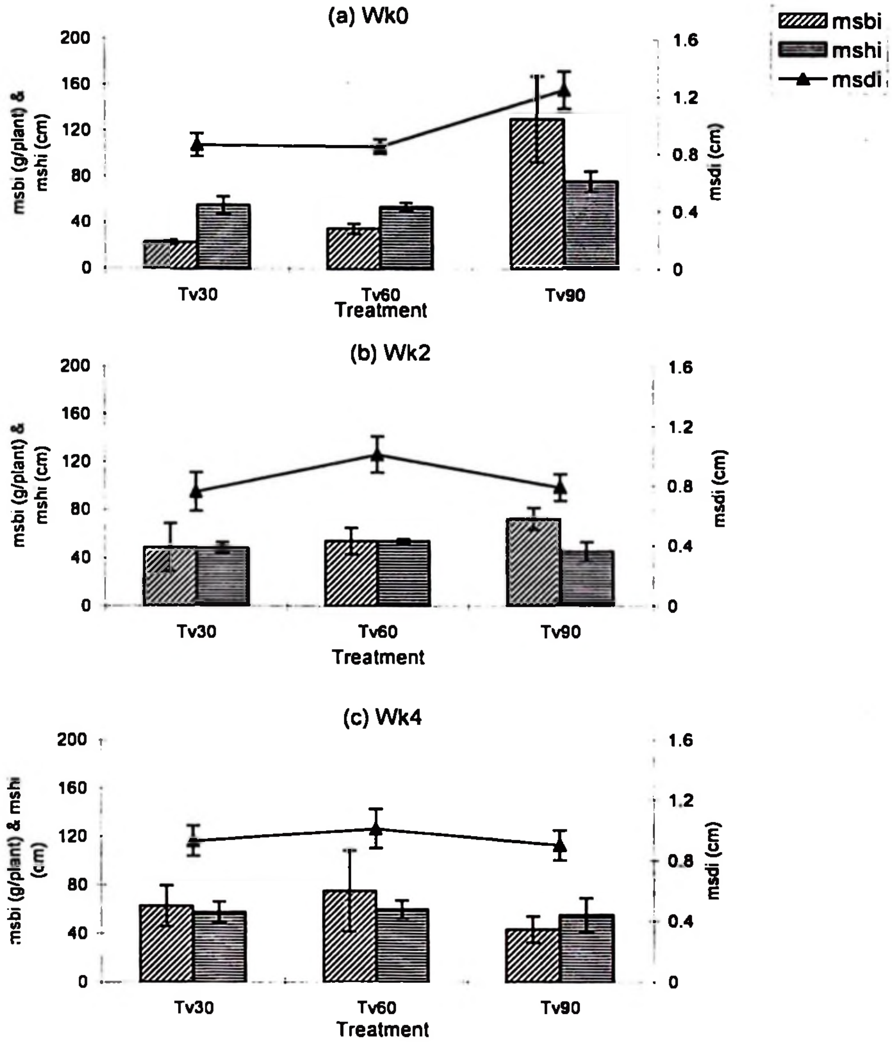

Figure 25: Interaction effect of time planting and spacing on mean shrub biomass increment, mean shrub height increment and mean shrub diameter increment between sixth and eleventh month's assessments for intercrops in relay intercropping at Gairo, Tanzania

Note: The acronyms in the charts msbi= mean shrub biomass increment, mshi= mean shrub height increment and msdi= mean shrub diameter increment

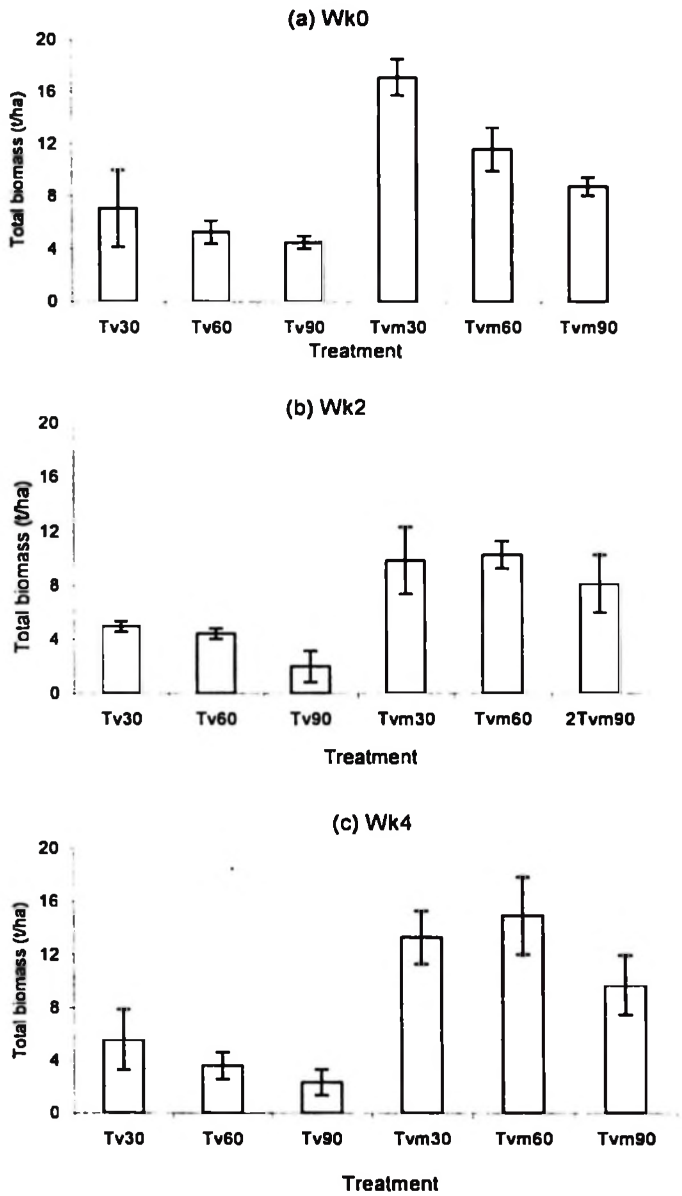

Figure 26: The interaction effect of time of planting and spacing on total biomass of *T. vogelii* at eleven months growth in relay intercropping experiment at Gairo, Tanzania (± standard error, n=3)

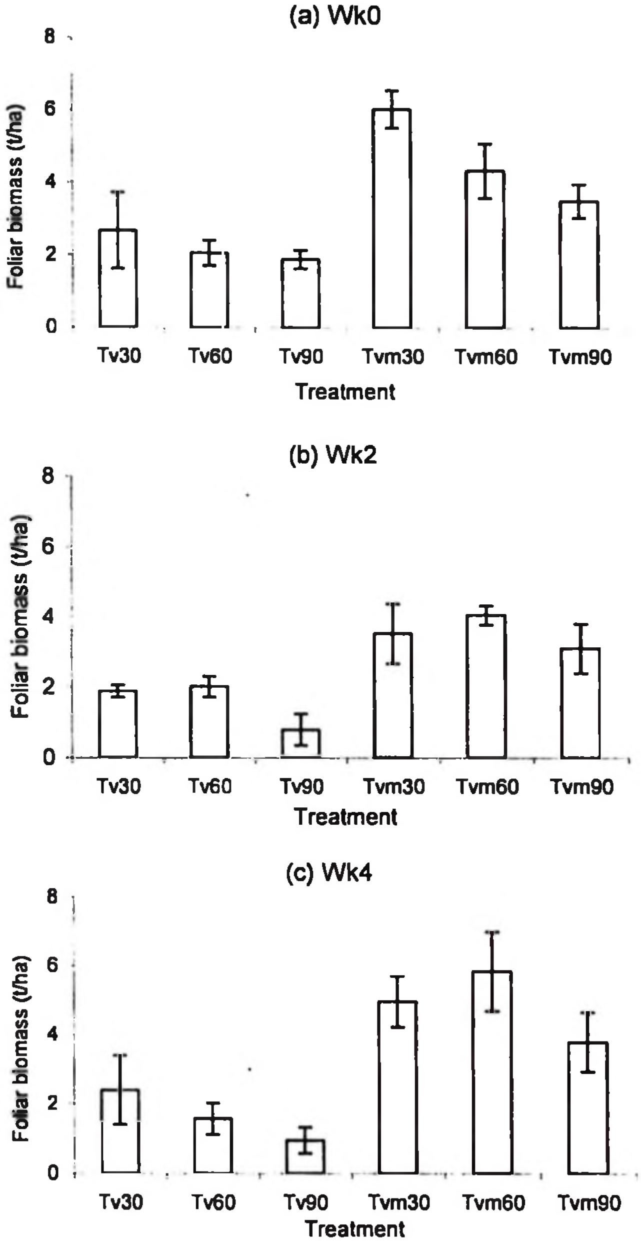

Figure 27: The interaction effect of time of planting and spacing on foliar biomass of *T. vogelii* at eleven months growth in relay intercropping experiment at Gairo, Tanzania (± standard error, n=3)

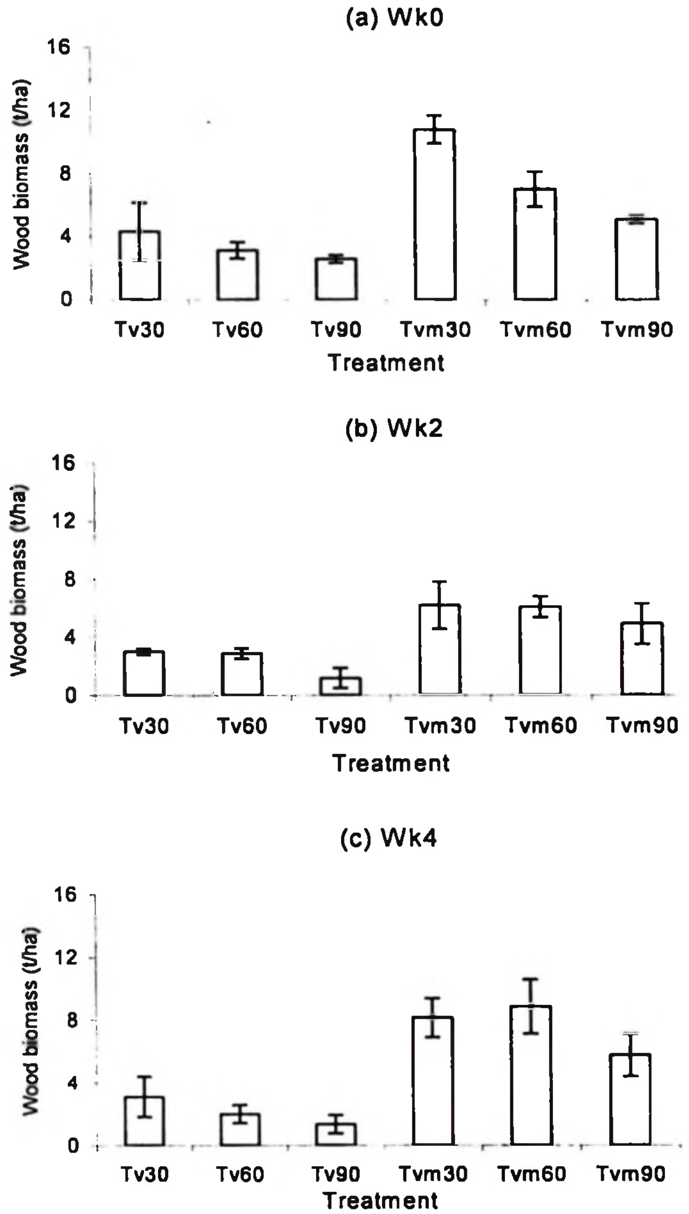

Figure 28: The interaction effect of time of planting and spacing on wood biomass of *T. vogelii* at eleven months growth in relay intercropping experiment at Gairo, Tanzania (± standard error, n=3)

Table 17: *T. vogelii* small root biomass as affected by individual factors of time of planting and spacing of the shrub in relay intercropping experiment at Gairo, Tanzania

	Soil depth (cm)			
Treatment	0-15	15-30	30-50	N
		Effect time of planting (kg ha^{-1})		
Week0	7.83^{b} (0.52)^{1}	8.16^{a} (0.49)	5.70^{a} (0.40)	18
Week2	9.17^{a} (0.49)	8.06^{a} (0.47)	4.73^{a} (0.29)	18
Week4	7.73^{b} (0.55)	7.80^{a} (0.43)	5.38^{a} (0.34)	18
		Effect of spacing (kg ha^{-1})		
Tv30	8.52^{a} (0.73)	7.86^{ab} (0.77)	5.01^{a} (0.39)	9
Tv60	8.75^{a} (0.88)	7.59^{ab} (0.46)	4.90^{a} (0.47)	9
Tv90	7.04a (0.49)	6.93^{b} (0.60)	4.85^{a} (0.61)	9
Tvm30	8.21^{a} (0.90)	9.17^{a} (0.64)	6.18^{a} (0.66)	9
Tvm60	8.16^{a} 0.61	8.00^{ab} (0.56)	5.18^{a} (0.48)	9
Tvm90	8.87^{a} (0.87)	8.51^{ab} (0.70)	5.50^{a} (0.32)	9

Note: Means in the same column within each factor followed by the same letter do not differ significantly (P=0.05) by DMRT;

4.2.4 Effect of time of planting and spacing of *Tephrosia* on shrub small root biomass yield at eleven months

Small root biomass yield differed significantly only at sampling depth 0-15 cm within time of planting, where Wk2 was significantly (P<0.05) higher than Wk0 and Wk4, but at depths two and three, Wk0 maintained higher small root biomass over others (Table 17). Within spacing, significant difference was recorded only at sampling depth two (15-30 cm), where Tvm30 (monoculture plot) was significantly higher than Tv90 (intercropped). At depth one (0-15 cm), though not significantly different, Tvm90 maintained highest small root biomass (8.875 Kg ha^{-1}) while Tvm30 was highest (6.177 Kg ha^{-1}) at depth three (30-50 cm).

4.3 Effect of Time of Planting and Spacing of *Tephrosia* on Selected Soil Properties and Crop Performance in First and Second Seasons after *Tephrosia* Removal

4.3.1 Effect of time of planting and spacing of *Tephrosia* on selected soil properties

4.3.1.1 Effect of time of planting and spacing of *Tephrosia* on soil bulk density and organic carbon at eleven months

Effects of time of planting and spacing of *Tephrosia* on soil bulk density are given in Table 18, while those of organic carbon are given in Figures 29 and 30. Within time of planting, soil bulk density did not differ significantly at all soil depths, but the least bulk density was recorded in Wk0 at all soil depths, while the highest was recorded in week4 at depth 0-10 and 10-20 cm and week2 at 20-30 and 30-50 cm. Within spacing, significant difference ($P<0.05$) was recorded only at depth 0-10 cm where Tv60 was higher than Tv30, while the rest did not differ significantly ($P>0.05$).

Soil OC did not differ significantly ($P>0.05$) within time of planting in the top 15 cm, but within spacing Tv0 was significantly lower ($P<0.05$) than treatment plots and Tvm90 was significantly higher ($P<0.05$) than other treatments.

Table 18: Individual effect of the factors of time of planting and spacing on soil bulk density at 11 months of *T. vogelii* growth in relay intercropping experiment at Gairo, Tanzania

Treatment	Soil depth (cm)				N
	0-10	10-20	20-30	30-50	
	Effect of time of planting				
Week0	1.25^{a} (0.02)[1]	1.27^{a} (0.03)	1.30^{a} (0.03)	1.353^{a} (0.02)	12
Week2	1.25^{a} (0.01)	1.29^{a} (0.02)	1.33^{a} (0.02)	1.38^{a} (0.02)	12
Week4	1.29^{a} (0.02)	1.32^{a} (0.01)	1.33^{a} (0.01)	1.35^{a} (0.02)	12
	Effect of spacing				
Tv0	1.27^{ab} (0.01)	1.28^{a} (0.02)	1.32^{a} (0.03)	1.39^{a} (0.02)	9
Tv30	1.24^{b} (0.02)	1.27^{a} (0.03)	1.30^{a} (0.04)	1.34^{a} (0.02)	9
Tv60	1.29^{a} (0.02)	1.30^{a} (0.02)	1.32^{a} (0.02)	1.33^{a} (0.02)	9
Tv90	1.25^{ab} (0.02)	1.33^{a} (0.01)	1.33^{a} (0.01)	1.37^{a} (0.03)	9

Note: Means in the same column within each factor followed by the same letter do not differ significantly (P=0.05)

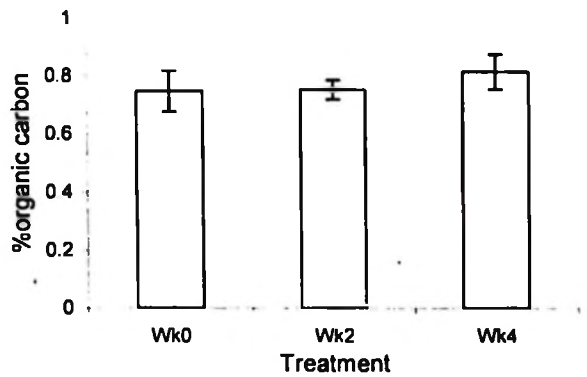

Figure 29: Effect of time of planting *T. vogelii* on soil organic carbon content in relay intercropping experiment at Gairo, Tanzania (± standard error).

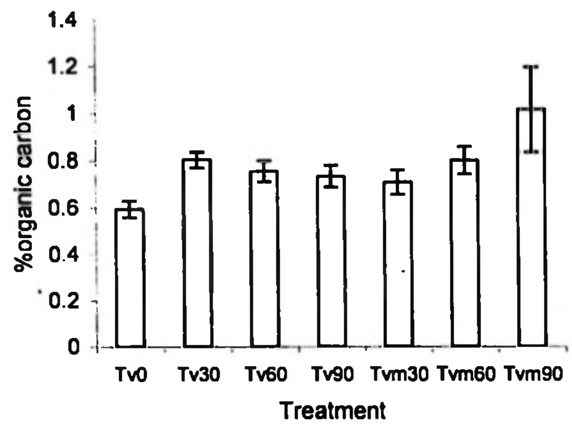

Figure 30: Effect of spacing of *T. vogelii* on soil organic carbon content in relay intercropping experiment at Gairo, Tanzania (±standard error).

4.3.1.2 Effect of time of planting and spacing of *Tephrosia* on field mineral nitrogen following intercropping phase

The residual effect of time of planting and spacing of *Tephrosia* on field mineral N (Min-N) in the form of nitrate (NO_3-N), ammonium (NH_4-N) and total mineral N (Total Min-N) for first and second residual seasons are presented in Figures 31 and 32 respectively. In the first residual season, NO_3-N and NH_4-N did not differ significantly within time of planting, but week0 maintained relatively higher level of NO_3-N over other treatments for all four sampling dates, while NH_4-N did not show any particular trend except that it had sharp upsurge at week four sampling date from about 40 to about 80 mg/Kg (Fig. 31). Total mineral N did differ significantly either in first residual season except at week two sampling date when week0 was significantly higher than the rest, the same maintaining slightly higher level over the others at other sampling dates. Generally, there has been a decline in field mineral-N from initial sampling time (week0) to time sixth sampling in the first residual season, except at time four, which showed a sharp increase from time two.

In the second residual season, NO_3-N showed some significant differences at sampling time four and six within time of planting. At time four, week0 was significantly ($P<0.05$) higher than both week2 and week4; and at time six, week4 was significantly ($P<0.05$) higher than both week0 and week2, while week0 was significantly ($P<0.05$) higher than week2. Ammonium-N did not differ significantly in second residual season and showed no particular trend, while total mineral-N showed exactly the same trend as NO_3-N. In general, mineral-N showed a gradual decline from initial to time four and a sudden upsurge at time six (Fig. 31b1, b2 and b3).

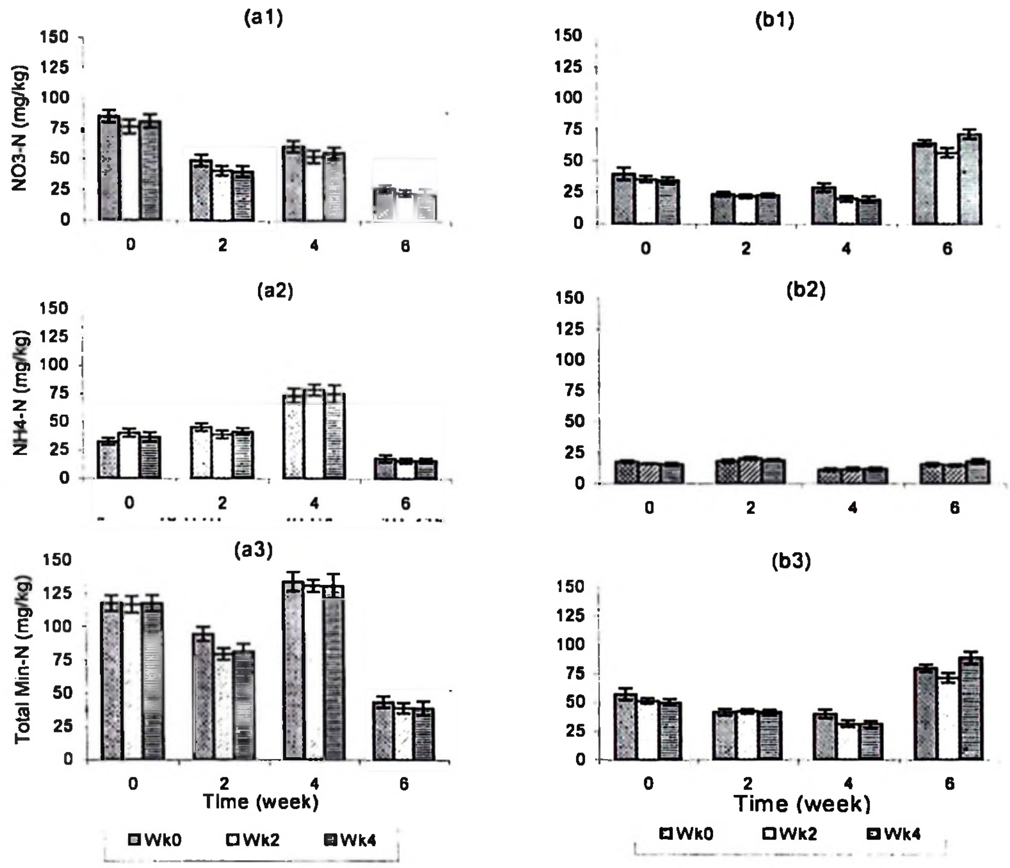

Figure 31: Nitrate nitrogen, ammonium nitrogen and total mineral nitrogen as effected by time of planting *T. vogelii* in first (a) and second (b) subsequent cropping seasons following relay intercropping at Gairo, Tanzania (± standard error).

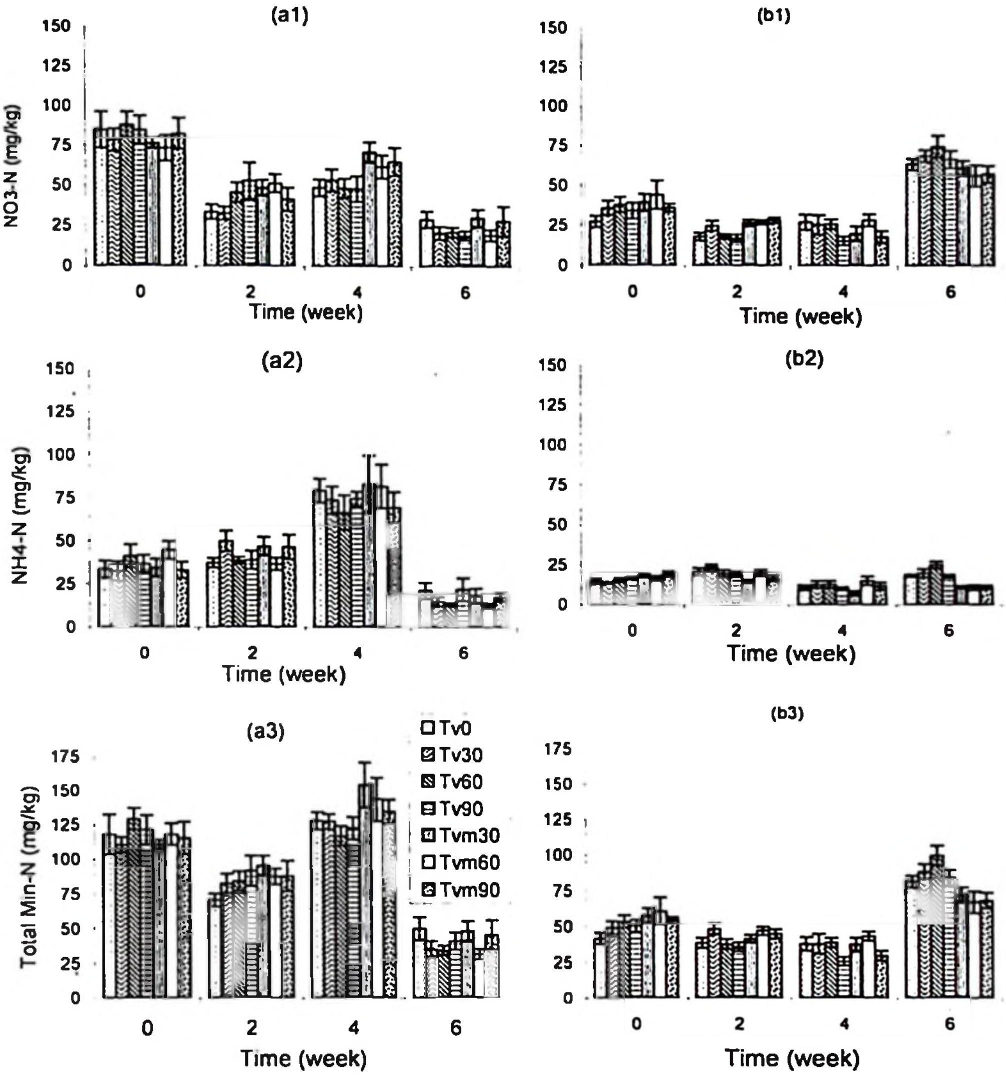

Figure 32: Soil nitrate nitrogen, ammonium nitrogen and total mineral nitrogen as affected by spacing of *T. vogelii* in first (a) and second (b) subsequent seasons following relay intercropping at Gairo, Tanzania (± standard error).

Within spacing in the first residual season, no particular trend was observed at sampling time zero and differences were not significant. Significant differences were recorded at sampling time two with some trend. The control plot (Tv0) was significantly lower than most treatments, especially for NO_3-N and total mineral-N; and monoculture plot of *Tephrosia* maintained slightly higher levels of mineral-N over intercropped plots. At times four and six, a few significant differences were recorded but without specific trend, except that monoculture plots of *Tephrosia* maintained slightly higher levels of mineral-N more frequently over intercropped plots and control plots had often shown higher levels of mineral-N over some treatments. Although a gradual decline in mineral-N from initial sampling to time six was noted, a sharp upsurge at time four as with time of planting was observed too. In second residual season, significant differences were recorded but without any specific trend, except that at sampling time zero, monoculture plots showed slightly higher levels of mineral-N over most intercropped plots, but the trend was reversed at time six, which also showed a sharp rise of mineral-N.

4.3.2 Effect of time of planting and spacing of *Tephrosia*, and fertilization on maize crop performance in first and second residual seasons

4.3.2.1 Individual effect of time of planting and spacing of *Tephrosia* and fertilization on maize shaft, stover and grain yield in first and second residual seasons

The data for the individual effect of time of planting, spacing and fertilization on maize stover, shaft and grain yield is given Table 19. Within time of planting and fertilization there were no significant differences in shaft, stover, and grain yield in both first and second residual seasons and no particular trend was observed. Within fertilization however, fertilized plots maintained slightly higher biomass yields over unfertilized. Within spacing, stover biomass was significantly ($P<0.05$) higher in all intercrop and control plots than all monoculture plots, while shaft yield was significantly higher in all monoculture plots than intercrop and control plots in the first residual season. Within intercropped plots plus control, no significant ($P>0.05$) differences were recorded in stover and shaft yield, and maize grain yield did not differ significantly ($P<0.05$) among all treatments in the first residual season. However, highest grain yield was recorded in

Tvm90 (3.678 t ha^{-1}) while the least was recorded in Tv0 (control) plot (3.08 t ha^{-1}). Unlike in the first residual season, effects of treatments on stover and shaft yield in the second residual season did not follow any particular trend except that stover yield in Tvm60 (monoculture plot) was significantly ($P<0.05$) higher than only Tv30 (intercropped plot), while the rest did not differ significantly ($P>0.05$). Maize grain yield in this season was significantly ($P<0.05$) higher in Tvm90 (monoculture plots) than control and Tv90 plots, while the rest did not differ significantly ($P>0.05$). A particular trend observed here was that grain yield in monoculture plots were higher than those of intercropped plots with 4.48 t ha^{-1} and 3.77 t ha^{-1} as the highest in each of the two systems respectively.

Table 19: Individual effects of factors of time of planting and spacing of *T. vogelii* and fertilization on maize biomass and grain yield in the two subsequent seasons following *Tephrosia*-maize intercropping in relay intercropping experiment at Gairo, Tanzania

Treatment	Maize yield in first residual season			Maize yield in second residual season			N
	Stover (t ha^{-1})	Shaft (t ha^{-1})	Grain (t ha^{-1})	Stover (t ha^{-1})	Shaft (t ha^{-1})	Grain (t ha^{-1})	
			Effect of time of planting				
Week0	3.89^{a} ±0.21	1.02^{a} ±0.05	3.36^{a} ±0.13	4.32^{a} ±0.20	0.87^{a} ±0.05	3.80^{a} ±0.14	42
Week2	3.87^{a} ±0.21	0.97^{a} ±0.03	3.59^{a} ±0.11	4.55^{a} ± 0.25	0.85^{a} ±0.04	3.86^{a} ±0.16	42
Week4	3.^{74a} ±0.18	0.93^{a} ±0.03	3.26^{a} ±0.14	4.28^{a} ±0.26	0.93^{a} ±0.04	3.86^{a} ±0.04	42
			Effect of spacing				
Tv0	4.22^{a} ±0.25	0.79^{c} ±0.05	3.08^{a} ±0.26	4.37^{ab}±0.42	0.80^{a} ±0.08	3.61^{b} ±0..26	18
Tv30	4.81^{a} ±0.32	0.87^{c} ±0.05	3.33^{a} ±0.21	3.54^{b} ±0.42	0.96^{a} ±0.05	3.77^{ab} ±0.15	18
Tv60	4.61^{a} ±0.25	0.86^{c} ±0.04	3.27^{a} ±0.19	4.03^{ab}±0.40	0.94^{a}±0.08	3.70^{ab} ±0.25	18
Tv90	4.24^{a} ±0.04	0.86^{c} ±0.04	3.49^{a} ±0.23	4.41^{ab}±0.47	0.80^{a} ±0.05	3.34^{b} ±0.18	18
Tvm30	2.70^{b} ±0.16	1.09^{b} ±0.04	3.48^{a} ±0.13	4.60^{ab}±0.14	0.87^{a} ±0.06	3.98^{ab} ±0.18	18
Tvm60	2.96^{b} ±0.16	1.24^{a} ±0.08	3.50^{a} ±0.16	5.05^{a} ±0.24	0.89^{a} ±0.07	4.03^{ab} ±0.21	18
Tv90	3.29^{b} ±0.15	1.12^{ab}±0.04	3.68^{a} ±0.16	4.67^{ab}±0.32	0.92^{a} ±0.08	4.48^{a} ±0.19	18
			Effect of fertilization				
F0	3.72^{a} ± 0.14	0.97^{a} ±0.04	3.31^{a} ±0.10	4.32^{a} ±0.20	0.81^{a} ±0.03	3.71^{a} ±0.12	63
F1	3.94^{a} ±0.18	0.98^{a} ±0.03	3.49^{a} ±0.10	4.45^{a} ±0.20	0.96^{a} ±0.03	3.98^{a} ±0.11	63

Note: Means in the same column within each factor followed by the same letter are not significantly different (P=0.05) by DMRT; ±standard error.

4.3.2.2 Effect of the interactions of time of planting and spacing of *T. vogelii* and fertilization on maize shaft, stover and grain yield in first and second residual seasons

The effect of interaction of time of planting and spacing of *Tephrosia* on maize stover and grain yields for first and second residual seasons are given in Figures 33 and 34 respectively. With regard to stover yield, intercrop plots maintained significantly higher levels over monoculture plots in the first residual season. The trend was almost the reverse in the second residual season though with only a few significant differences, where monoculture plots were more often on the upper side.

Maize grain yield in response to the interaction of time of planting and spacing ignoring the effect of fertilization did not follow any clear trend among treatments although monoculture plots showed some superiority over intercrops with significant differences in some cases. Also, treatments with *Tephrosia* were slightly than continuous maize cropping (Tv0). This trend of maize performance did not correspond to the trend of *Tephrosia* foliar biomass yield as shown in the chart (Fig. 34). Similarly, the response of maize stover and grain yields to the interaction of time of planting and fertilization showed neither significant differences nor any particular trend (data not presented).

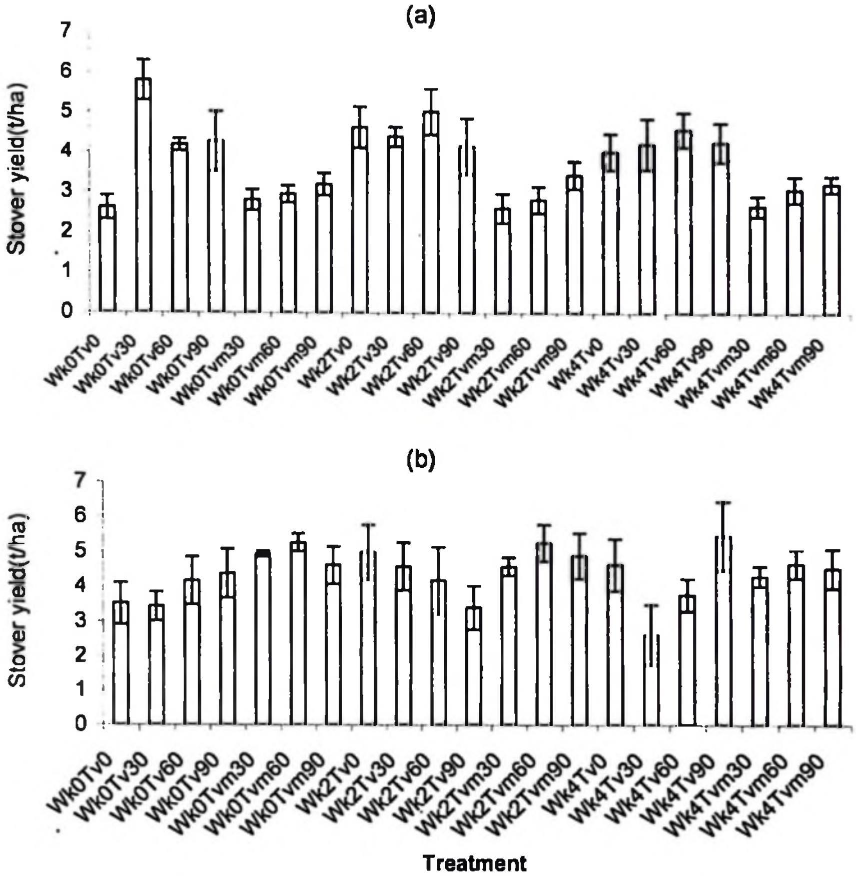

Figure 33: Effect of the interaction of time of planting and spacing of *T. vogelii* on maize stover yield in first (a) and second (b) residual seasons following the removal of shrub in relay intercropping experiment at Gairo, Tanzania (±standard error, n=6)

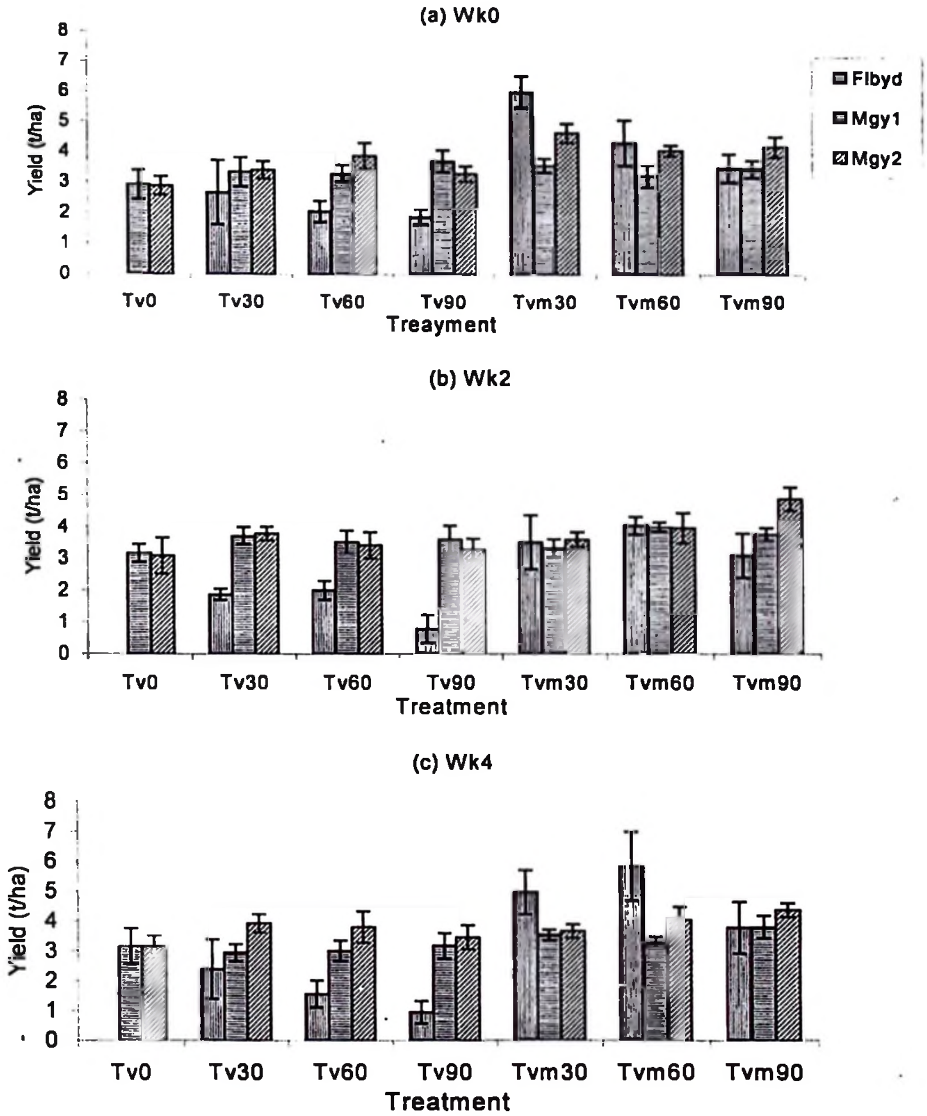

Figure 34: The Interaction effect of time of planting and spacing of *Tephrosia* on maize grain yield for first and second residual seasons along side the *Tephrosia* foliar biomass yields at eleven months growth in relay intercropping experiment at Gairo, Tanzania.

Note: The acronyms in the legend Flbyd= Foliar biomass yield, Mgy1= Maize grain yield in first residual season and Mgy2= Maize grain yield in second residual season

The response of maize stover and grain to the interaction of time of planting, spacing and fertilization for both first and second residual seasons are summarized in Table 20, which again showed no particular consistent trend. Highest stover yields were obtained in fertilized intercropped plots in both first and second residual seasons with treatments Wk0Tv30F1 (6.15 t ha^{-1}) and Wk4Tv90F1 (6.70 t ha^{-1}) respectively, while the least stover yield were most frequently obtained from *Tephrosia* monoculture plots, especially fertilized monoculture plots in the first residual season, given as low as 2.34 t ha^{-1} (Wk2Tv30F1). In the second residual season, lowest stover yields were mostly obtained in intercropped plots, but the differences were as large as in first residual season.

On the other hand, highest grain yields have been obtained with fertilized monoculture plots, but which were not necessarily significantly different from some unfertilized monoculture plots. In the first residual season the treatment Wk4Tvm90F1 was highest in grain yield (4.33±0.27 t ha^{-1}), a fertilized monoculture plot followed by Wk2Tvm60F0 (4.22±0.14 t ha^{-1}) and Wk2Tvm90F0 (4.05±0.14 t ha^{-1}), both unfertilized monoculture plots, while the least was obtained with unfertilized control plot Wk0Tv0F0 (2.70±0.89 t ha^{-1}). However, an unfertilized intercrop plots (Wk2Tv30F0) attained grain yield of 4.04±0.48 t ha^{-1}.

Table 20: The effect of time of planting and spacing of *T. vogelii* and fertilization on mean maize stover and grain yield (± standard error) in relay intercropping experiment at Gairo, Tanzania

Treatment			First residual season		Second residual season		
			Stover (t ha^{-1})	Grain (t ha^{-1})	Stover (t ha^{-1})	Grain (t ha^{-1})	N
Wk0	Tv0	F0	3.97 ±0.07	2.70 ±0.89	4.15 ±0.79	2.56 ±0.42	3
		F1	3.98 ±0.66	3.13 ±0.49	2.86 ±0.84	3.19 ±0.42	3
	Tv30	F0	5.46 ±0.80	3.17 ±0.54	2.57 ±0.24	3.48 ±0.45	3
		F1	6.15 ±0.70	3.49 ±0.90	4.28 ±0.20	3.71 ±0.44	3
	Tv60	F0	4.36 ±0.27	3.27 ±0.52	5.22 ±1.06	3.18 ±0.39	3
		F1	4.02 ±0.11	3.31 ±0.38	3.10 ±0.34	4.58 ±0.54	3
	Tv90	F0	3.51 ±0.81	3.36 ±0.41	3.40 ±0.75	2.86 ±0.30	3
		F1	5.04 ±1.27	4.05 ±0.64	5.33 ±1.01	3.74 ±0.19	3
	Tvm30	F0	2.93 ±0.19	3.55 ±0.44	4.79 ±0.06	4.68 ±0.58	3
		F1	2.69 ±0.53	3.60 ±0.28	5.06 ±0.11	4.65 ±0.40	3
	Tvm60	F0	3.26 ±0.18	3.02 ±0.66	5.33 ±0.48	4.24 ±0.14	3
		F1	2.66 ±0.33	3.47 ±0.40	5.17 ±0.30	3.91 ±0.32	3
	Tvm90	F0	3.21 ±0.42	3.38 ±0.39	3.98 ±0.85	4.06 ±0.66	3
		F1	3.19 ±0.46	3.59 ±0.47	5.24 ±0.56	4.34 ±0.35	3
Wk2	Tv0	F0	4.50 ±0.93	3.11 ±0.31	5.91 ±1.40	3.94 ±0.86	3
		F1	4.77 ±0.67	3.24 ±0.52	4.05 ±0.50	4.24 ±0.90	3
	Tv30	F0	4.73 ±0.17	***4.04 ±0.48***	4.54 ±1.37	***4.04 ±0.27***	3
		F1	4.07 ±0.40	3.38 ±0.20	4.61± 0.70	3.54 ±0.29	3
	Tv60	F0	4.29 ±0.83	3.34 ±0.24	3.33 ±1.60	3.10 ±0.40	3
		F1	5.78 ±0.66	3.72 ±0.73	5.02 ±1.17	3.76 ±0.76	3

Table 20: Continues

Treatment			First residual season		Second residual season		
			Stover (t ha^{-1})	Grain (t ha^{-1})	Stover (t ha^{-1})	Grain (t ha^{-1})	N
Wk2	Tv90	F0	3.82 ±0.61	3.37 ±0.57	3.72 ±0.46	3.18 ±0.70	3
		F1	4.52 ±1.41	3.85 ±0.75	3.07 ±1.29	3.39 ±0.29	3
	Tvm30	F0	2.89 ±0.58	3.34 ±0.25	4.63 ±0.05	3.65 ±0.40	3
		F1	2.37 ±0.52	3.33 ±0.58	4.51 ±0.57	3.57 ±0.30	3
	Tvm60	F0	2.65 ±0.21	4.22 ±0.14	4.61 ±0.70	3.55 ±0.53	3
		F1	2.99 ±0.70	3.76 ±0.23	5.90 ±0.70	4.38 ±0.82	3
	Tvm90	F0	3.25 ±0.53	4.05 ±0.29	5.38 ±0.28	4.51 ±0.45	3
		F1	3.47 ±0.53	3.49 ±0.14	4.39 ±1.36	5.25 ±0.59	3
Wk4	Tv0	F0	3.72 ±0.29	2.89 ±0.88	5.01 ±0.94	3.55 ±0.49	3
		F1	4.36 ±0.93	3.38 ±1.01	4.23 ±1.32	4.16 ±0.52	3
	Tv30	F0	4.53 ±1.09	2.77 ±0.11	2.09 ±1.16	*4.05 ±0.64*	3
		F1	3.94 ±0.90	3.10± 0.58	3.15 ±1.45	3.76 ±0.19	3
	Tv60	F0	4.66 ±0.71	2.83 ±0.57	3.67 ±0.84	3.48 ±1.00	3
		F1	4.56 ±0.67	3.15 ±0.51	3.86 ±0.58	4.09 ±0.52	3
	Tv90	F0	4.28 ±0.64	3.11 ±0.66	4.23 ±1.09	3.25 ±0.13	3
		F1	4.27 ±0.90	3.22 ±0.65	6.70 ±1.47	3.63 ±0.89	3
	Tvm30	F0	2.31 ±0.42	3.46 ±0.35	4.38 ±0.59	3.69 ±0.23	3
		F1	3.04 ±0.17	3.60 ±0.10	4.20 ±0.26	3.61 ±0.46	3
	Tvm60	F0	2.79 ±0.13	3.34 ±0.41	5.44± 0.25	4.58 ±0.70	3
		F1	3.40 ±0.66	3.18 ±0.17	3.87 ±0.41	3.49 ±0.35	3
	Tvm90	F0	3.11 ±0.21	3.23 ±0.61	4.25 ±1.02	4.25 ±0.50	3
		F1	3.36 ±0.37	4.33 ±0.27	4.79 ±0.70	4.46 ±0.08	3

In the second residual season, highest grain yield was obtained from the treatment Wk2Tvm90F1 (5.25±0.59 t ha^{-1}), a fertilized monoculture plot, followed by Wk0Tvm30F0 (4.68±0.58 t ha^{-1}), an unfertilized monoculture plot, while the least grain yield was obtained with unfertilized control plot Wk0Tv0F0 (2.56±0.42 t ha^{-1}). Similarly, like in the first residual season, an unfertilized intercrop plots Wk2Tv30F0 and Wk4Tv30F0 obtained grain yield of 4.04±0.27 t ha^{-1} and 4.05 ±0.64 t ha^{-1} respectively.

CHAPTER FIVE

5.0 DISCUSSION

The daunting task of the piece of work being reported here was in three major parts: 1) the production of sufficient biomass to enhance soil fertility for subsequent crop by an AF tree/shrub species in a semi-simultaneous system, 2) maintain or enhance the yield of current crop species through the reduction of undue competition for soil moisture especially, under limited moisture availability and 3) transcend the endemic social problem of arable land scarcity in high agricultural activity communities.

This chapter brings to light how *T. vogelii*, a moderately vigorous N fixing shrub species presented itself as the right candidate for accomplishing the above goal in the light of earlier relevant undertakings. It is presented in three main sections, namely, (5.1) system's effect on soil moisture content and the component species (maize and *Tephrosia*) in intercrop, (5.2) the response of *Tephrosia* to the system following maize removal, at six and eleven months and (5.3) residual effect of system on soil and maize following the removal of shrub. Synthesis of the implications of findings from the three objectives in achieving the overall goal of the utilization of less land-demanding AF technology that maintains sustainable intensive arable crop production in a land-scarce semi-arid environment is the last section (5.4)

5.1 System's Effect on Soil Moisture Content, Maize and *Tephrosia* Performance in Intercrop

5.1.1 The individual effect of time of planting *Tephrosia* on soil moisture content

The consistent significant differences recorded at soil depths 10-20 and 40-60 cm and the non-significant differences at other depths for all 11 months of assessment (Fig. 8, 9 and 10) suggests that with regard to time of planting, the root systems of *Tephrosia* were most likely more active within these two depths than the rest at this stage of growth, where the fine and young lateral roots exploited the top horizon while the tap and lower lateral roots concentrated on the lower horizon. Odhiambo *et al.*, (2001) reported maximum fine root concentration for both tree and maize in the top 20 cm of the soil profile, which declined with increase in soil depth. On the other hand, the significantly higher soil moisture content recorded in Wk4 over Wk0 suggests that *Tephrosia* planted four weeks earlier stands the chance of developing more structures to facilitate better moisture and other resources utilization. While the non-significant differences between treatments of two-week intervals suggest that the difference in time of planting is hardly sufficient by itself to cause differences that can result into significant differences in moisture utilization. In a semi arid environment, a significant difference in soil water content between treatments is taken seriously as such differences can easily be translated into crop response (Zeiger and Teize, 1991).

5.1.2 Individual effect of spacing of *Tephrosia* on soil moisture content

The non-significant differences recorded with respect to spacing on soil moisture (Fig. 12, 13 and 14) may be due to compensatory growth effect, where the plant part would grow to occupy an available free or favourable space when restricted in other directions (Schroth, 1999). At the same time, it is also possible that differences in spacing were not sufficient to result in any significant difference in soil water use. However, the general consistent trend of soil moisture content being highest in Tv0 (control) plots and declining from highest density to lowest density within 0-30 cm profile, first of all suggests that soil water use is higher in tree/shrub-crop intercrop than in sole cropping. Secondly, it suggests that *Tephrosia* planted at lower density may consume more water than those planted at high density in the upper horizons; and this conforms with the findings of others that trees planted at close spacing or high density in association with annual crops develop more deeper lateral roots while trees planted at wider spacing or low density develop larger proportion of shallow lateral roots (Atkinson *et al.*, 1976; Eastham *et al.*, 1990; Lefroy and Stirzaker, 1999; Schroth, 1999), thus affecting the use of below-ground growth resources accordingly.

A study involving apple trees (*Malus sylvestris*) in Britain shows that the closer the spacing of trees the more root grew vertically into the soil instead of spreading horizontally near the soil surface indicating intra-specific competition in the top soil (Atkinson *et al.*, 1976). In Australia, Eastham *et al.*, (1990) observed that increasing tree density increased the subsoil water use in a silvopastural system.

Regarding non-significant differences at lower depths, the effect of tree roots on soil moisture content at lower depths may sometimes not be noticeable where the clay content of the subsoil is high enough to cause recharge of moisture from soil storage at lower depth by capillary movement (Lefroy and Stirzaker, 1999), thus resulting in less noticeable effect.

5.1.3 Soil moisture status as affected by the interaction of time of planting and spacing of *Tephrosia* in intercrop

The significant differences recorded mostly within 10-40 cm soil profile for the interaction of time of planting and spacing of *Tephrosia* (Table 13 and Fig. 16, 17 and 18) only emphasize the fact that active rooting zone for *Tephrosia* may not be beyond 50 cm soil depth, especially for the first four months of growth.

The consistent superiority of Wk2 time of planting and spacing 60 x 90 cm (Tv60) treatments in soil moisture content within the 10-40 cm soil profile zone was quite distinct (Fig. 16, 17 and 18). The Wk2 time of planting though by itself did not show higher soil water content over other treatments at all the active rooting depths, but in combination with Tv60 spacing was able to maintain highest soil water content. Planting two weeks after maize provides the shrub time to develop both shoot and root before the available growth space (below- and aboveground) is largely taken over by maize as in the case of Wk4 time of planting. *Tephrosia vogelii* is not a vigorous shrub compared with *S. sesban* and *G. sepium* (Mgangamundo, 2000), hence if planted too late in close association with fast growing annuals like maize, there is likelihood that it will be suppressed by annual crop. Hence Wk0 time of planting yielded 11 percent more aboveground biomass of *Tephrosia* than Wk4 at three months old (Table14). On the other hand, if planted at the same time with maize, being a woody perennial is likely to acquire improved chances of inducing competition with maize crop for limited resources even though it is less vigorous, except if the shrub root system is flexible enough to allow vertical displacement and compensatory growth in depth (Schroth, 1999).

5.1.4 The response of *Tephrosia* and maize crop to time of planting and spacing of *Tephrosia* in intercrop

Although significant difference in soil moisture content was obtained within time of planting, this however did not reflect *Tephrosia* performance accordingly, which did not differ significantly at this stage. However, in terms of mean plant total biomass which was highest in Wk0 agrees with moisture result, which was lowest in the same treatment (Fig. 8). The significantly high total biomass recorded with Tv30 spacing reflects the effect of high density on total biomass production per unit area; the higher the density the higher the total biomass per unit area (Philip, 1992). The significantly high total biomass yield obtained in the interaction of Wk2 time of planting and Tv30 spacing reflects shrub density much more than time of planting. Hence the contribution of the factor of time of planting here may be attributed to either root orientation of plant in response to soil conditions prompted by time of planting, or climatic conditions at planting, affecting growth rate (Schroth, 1999). Keen observation over time has revealed that sunny weather other than heavy rainy weather favours the establishment and growth of *Tephrosia* (Mugasha, personal comm.). This high biomass yield of Wk2Tv30 to some extent reflects the moisture status of the soil, which was lowest among Wk2 and Wk4 treatments at that stage. Generally, high biomass yield reflects high soil water utilization when all other things are normal, as the process of photosynthesis demands sufficient water, which result into biomass production (Zeiger and Teize, 1991).

With regard to its effect on maize, the non-significant difference in grain yield among treatments for the two factors (Fig. 20 and 21) and their interactions (Fig. 22) suggests that firstly, it is possible that two-week difference in time of planting is insufficient to cause appreciable differences in resource use by the shrub component especially, or the system as a whole. On the other hand, even where it may result into significant differences in resource use, like the case of soil water (Fig. 9), such differences may not be sufficient to bring about corresponding significant differences in crop yield especially when the resource in question is not highly limited at the time, as it was the case with soil moisture in this study during the growing period. Rainfall and distribution data in this period for that season was good enough to maintain sufficient soil moisture in spite of the few intermittent draughts (Fig. 3).

The slight differences observed, in which the Wk2 time of planting and Tv60 spacing and their interaction maintained highest grain yield over others, suggest that the higher moisture content maintained by these treatments had some direct influence on maize yield. The consistent variation in moisture content with maize grain yield as influenced by the same treatments above further suggests that those slight differences in maize grain yield could only be attributed to variation in soil moisture rather than other factors. This then affirms the suggestions of earlier authors that soil water availability is indeed most limiting for the success of simultaneous AF in semi arid environments (McIntyre *et al.*, 1997; Ong *et al.*, 1996; Smith *et al.*, 1998).

The fact that significant differences in soil moisture content were not equally translated into corresponding significant differences in crop yield, may be attributed to the following: First, the resource was not limited during the growing period since that was the rainy period and rainfall amount and distribution during that season was fairly good (Fig. 3). Secondly, the perennial component (*T. vogelii*) is not an aggressive competitor; hence it was heavily overshadowed by maize throughout the cropping period, recovering only after the maize was removed (Fig. 32 and 33). In effect, maize in this association may be described as an example of plant species that establishes earlier and takes advantage in light capture through more rapid initial shoot growth, which may also lead to greater root growth and hence more belowground resource utilization due to increased availability of photosynthate. This in turn may further improve shoot growth and more light interception to the detriment of the less competitive *Tephrosia* in the association (Ong *et al.*, 1996). Contrary to this finding, Broadhead (2003) dealing with more vigorous tree species found 50-70% reduction in maize yield in AF treatments using *Senna spectabilis*, *Gliricidia sepium*, *Melia volkensii* and *Croton megalocarpus* in semi arid Kenya.

Figure 35: *Tephrosia vogelii* at three months in intercropping with maize crop in relay intercropping experiment at Gairo, Tanzania.

Figure 36: *Tephrosia vogelii*, eight months after the removal of maize crop in relay intercropping experiment at Gairo, Tanzania.

In general, the fact that active rooting zone was found to be within 50 cm soil depth, based on the soil moisture results and small root biomass result (Table 17), suggests that the most active rooting zones of maize and *Tephrosia* may not be very different from each other. As such, it is most likely that their association in simultaneous systems would result in competition in which the shrub is the weaker competitor since maize yield in intercropped plots did not decline against that of Tv0, but the shrub was greatly suppressed throughout the intercropping period. This affirms the preposition of Smith *et al.* (1999) that as the root distribution of most trees/shrubs and annual crops appear to coincide, there seems to be little prospect in finding tree/shrub species with root systems ideally suited to AF. Hence some level of trade-off must be accepted. From this argument, it can be further suggested that the interspecies competition that delayed *Tephrosia* growth in this association may not be largely for soil moisture, but rather for sunlight and growth space or shading effect (above-ground). Furthermore, the fact that maize yield was still lowest in Tv0 plots (Fig. 21 and 22), compared with intercrop plots, suggests that *Tephrosia* in fact has positive effect on maize grown in closed association (in simultaneous system), with carefully selected spacing.

5.2 The Response of *Tephrosia* to Time of Planting and Spacing at Six and Eleven Months

5.2.1 Mean plant performance of *Tephrosia* at six and eleven months of growth

The superiority of Wk2 time of planting in mean shrub biomass, mean shrub diameter and mean shrub height at six months growth over Wk0 and Wk4 (Table 15) may still be attributed to root orientation in response to soil and climatic conditions at early stage of establishment to enhance its advantage in resource capture over other treatments (Schroth, 1999). The non-significant difference in the above parameters within spacing at six months may be due to the fact that intra-species competition had not yet set in at that stage to cause any significant differences in average plant performance in intercrop. On the other hand, the significantly high mean shrub parameters at eleven months for monoculture plots over intercrop plots (Table 15) indicates that with the prescribed spacing, interspecies competition is capable of significantly reducing average shrub performance between monoculture plots and intercrops. Also depending on spacing, intra-species competition may cause significant reduction in average shrub performance as indicated by the significantly low mean shrub biomass and mean shrub diameter in Tvm30 against Tvm60 and Tvm90 (monoculture systems), and lower in Tv30 against Tv60 and Tv90 (intercrop systems) (Ong and Leakey, 1999).

5.2.2 Effect of time of planting and spacing on total aboveground biomass yield of *Tephrosia* at six and eleven months

The significantly high foliar, wood and total biomass for Wk2 over Wk4 at six months and the non significant difference at eleven months indicate that varying time of planting by two weeks can make some difference in biomass yield of component shrub of simultaneous systems at early stages of growth before compensatory growth over time set in to nullify the effect of time as shown in Table 16. The significantly higher total aboveground biomass in Tv30 (8.51 and 5.85 t ha^{-1}) over Tv90 (2.53 and 2.93 t ha^{-1}) within intercrop at six and eleven months respectively, and Tvm30 (13.41 t ha^{-1}) over Tvm90 (8.84 t ha^{-1}) within monoculture at eleven months, indicate that low spacing (high density) may maximize biomass yield over higher spacing (low density). Furthermore, the significantly high biomass yield of monoculture plots over intercrop emphasizes earlier deduction that biomass production of *Tephrosia* is maximized in monoculture systems over intercrops. This also confirms the inter-species competition in simultaneous AF and its adverse effect on the performance of the weaker component. In Rwanda, biomass production of sole or mixed legumes (including *Tephrosia* green manure), from a number of fields and seasons was found to be ranging between 5 – 17 t d. m. ha^{-1} in one year improved fallow, and 4 – 7 t d. m. ha^{-1} in intercrop systems with maize or sorghum in one year (Steiner *et al.*, 1994) cited by Drechsel *et al.* (1996). Total aboveground biomass production of 9.5 t ha^{-1}, 10.04 t ha^{-1} and 8.9 t ha^{-1} in six months, one year six months and two years of *Tephrosia* improved fallows from Kenya (Rutunga *et al.*, 1999), Zambia (Mafongoya *et al.*, 2003) and Tanzania (Mgangamundo, 2000) respectively, has been reported, indicating that biomass yield of trees/shrubs depends also very much on site quality.

5.2.3 The effect of the interaction of time of planting and spacing of *Tephrosia* on mean and total shrub performance at six and eleven months

During growing period of the intercropping phase, the mean shrub performance is important for assessing the competitiveness of system. The higher the mean shrub performance (height, diameter and biomass), the higher the likelihood for inter-species competition, and usually the lower the total biomass per unit area, which is undesirable for a system aimed at minimizing competition for current crop and optimizing biomass production for subsequent cropping. Hence with respect to intercropping, the treatment Wk2Tv30, which maintained a moderately high mean shrub biomass at both six and eleven months (Fig. 23 and 24), may be considered superior, especially when considered in the light of soil moisture status under the same treatment during maize growing period. The significantly higher mean shrub growth increment in Wk0Tv90 treatment over other treatments (Fig. 25) shows that mean shrub growth increment can be maximized with early planting of *Tephrosia* at wider spacing than late planting at narrow spacing. Such a trend will only be of important if survival rate at shrub clearing is maintained high.

Probably of greater interest after the removal of maize is total biomass per unit area, which affects soil properties and subsequent crop performance. Hence the decline in biomass yield with increase in time of planting and spacing emphasizes how early planting and narrower spacing can maximize biomass yield per unit area in both intercrop and monoculture (Fig. 26, 27 and 28). The high foliar biomass yield of up to a mean of 6 t ha^{-1} (with pods) for narrower spacing of monoculture stand would probably not have been very different from the result of pure *Tephrosia* improved fallow trial in the same area, which recorded up to 4.1 t ha^{-1} (foliar biomass without pods) (Mgangamundo, 2000), if pods were not included in the former. The extremely higher foliar biomass yield of monoculture plots over intercrops points out how high the potential of sequential AF to improve soil fertility over intercrops, where the highest foliar biomass per season was less than 3 t ha^{-1} (Fig. 27), if arable land scarcity is not a hindrance.

5.2.4 Root biomass yield of *Tephrosia* as affected by time of planting and spacing at eleven month

The amount of small root biomass of *Tephrosia* estimated in this study ranging between 4.7 - 9.2 kg ha^{-1} (Table 17) is far less than that estimated in six month old *Tephrosia* in Maseno, western Kenya, which ranged between 132 – 523 kg ha^{-1} (Rutunga *et al.*, 1999). Such a vast disparity may be connected with methods of estimation and/or initial nutrient and moisture status of the experimental site. Plants would generally tend to build up higher quantity of root biomass where initial soil fertility is extremely low than where it is fairly higher (Eastham *et al.*, 1990; Schroth, 1999). The significantly higher small root mass recorded in week2 time of planting at soil depth 0-15 cm over other treatments further supports the earlier suggestion of possible root orientation in this treatment in response to soil and climatic conditions at early establishment stage (Schruth, 1999). This trend very much agrees with the trend of soil moisture content as well within the same soil depth, where it was least, especially for the months of January, February and March (main growing period). The higher small root biomass at Tv30 (intercropped plot) and Tvm30 (monoculture plot) at lower depths (15-30 and 30-50 cm), and the superiority of Tvm90 over other treatments in the upper horizon (0 – 15 cm) affirms views of earlier authors that plants with narrow spacing (high density) would develop deeper lateral root system while those with wide spacing (low density) would tend to develop shallow lateral root system (Eastham *et al.*, 1990; Lefroy and Stirzaker, 1999).

5.3 Residual Effect of System on Soil and Maize Crop Following the Removal of Shrub

5.3.1 Soil bulk density and organic carbon as affected by time of planting and spacing of *Tephrosia* after eleven months of growth

The non-significant difference in soil bulk density within time of planting indicates that varying planting time by two weeks would not result in any significant difference in soil bulk density, nor was eleven months old shrub in intercrop capable of changing soil bulk density significantly over sole maize cropping (Tv0). However, the consistently lower soil bulk density at all four soil depths under Tv30 over other treatments indicates that higher shrub density has potential to improve soil bulk density better than low shrub density, especially in the upper horizon (Table 18). Compared to the initial soil bulk density before the experiment, treatments have to some extent improved soil bulk density from the range of 1.34 - 1.43 g cm^{-3} to the range of 1.24 – 1.39 g cm^{-3} within 50 cm soil depth. In Machakos, Kenya, soil bulk density of 1.31 g cm^{-3} was obtained under 4 year *Senna siamea* contour hedgerows compared with 1.39 g cm^{-3} in alleys (Kiepe, 1995b).

The significantly ($P<0.05$) low OC content of Tv0 (control) plots against treatments within spacing (Fig. 30) indicates that treatments had effect on organic matter content of soil. Generally, the OC content obtained in this trial ranging between 0.6 % (continuous maize or Tv0) to 1.02% (highest treatment- Tvm90) is considered extremely low even for semi arid areas (Landon, 1991). It is likely that assessing soil organic matter content before clearing and incorporation of foliar biomass of a season-old shrub fallow is unlikely to result in any significant changes, probably due to little litter fall and root decomposition as indicated by the non-significant and lack of trend in OC content within both time of planting and spacing (Fig. 29 and 30). In AF systems involving arable cropping, it is often not uncommon to have no significant differences in organic matter between treatments and crop-only controls (Young, 1997). However, in Ibadan, Nigeria, after 6 years intercropping with *Leucaena*, soil OC level was 1.07% with pruning retained, equal to pretrial level, but declined to 0.65% with removal of pruning (Kang *et al.*, 1985).

5.3.2 Soil inorganic nitrogen as affected by time of planting and spacing of *Tephrosia* in first and second residual season

The field mineral N ranging between 30 and 120 mg kg^{-1} (Fig. 31 and 32) appears to be high for arable land, especially one under continuous cropping with no deliberate external fertilizer input. This is likely to be due to spillover effect of long-term experimental activities involving N fixing trees and shrubs at the upper side of the site, which gently slopes down to the site where this study was conducted. The mineral-N level here greatly contrasts with results obtained in Zambia with two-year fallows of *Tephrosia* provenances, which ranged between 3.5 – 14.1 µg g^{-1} (Mafongoya *et al.*, 2003). However, the result does not greatly contrast with results obtained in the same area after two-year improved fallow of *Gliricidia sepium*, which obtained between 40 – 120 mg kg^{-1} of NO_3-N and 20 – 60 mg kg^{-1} of NH_4-N (Chingonyikaya, 1999).

Although not significantly at some points, the consistently high NO_3-N in Wk0 time of planting, which decreased gradually through Wk2 and Wk4 for all sampling times in both first and second residual seasons indicates that varying time planting of woody perennial component in simultaneous AF system can make some difference in mineral-N content of the soil. This incidentally followed the same trend as total biomass yield, which decreased from Wk0 through Wk2 and Wk4 time of planting.

In spite of the very high amount of biomass recorded in monoculture plots over intercrops, and the consistently increasing total biomass yield with decreasing spacing, the trend of field mineral-N does not reflect the above trend so much. The possible reason for this may be the irregular rainfall amount and distribution. Especially during the residual seasons of this experiment, there were several long periods of drought going up to three weeks or more (Fig. 3). Among the factors that influence N mineralization in soil, moisture content is paramount (Swift *et al.*, 1979) and it equally affects the uptake of available nutrients. The high mineral-N, especially NO_3-N recorded under control plots sometimes to the level of treatment plots or higher at initial sampling (time zero) in the first residual season may be due to two main reasons: first the treatment may not have yet affected the soil in terms of chemical properties as biomass was not yet incorporated, and second, the shrub may have taken up some of the initial available N under treatments. Highest preseason soil NO_3-N accumulation of 12 kg N ha^{-1} in continuous maize treatment at 100 – 120 cm soil depth compared to 2.1 and 2.6 kg N ha^{-1} of *Sesbania sesban* and *Acacia anguistissima* treatments respectively has been reported in Zimbabwean sandy clay loam soil (Chikowo *et al.*, 2003). This suggests leaching of mineral-N in the absence of uptake during non-cropping period (in the continuous maize treatment), which to an extent is supported by the mineral-N trend in initial sampling of the second season following shrub removal in this study, where mineral-N was lowest in Tv0 (control) plots. On the other hand the level of mineral-N being high in control plots in several cases than treatment plots may be due to two reasons again: first the possibility of spillover effect of long term experimental activities from old sites on the upper side discussed earlier, which may have been aggravated by the presence of phenolic compounds in *Tephrosia* biomass that have regulatory effect on mineralization rate at different concentrations (Palm *et al.*, 2001; Mafongoya *et al.*, 1998; Mafongoya *et al.*, 2003).

In the first residual season especially, the level of mineral-N was frequently higher in monoculture plots than intercrops; this may be due to differences in C: N and/polyphenol + lignin: N ratios. *Tephrosia* foliar biomass without been mixed with either *Tephrosia* woody biomass or straws of maize, sorghum and the like is considered high quality material, while those mixed are considered medium quality. These two obviously have different rates of decomposition and N release (Mafongoya *et al.*, 1998; & 2003; Rutunga *et al.*, 2001).

5.3.3 Maize crop performance as affected by time of planting and spacing of *Tephrosia* and fertilization in first and second residual seasons

The non-significant differences in maize stover, shaft and grain yield in both first and second residual seasons in response to the individual effect of time of planting (Table 19) seems to be consistent with the *Tephrosia* foliar biomass yield at eleven months (Table 16), which showed neither significant differences, nor any consistent trend. This trend supports earlier deduction, that varying time of planting alone by two weeks is likely insufficient to significantly affect some parameters of the system. On the other hand, the consistently higher maize yield (stover, shaft and grain) obtained in sole *Tephrosia* plots over intercropped plots (significant in some cases) especially in second residual season may be explained by higher rate of mineralization in sole *Tephrosia* plots as a result of better quality biomass of unmixed *Tephrosia* foliar biomass compared to *Tephrosia* foliar biomass mixed with maize residue in intercropped plots (Rubaduka *et al.*, 1993; Hagedorn *et al.*, 1997; Mafongoya *et al.*, 2003). This trend to a large extent tends to agree with mineral-N trend where sole *Tephrosia* plots were relatively higher than intercropped plots in most cases, especially with NO_3-N and total mineral-N (Fig. 32), except for week6 sampling date of second residual season.

However, just as mineralization was largely inconsistent, maize performance was similarly largely inconsistent as the higher biomass yield of *Tephrosia* recorded with monoculture plots over intercrops did not result in a corresponding higher maize yield in the residual seasons, especially for the interaction effect of time of planting and spacing (Fig. 34). This may be explained in light of the poor distribution of rains in 2002/2003 and 2003/2004 cropping seasons (Fig. 3), with annual totals less than 500 mm and long intermittent drought during cropping periods most likely leading to inconsistent N mineralization, hence inconsistent crop response. In their review on the potential of improved fallows and green manure in Rwanda, Drechsel *et al.*, (1996) reported that despite considerable biomass and nutrient accumulation by one and two season green manures, residual effect on topsoil fertility or foliar nutrient levels of subsequent crops were insignificantly low, a condition they largely attributed to poor rainfall amount and distribution.

In the interaction of all three factors (time of planting and spacing of *Tephrosia* and fertilization), although maize grain yield was maximized with fertilized *Tephrosia* monoculture plots with the highest being Wk4Tvm90 (4.33 t ha^{-1}) and Wk2Tvm90 (5.25 t ha^{-1}) for first and second residual seasons respectively, unfertilized intercropped plots yielded 50 % and 58 % more than unfertilized continuous maize cropping (Tv0) in first and second residual seasons respectively (Table 20). Since unfertilized *Tephrosia*-maize intercrop would save money and labour from fertilization as well as maximize the use of land as *Tephrosia* is cultivated by direct seeding, the system may be more preferable still to higher yield of fertilized sole *Tephrosia* in land scarce situations (Drechsel *et al.*, 1996).

In the same experimental area at Gairo, Mgangamundo (2000) reported maize stover and grain yields from one year unfertilized and fertilized (at 40 kg N/ha and 40 kg P/ha)

Tephrosia improved fallow plots of 3.6 and 6.06 t ha^{-1}, and 3.32 and 7.3 t ha^{-1} respectively, which largely agree with the results of this study. However, in great contrast with the result of this study, maize yield obtained from two-year fallows of different provenances of *Tephrosia vogelii* in Zambia ranged between 0.2 – 0.7 t ha^{-1} and 0.6 – 1.3 t ha^{-1} in the first and second residual seasons respectively (Mafongoya *et al.*, 2003). This result to an extent corresponds with mineral-N content of the soil, which barely ranged between 5.2 – 10.7 µg g^{-1}, which in turn may have been influenced by N mineralization due to soil moisture availability, as foliar biomass yield was fairly high ranging between 1.7 – 2.9 t ha^{-1} (Mafongoya *et al.*, 2003).

5.4 Synthesis of the of the Practical Implications of Findings

The application of AF practices in farming systems in Sub-Sahara Africa is indisputably an indispensable alternative to traditional shifting cultivation as well as to the costly practice of continuous cropping with industrial fertilizers. However, in spite of this potential of AF in this region, in semi arid areas with limited per capita arable landholding the three daunting tasks mentioned earlier in this chapter must be tackled before any success toward sustainable maize production can be realized. Based on the findings of this study, this section summarizes how and to what extent the three daunting tasks have been tackled.

Relay intercropping technology with *T. vogelii* and maize crop was used in this study. Various combinations of the factors of time of planting and spacing of *T. vogelii* as well as mineral fertilizer were applied. The study has shown that the moderate growth vigour of *T. vogelii* can be utilized with proper adjustment of planting time and spacing in a semi-simultaneous system like relay intercropping to achieve the above mentioned goals.

The study has shown that proper adjustment of time of planting and spacing can minimize competition that could have disfavoured the crop component, which is one of the greatest deterrents to the adoption of simultaneous AF systems in soil moisture limited environments like Gairo.

The study has further shown that prompt harvesting of maize (the crop component) from the system would leave the less competitive *Tephrosia* (the woody component) enough time to recover (i.e., increase biomass yield) and enhance soil fertility and maize yield in the subsequent season on the same site. The moderate response to fertilization (a costly input) in intercrop and monoculture *Tephrosia* and the inconsistent increase in maize yield under monoculture compared to intercrop, mitigate against recommending both fertilization and one year idle fallow under low input agriculture and acute land scarce condition. However, since the study showed that interspecies competition do occur in the system in all levels of planting time and spacing of the shrub component, and it severely reduces shrub biomass yield, the need to repeat the intercropping phase at least once is worth considering in the fields as well.

With this background, it is evident that the study has demonstrated that substantial quantity of retainable shrub biomass can be produced in semi-simultaneous system with *Tephrosia vogelii* to positively influence soil .fertility and maize yield in the subsequent season, without causing reduction in maize crop yield in intercropping season. Essentially, maize yield increased with increase in shrub biomass yield per unit area where continuous maize cropping (Tv0 or control) gave the least maize yield (Table 14 and Fig. 19b & 21a). Furthermore, the study has demonstrated that where it is impossible to practice sequential AF due to limited arable landholding, *Tephrosia* can be relay-intercropped with maize to achieve the same goal as sequential system. Lastly, the literature search of this study has demonstrated that the shrub *Tephrosia*, though does not provide food directly to the farmer (an additional incentive for adoption), do provide other benefits to offset the deficiency of not having an edible product. *Tephrosia* leaves can be used to control some storage pests and to repel some insect pests in the field as well.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

In light of the main objective of utilizing less land-demanding AF technology that enhances sustainable increase in crop yield in land-scarce semi arid Gairo in Tanzania, for ensuring household food security and improved income of resource-poor farmers, the following conclusions are suggested from this study:

(i) Soil moisture content at intercropping phase

- Soil moisture content is indeed influenced by the factors of time of planting and in combination with spacing of *T. vogelii,* but the degree of influence varies with levels of the two factors and soil depth.
- The treatment combination of week2 time of planting and spacing 60 x 90 cm (Wk2Tv60) have highest potential to conserve soil moisture within the active rooting zone of maize and shrub (0-50 cm).

(ii) Shrub and maize performance at intercropping phase

- Optimum production of shrub is attained with the treatment Wk2Tv60 in consideration of moisture conservation, but shrub biomass production is maximized with the treatment Wk2Tv30.
- Optimum maize yield is also obtained with Wk2Tv30, considering that there is no significant difference ($P>0.05$) in maize yield between the treatment and Wk2Tv60.
- There is competition in the *Tephrosia*-maize association, but the competition that delayed *Tephrosia* growth and reduced its biomass yield at

clearing is most likely for sunlight and growth space (shade effect) rather than for soil water, which favoured maize crop at the detriment of shrub. However, the slight variation in maize grain yield at intercropping phase is most probably from competition for soil moisture as the treatment with highest soil moisture also recorded the highest maize grain yield.

(iii)*Tephrosia* performance and its effect on the soil following removal of maize:

- The shrub growth which is suppressed during cropping period has the potential to recover remarkably to the point of influencing soil properties after the maize crop component is removed.
- With intercropping, six months is hardly sufficient to observe any significant differences in *Tephrosia* performance that would have any significant effect on soil properties, but monoculture *Tephrosia* might do.
- Total *Tephrosia* biomass production per unit area at both six and eleven months of growth can be optimized with narrower spacing of week2 time of planting in both intercrop and monoculture systems.
- Between intercrop and monoculture systems, *Tephrosia* biomass production can be maximized with monoculture system more, which should be more preferable where arable landholding is not a limiting factor to adoption.
- Narrow spacing of shrub would more positively affect small root biomass, soil bulk density and organic carbon than wider spacing.

(iv) Residual effect on soil mineral nitrogen and maize yield

- Although maize grain yield would be maximized with fertilized monoculture *Tephrosia* treatment in Wk2 time of planting, however, in the face of scarce arable land and resource-poor agriculture, unfertilized intercrop treatment has the potential to optimize maize production in Wk2 time of planting with insignificant difference from half and full recommended doses of N and P fertilizer treatments respectively at Gairo.

- Thus, in light of the foregone argument, optimum maize production can be obtained with Wk2Tv30F0 treatment (unfertilized intercrop plots).

Against the background in the foregone discussions and coupled with other beneficial properties of the shrub, this study concludes that *Tephrosia* relay-intercropped with maize has potential for sustainable maize production in land-scarce semi arid areas on well drained soils with good water holding capacity and where sustainable increase in crop yield at optimum profitability is the main goal.

6.2 Recommendations

(i) Since the shrub-crop moisture interaction in this association has no negative effect on crop yield, which is in fact slightly improved over sole maize system, implies that relay intercropping maize with *Tephrosia* is recommendable in land scarce semi arid areas.

(ii) Planting two weeks after maize at the spacing of 30 x 90 cm is recommended for moderate competition effect and optimum crop yield at both intercropping and residual phases. However, under continuous relay intercropping system, the treatment combination of week2 time of planting and spacing 60 x 90 cm is more recommendable for minimum moisture competition and optimum crop yield.

(iii) Since competition in this association was against *Tephrosia* whose growth was adversely affected, hence to realize any significant increase in crop yield in the subsequent years from the residual effect of *Tephrosia*, the intercropping phase should be done for at least two consecutive seasons in order to ensure sufficient humus accumulation.

(iv) Further studies to determine the effect of continuous relay intercropping of various species and/or provenances of *Tephrosia* and maize on soil properties and crop yield in semi arid condition is a need.

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