EVALUATION OF GROWTH OF *GLIRICIDIA SEPIUM* PROVENANCES AT GAIRO, KIBAHA AND SUA FARM, TANZANIA

BY

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A DISSERTATION SUBMITTED IN PARTIAL FULFULMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN
FORESTRY OF SOKOINE UNIVERSITY OF AGRICULTURE.
MOROGORO, TANZANIA

2003

ABSTRACT

Growth evaluation was conducted among seventeen provenances of *Gliricidia sepium* at Gairo, Sokoine University of Agriculture (SUA) farm and Kibaha, Tanzania. Assessment was done at irregular intervals for survival, root collar diameter and diameter at 30 cm above the ground, height, multiple stems production, foliage and wood and total biomass production. Final assessment of these tree attributes was done at 70, 69 and 34 months after planting for Gairo, SUA farm and Kibaha site respectively while unit leaf mass, foliar N and P concentrations was assessed at 73, 72 and 36 months after planting for Gairo, SUA farm and Kibaha site correspondingly. For SUA farm site, during the final assessment occasion, height ranged from 3.77 (Taxico) to 4.85 m (Belen Rivas), foliar N concentration ranged from 3.58 (Taxico) to 4.24% (Thailand) while P concentration ranged 0.16 (Playa Tamarindo) to 0.19% (Gualan). Multiple stems production ranged from 15000 (Cuyatenango) to 28750 stems ha^{-1} (sph) (Thailand) while biomass yields were 17.34 (Retalhuleu) to 27.73 t ha^{-1} (Belen Rivas), 72.99 (Retalhuleu) to 118.54 t ha^{-1} (Belen Rivas) for foliar and wood biomass respectively. For Gairo site, height ranged from 3.87 (Monterrico) to 4.39 m (Cuyatenango), foliar N concentration ranged from 3.68 (Kihonda) to 4.38% (Cuyatenango) while P concentration ranged 0.26 (Kihonda and Taxico) to 0.30% (Balen Rivas). Multiple stems production ranged from 27500 (Cuyatenango and Monterrico) to 33438 sph (Retalhuleu) while biomass yields were 13.72 (Monterrico) to 18.68 t ha^{-1} (Cuyatenango) and 60.76 (Monterrico) to 95.15 t ha^{-1} (Cuyatenango) for foliar and wood biomass respectively. For Kibaha site, height ranged from 4.45 (Nigeria) to 5.26 m (Jutiapa), foliar N concentration ranged from 3.69 (Ibadan) to 3.93% (Jutiapa) while P concentration ranged from 0.20 (Ibadan) to 0.24% (Taxico). Multiple stems production ranged between 16563 (Jutiapa) to 22031 sph (Nigeria) while biomass yields were 15.45 (Nigeria) to 20.19 t ha^{-1} (Cuyatenango), 37.26 (Nigeria) to 49.15 t ha^{-1} (Cuyatenango) for foliar and wood biomass respectively. Based on the findings, provenances Balen Rivas, Cuyatenango and Jutiapa are recommended for SUA farm; Cuyatenango and Taxico for Gairo; and Cuyatenango and Jutiapa for Kibaha. Further evaluation of these and other provenances on resistance to pests and disease, nitrogen fixation and coppicing ability for various conditions in Tanzania are recommended. In addition, more studies to compare performance of other *G. sepium* provenances in more contrasting sites should be undertaken.

DECLARATION

I, Vincent Vyamana Kavura Gerald, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and that it has never been submitted for a degree award to any other University.

Signature……………………………………………………

Gerald Vincent Vyamana Kavura

Date…24/7/2003……………………………………………

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ACKNOWLEDGEMENTS

I wish to convey my heartfelt gratitude to Norwegian Agency for Development Cooperation (NORAD) for sponsoring my M. Sc. Programme.

Professor A.G. Mugasha deserves special thanks for his guidance, very useful suggestions, constructive deprecation and untiring encouragements from the research concept and proposal development to the completion of this dissertation. His willingness to assist contributed considerably to my success.

My sincere gratitude goes to Professor S.A.O. Chamshama for his valuable comments on this dissertation.

I am indebted to Mr. M. Mndolwa and all staff at Ruvu Fuelwood Pilot Project for their assistance when I was collecting data from Kibaha.

I am also grateful to Mrs. E. Mtengeti, Mr. J. Msalilwa, Mr. N.M. Maseki and all staff at the laboratory of the Department of Forest Biology for their cooperation during laboratory analysis.

Last but not least, I express my sincere appreciation to all people who helped me in one way or another at the Department of Forest Biology and in the Faculty of Forestry and Nature Conservation. I thank them all.

DEDICATION

This work is dedicated to my mother Catherine Kayika and my father Gerald Vyamana Kavura for their love, to my brother Gilles Gerald and my sister in law Rosemary Zacharia who supported me during my primary education and to my uncles Germanico Ntezidyo, and Emmanuel Shuli and Fortunate Ntezidyo who encouraged me and supported me morally and financially during my secondary education.

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LIST OF ABBREVIATIONS AND SYMBOLS

AF	Agroforestry
Al	Aluminium
ANOVA	Analysis of variance
a.s.l.	Above sea level
Ca	Calcium
CEC	Cation exchange capacity
cm	Centimeter
Cmol(+) kg^{-1}	Centimoles per kilogramme
CV	Coefficient of variation
DMRT	Duncan's Multiple Range Test
D30	Diameter at 30 cm above ground
E	East
EC	Electrical conductivity
et al.	And others
Fig	Figure
g	Gramme
g cm^{-3}	Gramme per cubic centimeter
GLM	General Linear Model
ha	Hectare
i.e.	That is
K	Potassium

kg	Kilogramme
kg ha^{-1}	Kilogramme per hectare
m	Metre
mg	Milligramme
Mo	Molybdenum
mS cm^{-1}	Millisiemen per centimetre
N	Nitrogen
No.	Number
OC	Organic carbon
OM	Organic matter
P	Phosphorus
RMSE	Root Mean Square Error
SAP	Structural adjustment programme
S	South
SAS	Statistical Analysis System
SE	Standard error
SUA	Sokoine University of Agriculture
t	Tonnes
TAFORI	Tanzania Forestry Research Insititute
W	West

CHAPTER ONE

1. INTRODUCTION

In many tropical countries including Tanzania there has been falling crop production due to decline in soil fertility status leading to shortages of food and low income. Factors responsible for the decline in soil fertility include continuous cultivation without application of inorganic fertilizers or manure, soil erosion and inherent low soil fertility (Nyamai *et al.*, 1996). It is estimated that about 62 million ha in Africa suffer the loss of soil nutrients owing to unsustainable agricultural practices (Oldeman *et al.*, 1991 cited in Mgangamundo, 2000). Recently continuous cropping without adequate measures to replenish or maintain soil fertility in consequence of current population explosion has aggravated the situation (FAO, 1994). Continuous cropping without external inputs lowers crop yields due to the depletion of soil native nutrient reserves and organic matter as a result of nutrients export from the soil through harvesting (Hartemink, 1997; Young, 1997). In addition, soil fertility depletion in agricultural lands can as well originate from mechanization that may adversely alter soil physical conditions, and loss of nutrients through leaching and erosion. Recently, reduced plant growth and productivity due to soil compaction after long-term tractor use has been reported at SUA Farm in Morogoro, Tanzania (Fasuluku, 1998; Herbert *et al.*, 2002).

The inherent low content of nitrogen (N), phosphorus (P), organic matter (OM) and mineral nutrients have been frequently reported as the major soil fertility constraints widely spread in the Sub-Saharan Africa (Rochleau *et al.*, 1988, Buresh and Tian, 1998) including Tanzania. Moreover, most of these soils are chemically fragile and also suffer ionic imbalance and acidity coupled with use of unbalanced fertilizers; especially those with low buffering capacity (Nyamai *et al.*, 1996).

The problem of dwindling crop production is aggravated by fuelwood shortages together with the use of precious animal dung and crop remains as fuel instead of using them as fertilizer (FAO, 1980; Kaale, 1981; Killenga, 1995), and diversion of productive time from crop production to collection of fuel wood (Forest Division, 1984). The dependency of Tanzania's economy on the agriculture sector insinuates that low crop production and fuelwood shortage has both social and economic dimensions. This means that the economy of Tanzania cannot be improved unless the constraints that prevent agriculture from making maximum contribution such as the dwindling crop production are identified and alleviated.

High crop yields require a sustained restoration of soil fertility especially OM, N and P through frequent addition of organic materials and inorganic fertilizers (Nair, 1993). However, the application of organic and inorganic fertilizers does not appear to be a sustainable solution to the problem (Ladha, 1995). The high cost and unreliable supply of mineral fertilizer in rural areas coupled with the ecological implication of its long-term use altogether make it unpopular. The recent structural adjustment programmes (SAPs) under which the governments have removed subsidies on farm inputs have even exacerbated the situation. Hitherto those farmers who were previously using inorganic fertilizers cannot afford them any longer or apply sub-optimal amounts because of the high prices. In addition, where inorganic fertilizers have been used for long periods, decline in crop yields has been observed (Kwesiga and Coe, 1994; Pieri, 1995) due to mining of nutrients (during crop harvesting) other than those added during fertilization (Mugasha *et al.*, 2000). Organic fertilizers such as farmyard manure and compost on the other hand, are not only widely unavailable, but their bulky nature makes their use very high labour demanding, hence out of favour too (Kasembe *et al.*, 1983; Nyamai *et al.*, 1996).

Local farmers have, with much success in the past been able to maintain acceptable levels of soil fertility through shifting cultivation with long fallow periods of 10 – 20 years (Nair, 1984; 1993; Oxyby and Boerboom, 1985; Tiessen *et al.*, 1992; Boonman, 1993; Brady, 1984). This practice, however, is more and more becoming impracticable due to reduced landholdings as a consequence of rising human population (Boonman, 1993; Nair, 1993; Niang *et al.*, 1996) resulting in short fallow periods, rapid soil degradation, decreasing crop yields, scarcity of wood and tree products and scarcity of fodder for livestock (FAO, 1994; Otsyina and Karachi, 1998). Alternative crop production systems that require low resource such as agroforestry and on farm afforestation systems are therefore imperative (ICRAF, 1995).

Agroforestry (AF) is an approach to land use based on the deliberate integration of trees in crop and/or livestock production systems (Young, 1989; Kang *et al.*, 1999). It has the potential to provide rural households with different tree, crop and livestock products, while at the same time ensuring the sustained productivity of crops and animals by protecting and enhancing the natural resource base (ICRAF, 1998). When nutrient supplies in the soil are limited, AF and other tree-based systems are more efficient than herbaceous mono-cropping systems in the utilization of nutrients to sustain modest levels of agricultural production (Nair, 1993; Kang *et al.*, 1999 cited in Yadessa *et al.*, 2001). Besides, the AF option does not require inputs that are costly or in short supply, and it is a relatively inexpensive form of land development (Young, 1989), an option that needs to be encouraged more than ever for resource poor farmers. Multipurpose trees/shrubs used in AF grow and mature within a short period of time and have the ability to enhance soil fertility by bringing up nutrients from lower soil layers, litter fall and atmospheric nitrogen fixation (Sanchez *et al.*, 1985; Wani *et al.*, 1995). In addition, the woody biomass produced by the multipurpose trees trees/shrubs can be used as fuelwood while the foliage of most leguminous trees/shrubs can be used as fodder or green manure.

In recent times, various AF technologies such as relay cropping and improved fallow in concert with exotic multipurpose trees/shrubs have been introduced in Tanzania (Chamshama *et al.*, 2000). Recent studies in Tanzania have demonstrated the prospective aptitude of some AF technologies such as relay cropping and improved fallow in improving soil fertility and increase food and wood production

(Chingonikaya, 1999; Chamshama *et al.*, 1998; 2000; Mgangamundo *et al.*, 2000a,b,c,d). For example, considerable increases in maize yields (up to 250% increase over natural fallows) and soil fertility after short fallow (1-3 years) have been recorded in semi-arid areas of Tanzania (Chingonikaya, 1999; Chamshama *et al.*, 2000; Mgangamundo *et al.*, 2000 a, b, c). Improved wood supply through AF has as well been reported (Chingonikaya, 1999; Chamshama *et al.*, 2000; Mgangamundo *et al.*, 2000d). However, utilization of these technologies to their full potential requires among others careful selection of appropriate local or exotic species/provenances. One of the exotic multipurpose shrubs recommended for use in AF is *Gliricidia sepium* (Jacq.) Steud. This exotic tree species is reported to have high potential for AF and is considered to yield high biomass and high quality fodder, adds N and other nutrients to the soil (National Academy of Science, 1983; Stewart, 1996; Allison and Simons, 1996). In addition, it grows in a wide range of soil types and endures a wide range of soil conditions (NFTA, 1998).

Whilst tree/shrub species are known to show the patterns of variation over their natural range due to vast genetic variation (Zobel and Talbert, 1984; Krishan and Tocky, 1995), most exotic introductions of multipurpose tree/shrub species including *G. sepium* are from unknown origin and are likely to be narrowly based (Stewart *et al.*, 1996). This has a strong bearing on the success of any given AF system (Hughes, 1987; Simons and Dunsdon, 1992). Genetic variation in growth and productivity among *Gliricidia sepium* provenances has been reported elsewhere (Bumatay *et al.*, 1987; Hughes, 1987; Cobbina and Atta-Krah, 1992; Simons and Dunsdon, 1992;

Kwesiga, 1994; Ngulube, 1994; Sukanten *et al.*, 1995). Differences up to 500% in biomass production among *G. sepium* provenances have been reported (Simons and Dunsdon, 1992). Such variation may be extremely useful as a basis for future genetic selection (Cannel, 1982; Burley *et al.*, 1984; Kwesiga, 1994). This calls for careful selection of provenances of *G. sepium* for adaptability and productivity when grown in new conditions.

Broadly, provenance trials are important because the generally used principle of matching environmental characteristics of species' origin to that of introduction can only serve as a guide and are not flawless. It has been reported that using a strategy of provenance identification, recurrent selection for general combining ability and seed production from progeny tested orchards, average gains of about 100% for provenance selection with further 20% for progeny selection can be attained in the first generation of selection (Barnes and Simons, 1994). Starting with species or provenances that are not adapted to the planting site has lead to failure of many tree-planting projects (NFTA, 1998). Therefore provenance trials for introduced AF trees and shrubs such as *G. sepium* are imperative.

The need to use the best-adapted source of seed was revealed in the early 1920s in forestry and it has been attributed to success in the establishment and productivity of forest tree plantations (Zobel and Talbert, 1984). According to Nshubemuki (1998) much has been done on species and provenance selection for forest plantations in Tanzania. On the other hand, AF tree/shrub species/provenances selection has only recently received attention. There have been meager provenance trials for multipurpose tree/shrub species in Tanzania (Maghembe *et al.*, 1996).

In view of the above facts, provenance trials for multipurpose trees/shrubs including *Sesbania macrantha* E. Phillips & Hutch. *Sesbania sesban* (L.) Merr., *Gliricidia sepium, Calliandra calothyrsus* Meissner, *Casuarina junghuhniana* Miq. and *Casuarina equisitefolia* Forst. & Forst. were established between 1996 and 1999 under auspices of the Sokoine University of Agriculture (SUA) AF Research Project. Mgangamundo *et al.* (1999) reported the results for *Sesbania macrantha*, Munyonga (2001) reported results for *Casuarina junghuhniana and Casuarina equesitifolia,* Herbert *et al.* (2002) reported the results for *Calliandra calothyrsus* while Mwihomeke *et al.* (2002) reported results for *Casuarina junghuhniana/equisitefolia* provenance trials.

In this study growth of *G. sepium* provenances growing at three contrasting sites i.e. SUA Farm, Gairo and Kibaha were evaluated. The overall objective of this study was to evaluate the growth of *G. sepium* provenances grown at the three contrasting sites with the following specific objectives:

(i) To evaluate survival, diameter and height growth performance of different provenances grown at different sites.

(ii) To evaluate foliar N and P concentration and content of different provenances grown at different sites.

(iii) To evaluate variation in production of multiple stems by different provenances at the different sites.

(iv) To evaluate biomass production of different provenances at the different sites.

1.2 Hypotheses

Null hypotheses

That different provenances at different sites do not differ in their:

(i) survival, diameter and height growth.

(ii) foliar N and P concentration, content and accumulation;

(iii) multiple stem production, and

(iv) biomass production.

Alternative hypotheses

That different provenances at different sites differ in their:

(i) survival, diameter and height growth,

(ii) foliar N and P concentration, content and accumulation;

(iii) multiple stem production, and

(iv) biomass production.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Study species description

Gliricidia sepium is a multi-stemmed nitrogen fixing tree native to Mexico and Central America (Nair, 1993) which is now being integrated into farming systems in the tropics (Awoneike and Hardarson 1992). It belongs to the family Leguminosae (Papilionoideae) (National Academy of Science, 1983). It grows to a height of 10 m at 0 to 1200 metres above sea level (m a.s.l) in areas receiving at least 600 mm of rainfall with temperatures ranging from 20 to 30^0 C. It tolerates dry season of up to 9 months (Simons, 1996; Glover, 1989). The species grows in a wide range of soil types ranging from volcanic to heavy clays, including Vertisols and it endures a wide range of soil conditions: saline and slightly acidic soils but not severe acidity (pH less than 4.5) nor high aluminium (Al) saturation (greater than 60 %) (NFTA, 1998). Consequently, it has been transported to most tropical countries and is now pan tropical in distribution. In Tanzania, *G. sepium* has been grown mainly in humid coastal lowlands or lake basins at altitude from 0 to 1,600 m (Mbuya *et al.*, 1994).

Its products include fodder for livestock, fuelwood, food and it adds N and other nutrients to the soil (National Academy of Science, 1983; Glover, 1989; Stewart, 1996; Allison and Simons, 1996). Under suitable conditions, *G. sepium* will yield as much as or more biomass than *Leucaena leucocephala* (Lam.) De Wit (20-30 m^3 $year^{-1}$ or more) (Stewart *et al.*, 1992). In Tanzania, in a two year improved fallow trial of *G. sepium* at Gairo in Morogoro (a semi arid area), a yield of 7.34, 8.81 and 15.52 t ha^{-1} of foliage, wood and total biomass respectively have been reported (Chamshama *et al.*, 2000).

Next to *Leucaena*, *G. sepium* is perhaps best known as fodder plant for ruminant animals with abundant amounts of nutritious fodder containing 18 to 30 % crude protein (Glover 1989; Allison and Simons 1996; Stewart 1996). Its hard heavy wood coupled with its coppicing ability makes it especially suitable for fuel. Calorific value of 4,900 kcal per kg for naturally occurring *G. sepium* has been reported (National Academy of Science, 1983). However, this can be expected to vary with environmental and silvicultural factors.

2.1.1 Ecology

Despite the widespread present occurrence of *G. sepium* in cultivation throughout Central American countries and Mexico, it is likely to be native only in the seasonally dry forest (Hughes 1987). It is largely deciduous during the dry season. In areas where sufficient moisture prevails, however, the tree does not become leafless (Seibert, 1987). Flowering begins at the start of the dry season and can continue in some native populations until the end of the first rainy month. Altitude was suggested by Hughes (1987) to exert a large influence on the onset of flowering with lower coastal sites flowering well before sites at higher altitudes (i.e. up to 1,200 m). The periodicity of pod ripening is partly dependent upon the climatic conditions and typically takes 45-60 days. *Gliricidia sepium* in cultivation in wet areas may often flower, although sets little if any fruit.

Seeds are shed from pods through explosive dehiscence and seed dispersal distances of up to 40 m have been reported (Simons and Dunsdon, 1992). No scarification or pretreatment of seeds is required prior to germination, and germination rates above 90% are typical. Following germination, trees grow extremely quickly and may attain a height of 3 m before flowering at age 6-8 months in humid areas (Simons and Dunsdon, 1992). Its rapid growth makes it an aggressive pioneer capable of colonising secondary forest and fallow *Imperata* dominated grassland often forming dense, pure stands (Anoka *et al.*, 1991).

In its natural range, individual trees display vast numbers of flowers (up to 30,000) that attract a wide variety of insect visitors. Foremost amongst these is a conspicuous species of carpenter bee (*Xylocopa fimbriata*) that was suggested by Janzen (1983) and confirmed by Simons and Dunsdon (1992) to be the primary pollinator of *G. sepium*. *Xylocopa fimbriata* is a large (up to 30 mm in length), solitary bee that is principally attracted to the abundant nectar of *G. sepium*, and is capable of flight distances of several kilometres thus effecting pollen dispersal at great distances between parents. Another genus of large bees (*Centric* sp.) was also observed to visit *G. sepium* trees in Guanacaste, Costa Rica (Coville *et al.*, 1986).

The temperature requirements of *G. sepium* are not too exacting as shown by the wide variation in mean monthly temperature (20.7-29.2°C) at native sites. It will, however, not tolerate frosts, which partly explains its absence above 1.200 m in the native range. Whiteman *et al.* (1986) in southeast Queensland, found that trees became leafless when night temperatures fell below 15°C. *Gliricidia* can, however, be managed in a coppice system in areas with light frost, by cutting the new growth before frosts occur (Stewart *et al.* 1992).

The 30 sites sampled by Hughes (1987) in his range-wide collection of populations of *G. sepium,* represent a great diversity of soil types. Most of the soils were highly eroded, of acid reaction (pH 4.5-6.2) originating from volcanic parent material but also included sands, heavy clays and calcareous limestone soils, which were slightly alkaline. At exotic locations, such as Peru, Szott *et al.* (1991) suggested that *G. sepium* was suitable for acid, infertile soils. Furthermore, Whiteman *et al.* (1986) considered *G. sepium to* be well adapted to low calcium (Ca) soils in Australia, although *G. sepium* was seen to have poor survival on Indonesian soils with high Al saturation (Dierolf and Yost, 1989).

Gliricidia sepium tolerates fires well and trees quickly resprout with arrival of the rains. The increased frequency of fires through deliberate burning may be responsible for the high occurrence of *G. sepium* in secondary vegetation and agricultural fallows in its natural ranges. Holm *et al.* (1979) report *G. sepium* as a severe weed in Jamaica, whereas Hughes and Styles (1984) consider *G. sepium* to have only a slight weediness hazard.

2.1.2 Distribution

Naturally *G. sepium* occur up to an altitude of 1,600 m from Mexico through Central America to northern South America (National Academy of Science, 1980; Falvey, 1982). Hughes (1987) was the first to distinguish between native and naturalised distributions of *G. sepium* in his comprehensive genecological survey of the native range. In his tentative distribution map, Atlantic coastal populations and northern South American populations were assigned as naturalised thus restricting native sites to only the dry forests of the Pacific coast in Mexico and Central America. The sites sampled by Hughes ranged in altitude from sea level to 1,100 m a.s.l, and in annual rainfall from 650 to 3,500 mm.

2.1.3 Uses

Few non-industrial tree species embody the concept of a multipurpose tree better than *G. sepium.* It is used to supply tree products such as fuelwood, construction poles, crop supports, green manure, fodder and bee forage. In addition, it is used in living fences, to stabilize soils and prevent erosion, to shade plantation crops, as an ornamental and in traditional medicine for eczema. Generally, however, it is cultivated for a particular purpose and the additional benefits are appreciated but not necessarily demanded, thus the concept of one individual tree supplying all of the above products is illusory.

2.1.3.1 Fuelwood

The easy coppicing nature of *G. sepium* contributes to its acceptability as a source of fuelwood. Fuelwood is obtained in its native range through the occasional lopping of branches or by completely coppicing trees to low levels above ground. Smaller diameter wood is not prized as much as larger diameters because of its lower specific gravity. Wood of gliricidia burns slowly thus producing good embers, and gives off little smoke or sparks explaining its general acceptability (CATIE, 1986). Heating value of 19.8 MJ/kg with an average specific gravity of 0.5-0.6 have been reported (Withington *et al.*, 1987).

2.1.3.2 Living fences

A distinct advantage of *G. sepium* is its ability to root from cuttings or stakes with high attendant survival. Stakes up to 2 m in length and 10-15 cm diameter can be placed directly in the ground, a point reflected by one of its common names, 'quick stick'. The benefit of using long stakes is that they are not grazed out and compete better with other vegetation relative to seedlings. Liyanage and Jayasundera (1989), however, reported that plants of *G. sepium* grown from seed were more productive, hardier and developed a deeper rooting system than plants derived from cuttings.

Several thousands of kilometres of living fences have been planted in both dry and wet sites throughout Central America and Mexico. These are commonly pollarded at a height of 1.0-2.5 m, and generally at least once per year. Individual posts may last beyond 30 years whilst loppings provide a ready supply of replacement posts. Loppings may also be used for animal forage or firewood whilst the spreading crowns of fenceline trees give shade and shelter to livestock. Living fences are used in the native range by a wide cross-section of the community from wealthy cattle ranchers who use it for pasture fences to resource-poor farmers who use it to mark boundaries and keep livestock out of cropped fields. Homestead gardens or domestic livestock may also be fenced off with closely spaced living fences of *G. sepium*.

2.1.3.3 Green manure

A less historic use of *G. sepium* but one that is increasing in occurrence is the use of leaves as a green manure; however, only isolated examples of mulching or incorporation of leaves into soil (e.g. El Gariton, Guatemala) are evident in the native range. Greater use of *G. sepium* as a green manure has been made outside the native range with reports as early as the 1930s in Malaysia (Anonymous, 1934) and Sri Lanka (Joachim and Kandiah, 1934) on its benefits. In Sri Lanka, *G. sepium* has been grown between rows of coconuts and found to be an excellent organic fertilizer (Liyanage, 1987). In Western Samoa, taro yields have been increased by up to 54% with the addition of *G. sepium* leaf mulch (Kidd and Taogaga, 1985). Leaf mulch of *G. sepium* increased the yield and reduced time to harvest of yam tubers in the Ivory

Coast (Budelman, 1989). Similarly, rice yields were boosted by up to 77% through the use of *G. sepium* mulch (Gonzal and Raros, 1988). In addition, where *G. sepium* was used as mulch in rice fields, the incidence of a rice leaf blight disease was reduced through stimulating growth of saprophytes parasitic to the causal organism (Rajan and Alexander, 1988). Yamoa *et al.* (1992) reports release of 71% of the total N required by maize by cutbacks of *G. sepium* in 120 days. While studying the effects of application of AF tree prunings on nine AF tree species Anthofer *et al.* (1998) reported the highest grain yield (2.48 t ha^{-1}) with *G. sepium*. Increase of maize grain yield of 34% as a result of applying 10 t ha^{-1} of *G. sepium* mulch have been reported in Morogoro, Tanzania (Ignatus, 2000). In addition, in a two year improved fallow study conducted in Gairo and SUA Farm, *G. sepium* was found to improve soil fertility most than *Cajanus cajan* (L.) Millsp. and *Sesbania sesban* (Chamshama *et al.*, 2000).

2.1.3.4 Shade

Gliricidia sepium derives many of its common names (e.g. madre de cacao) from its use in its native range to shade cocoa and coffee plantations. As an exotic, *G. sepium* has also been used extensively as a shade tree and the largest single cocoa plantation in the world (12,000 ha), in Indonesia, uses *G. sepium* as the sole shade tree (Seibert, 1987). The landraces, which have developed in exotic locations, are largely remnants of populations chosen for their arboreal form and may not be optimally suited for other uses. An additional benefit found from shading tea in Sri Lanka with trees of *G. sepium* was reduction in the incidence of termites (Kathiravetpillai, 1990).

2.1.3.5 Forage

Gliricidia is an important forage crop in cut-and-carry systems in many parts of the tropics including Southeast Asia, Sri Lanka and the Caribbean (Falvey, 1982, Chadhokar, 1982). In other areas such as West Africa, India and the Philippines, however, its use is severely limited by apparent palatability problems (Mahadevan, 1956). *Gliricidia* is also little used as forage within its native range in Central America. This is partly because extensive grazing systems are preferred over stall feeding in Central America but there may also be a palatability constraint since little grazing of trees is evident. In Costa Rica, for example, prunings from live fences are sometimes left outside the fields, out of reach of the cattle, even where the pasture is in poor condition.

2.2 Improvement of soil fertility and fuelwood supplies under agroforestry

Different AF technologies are suitable in different environment. For example, alley cropping (growing food crops between hedgerows of planted and regularly pruned shrubs/trees) and mixed intercropping (shrubs/trees widely scattered over farmlands) have been found to increase yield of food crops in humid areas partly due to improved nutrient relations (Kang, 1993; Nair, 1993). On the contrary, in semi-arid areas, food crop yields from these systems often decline with time due to increased below ground competition for moisture and nutrients between food crops and trees (Singh *et al.*, 1989; Kang, 1993; Ong, 1994; Chamshama *et al.*, 1994; 1998; Rao *et al.*, 1998). In semi-arid areas of Tanzania, improved fallow and rotational woodlot technologies in areas where there is no acute shortage of arable land. and relay intercropping in areas with acute land shortage have been found to be suitable and has resulted into improved soil fertility and fuelwood supplies (Anonymous. 1998; Fasuluku, 1998; Chingonikaya, 1999; Mgangamundo *et al.*, 2000a,b, c, d).

Studies in Tanzania on improved fallow have been carried out in Morogoro, Shinyanga and Tabora using *Cajanus cajan, Calliandra calothyrsus, Gliricidia sepium, Leucaena leucocephala, Sesbania macrantha, S. sesban, Tephrosia vogelii* Hook. f. and *Senna siamea* (Lam.) H.S. Irwin & Barneby. Substantial increases in maize yields (up to 250% increase over natural fallows) and soil fertility after short fallow (1-3 years) have been recorded (Otysina *et al.*, 1997a,b; Chingonikaya, 1999; Chamshama *et al.*, 2000; Mgangamundo *et al.*, 2000 a,b,c). Similar results have been reported elsewhere (Xu *et al.*, 1992; Kwesiga and Coe, 1994; Mappaona *et al.*, 1994). Soil fertility improvement has been attributed to N addition by N fixing tree/shrub legumes. Besides, species like *Tephrosia vogelii* Hook. f. and *Tithonia diversifolia* (Hemsley) A. Gray have been found to improve P status of the soil (Fasuluku *et al.*, 1998; ICRAF, 1999; Mgangamundo *et al.*, 2000d)

Improved fallow has also demonstrated potential for improving wood supply. For example, the wood biomass yield from 2 year fallows of *S. sesban* and *G. sepium* at Gairo was 52.0 and 25.6 t ha^{-1} respectively (Chingonikaya, 1999; Mgangamundo *et al.*, 2000d). Equivalent yields from SUA farm were 43.6 and 25.5 t ha^{-1} (Chamshama *et al.*, 2000). Similar results have been observed elsewhere (Kwesiga and Coe, 1994). The rotational woodlot is a low input and cost effective technology which can provide tree products, maintain soil fertility and provide fodder for livestock while conserving the environment (Otysina *et al.*, 1996). The system involves a tree establishment phase where fast growing multipurpose trees are intercropped with crops, a tree fallow phase when trees are allowed to grow and develop and post fallow phase when trees are harvested and the cropping cycle started again.

In Shinyanga and Tabora, six year-old rotational woodlots of *Acacia crassicarpa, A. polyacantha* and *Leucaena leucocephala* yielded 187, 77.4 and 68.1 t ha^{-1} of fuelwood respectively (Anonymous, 1998). In addition to wood production, rotational woodlots enhance soil fertility resulting in increased crop yields (Anonymous, 1998).

Relay cropping involves intercropping of trees/shrubs and crops during the cropping season. The woody component allowed to grow during the dry season and harvested just before the onset of the next cropping season when it is felled and the cropping cycle started again. Increased crop yields under this system have been reported in Morogoro, Tanzania (Fasuluku *et al.*, 1998, Chamshama *et al.*, 2000).

2.3 Mechanisms for soil fertility improvements in agroforestry

Soil fertility has been defined as "the capacity of soil to support the growth of plants on a sustainable basis under given conditions of climate and other properties of land (Young, 1989). Balagopalan and Jose (1995) describe factors that characterize high soil fertility. Thus the viability of any land use system is measured mainly by its ability to maintain soil productivity, which in turn is mainly measured by the yield of agricultural crops on that land (Lundgren and Raintree, 1982).

The introduction of AF into farming systems was mainly aimed at providing a sustainable option to traditional shifting cultivation (Nair, 1993). The design of AF technologies is strongly based on the hypothesis that trees with deep root systems can capture and transport nutrients upward from beyond the rooting zone of normal annual crops (Mekonnen *et al.*, 1997). Generally planting of compatible and desirable species of woody perennials on farmland results in an improvement in soil fertility. Possible mechanisms for this include (Nair, 1993):

- increase in the OM content of the soil through the addition of leaf litter and other plant parts;
- more efficient nutrient cycling within the system and consequently more efficient utilization of nutrients that are either inherently present in the soil or externally applied biological N fixation and solubilisation of relatively unavailable nutrients, for example phosphate, through the activity of mycorrhizae and phosphate-solubilising bacteria;

- increase in the plant cycling fraction of nutrients, with a resultant reduction in the loss of nutrients beyond the nutrient-absorbing zone of the soil;
- complementary interactions between the component species of the system, resulting in a more efficient sharing of nutrient resources among the components;
- enhanced nutrient economy because of different nutrient absorbing zones of the root systems of the component species; moderating effect of additional soil OM on extreme soil reactions and consequently improved nutrient release/ability patterns.

2.3.1 Nutrients capture

Tree management forms an integral component of many tropical agricultural systems, ranging in scope from extensive silvopastoral systems to intensively managed fodder banks. The benefits of integrating trees with crops is based on the premise that deep roots of trees can capture and 'pump-up' nutrients such as nitrate, that leach below the crop root zone (Van Noordwijk *et al.* 1996; Mekonnen *et al.*, 1997) while the N fixing ability of many leguminous species such as *G. sepium* is an added advantage (Matta-Machado and Jordan, 1995).

The integration of trees into farmlands has been suggested to combat soil nutrient depletion in tropical cropping systems (Sanchez, 1995). According to Yamoah *et al.* (1995) AF is innovation that is known to remedy or minimize P sorption and soil acidity, enrich the soil with N and control hillside erosion. Control of erosion by AF can considerably reduce nutrient losses (Crasswell *et al.*. 1997). Trees are able to mobilize nutrients from the subsoil and then return these nutrients to the topsoil making them available for annual crops (Buresh and Tian, 1998). In this way nitrate (NO_3) leaching is reduced leading to increased subsoil N utilization. This has been confirmed by a number of studies. For example, Hertmink *et al.* (1996) reported lower subsoil NO_3 and water in a *Sesbania* fallow than unfertilized maize monoculture, and presence of few maize roots below 120 cm while *Sesbania* and weed roots extended well below 200 cm. A 53% reduction in N leaching as a result of trees in the AF in comparison with sorghum monoculture has been reported (Lehman *et al.*, 1995). In addition, Browaldh (1995) reported better utilization of N and moisture in the soil, reduced potential for NO_3^- leaching and accumulation of N close to the trees. Higher water availability of soil due to presence of trees in AF has been attributed to interception and redistribution of rainwater within the system, reduced evapotranspiration and increased infiltration (Wallace, 1996). Decrease in soil bulk density and resistance to penetration and increased water infiltration was recorded in Zambia for 2-year fallow of *Sesbania sesban* (Torquebiau and Kwesiga, 1996).

Inclusion of leguminous trees such as *G. sepium* in AF have a potential to replenish N in the soil (Hati and Ray, 1984) through production of leaves of high quality which promote rapid N mineralization when applied to soil as mulch (Fernandes *et al.*, 1997). Thus legumes have been incorporated widely in intercropping systems to supplement the N requirements of the associated crop throughout much of the recorded history (Sarrantonio, 1992; Buresh and Tian, 1998). However, there is a room to improve the potential contribution of the trees/shrubs in this aspect through provenance selection.

2.3.2 Nutrient cycling, organic matter turnover and nutrient use efficiency

Trees play a very important and significant role in soil productivity regeneration through nutrient cycling, OM turnover (Otsyina and Karachi, 1998; Amara *et al.*, 1996) and nutrient use efficiency. Nwoboshi (2000) defined nutrient cycling as the entire process of nutrient absorption from the soil and atmosphere, their incorporation into complex organic molecules through biosynthesis, their immobilization for varying lengths of time in the bodies of various tree crop and animal components, their return through litterfall, death and excretion and subsequent decomposition to the soil, to be recycled.

One of the main principles of soil management in AF is to make the best use of its resource conserving and resource sharing potentials. Therefore it is extremely useful to have a proper nutrient budget for the whole system based on nutrient requirements of individual components and nutrient dynamics within the system. Nutrient cycling, proper nutrient processes, which take place to varying degrees in all land use systems, become particularly relevant in the AF context because of the likely effects of trees on such processes. Nutrients taken up by the plant are either stored in an increment (storage) compartment or are used for the production of non-storage organs and returned by decomposition of litter (Young, 1997; Nwoboshi, 2000). Nutrients are inevitably removed in harvest of both crops and trees, and, if they are not present in soil parent materials, recycling can reduce, but not replace, the need for inputs.

According to Young (1997) nutrient use efficiency entails manifestation of relatively high plant growth responses per unit of nutrients taken up by plants, which in turn depends on the passage of individual nutrient ions through plants many times before they are lost to the plant-soil ecosystem (nutrient cycling). Fertilizer application results in an input of nutrients and the accompanying ions into the solid phase of the uppermost layer of the soils. Depending on the water content of the soil and the solubility of the fertilizers, they pass into the solution phase of the same soil layer, then spread simultaneously, depending on the mobility of the ions in different layers of the soil, into the plant stand via uptake. Based on the flow rate of percolating water and the soil properties, part of the nutrients in the soil solution is washed out of the nutrients-absorbing zone and represents a loss (output) from the system.

Plant nutrients are in a constant and somewhat closed cycling within the soil and plant compartments of tree- based ecosystems, with minimal output (loss) from the system. The extent to which the system is closed or open depends on various factors, particularly tree/crop proportion. Even in AF systems with a high proportion of woody perennials, the frequency and method of harvesting their products, the structure and density of the root system, the type of magnitude of disturbance (including management) to the system, and the spatial and temporal arrangement of species are among the important factors that contribute to the effectiveness of the nutrient cycling processes in soil productivity. Some tree species have also been used in reclamation of problematic soils, such as saline and alkaline soils, for example *Prosopis juliflora* (Sw) DC., and *Acacia tortilis* (Forsskal) Hayne, through uptake of salts and addition of organic matter (Nair, 1993).

Sanchez (1976) reported encouraging results from studies conducted to assess the nutrient cycling potential of AF systems on Alfisols and Andepts of moderate to high fertility. In Costa Rica the use of *Erythrina poeppigina* (Walp.) Cook as shade trees in *Coffea arabica* L. yielded promising results (Alpizar *et al.*, 1986; Russo and Budowski, 1986). Juo and Lal (1977) reported significantly higher cation exchange capacity (CEC) and levels of exchangeable Ca and potassium (K) in a three year *Leucaena leucocephala* (Lam.) De Wit improved fallow where biomass was cut annually and returned as mulch. In Tanzania, increase in soil pH, exchangeable cation, soil organic carbon (OC) following improved fallow of *Cajanus cajan* (L.) Millsp., *G. Sepium*, *Sesbania sesban*(L.) Merr., *S. macrantha* and *Tephrosia vogelii* Hook. f. at Gairo, Morogoro have been reported (Chingonikaya, 1999; Mgangamundo, 2000). Adesina (1990) reported higher values of OC through improved fallow in Nigeria. The increase in OC due to presence of trees in AF has been attributed to higher humus as a result of decomposition of OM supplied through litterfall (Mgangamundo, 2000), an important aspect of nutrient cycling (Young, 1997).

2.3.3 Biological nitrogen fixation

Nitrogen fixing plants (NFP's) have been defined as "plants that can assimilate and fix molecular nitrogen (N_2) of the atmosphere by the aid of symbiotic bacteria living in root nodules" (Somani, 1989). Despite the abundance of molecular nitrogen (N_2) in the atmosphere, it is scarce in the form that living organisms can assimilate. This is due to the large amount of energy required to cleave the triple-bond atoms of the N_2 molecule. When these triple bonds are broken the individual atoms combine with hydrogen or oxygen to form ammonia (NH_3) or nitrate (NO_3^-) compounds that plant can use (Havelka *et al.*, 1982; Nwoboshi, 2000). In contrast to commercial Haber-Bosch process that requires high temperature and pressure to convert N_2 to NH_3, biological nitrogen fixation (BNF) is a unique enzymatic dinitrogen reduction process that converts atmospheric N_2 into a plant-usable form in presence of the microbial enzyme nitrogenase which catalyzes the conversion of dinitrogen into a reduced form (NH_3 - ammonia) under mild temperature and normal atmospheric pressure (Havelka *et al.*, 1982; Bohlool *et al.*, 1992). Thus nitrogen-fixing plants offer an economically attractive and ecologically sound means of reducing external inputs, which smallholder farmers in developing countries cannot afford.

BNF is of particular importance in sustaining production of soils in the tropics including Tanzania. Planting nitrogen fixing trees (NFTs) and crops in AF is one low-input technology that helps maintain levels of N, a key nutrient for plant growth. A number of trees and shrubs are known to have N fixing qualities. About 650 tree species are known to be, and several thousand suspected to be N fixing (Brewbaker, 1987). Yet according to Young (1989), herbaceous and woody legumes with associated rhizobium bacteria in the root nodules are imperative N fixing plants. While BNF by herbaceous legumes has long been recognized in agricultural practices, efforts to exploit N_2 fixing trees/shrubs such as *G. sepium* in productive land-use systems has recently received attention following the interest in AF (Nair, 1993). BNF can be a major source of N in agriculture when N-fixing trees/shrubs are used. The amount of N input by N-fixing trees and shrubs is reported to be as high as 360 kg ha^{-1} (Bohlloo *et al.*, 1992). The value for *G. sepium* is reported to be 86-300kg N ha^{-1} yr^{-1} (Sanginga *et al.*, 1995).

The amount of N fixed by the legume component in a given legume-cereal intercropping systems is determined by several factors, including species, plant morphology, density of component crops, management regimes, plant genotype/provenance and competitive abilities of the component crops (Ofori and Stern, 1987; Liyanage *et al.*, 1994). Sumberg (1985) reports variation in the amount fixed by different accessions of *G. sepium*. Liyanage *et al.* (1994) reported significant variation in N fixing ability among *G. sepium* provenances in Sri Lanka. This offers an opportunity to improve N fixation in the tropics including Tanzania where N deficiency is one of the factors limiting crop production.

2.4 Variation in foliar nutrient contents of multipurpose trees and shrubs

AF is concerned with the cycling of plant material and so is certainly concerned with the complete range of plant nutrients. In the tropics N and P are of particular importance since they are most frequently the limiting nutrients in tropical soils (Young, 1989, 1997; Mugasha *et al.*, 2000). In the face of limited availability of chemical fertilizers to smallholder farmers, environmental problems of soil acidification and water pollution due to continued use of chemical fertilizers (Young, 1997), and inadequate fodder supply during dry season, foliages of multipurpose trees/shrubs are used in AF as mulch and fodder in various places in the tropics including Tanzania (Nair, 1993; Mbuya *et al.*, 1994; Ngulube, 1994; Herbert *et al.*, 2002). Foliar nutrient content is one of the criteria used to describe quality of plant residues added to the soil (Young, 1997) and fodder. In addition, nutrient concentration can facilitate early selection of best-adapted provenances (Steinbeck, 1966). Therefore, information on foliage nutrient concentration is essential.

Studies have shown that foliar nutrient concentration varies greatly between and within species (Fasuluku, 1998; Hakizimana, 1999; Mgangamundo, 2000). Variation in foliar nutrient concentration for some multipurpose trees/shrubs reported by various authors is presented in Table 1.

2.5 Variation in growth and yield in *G. sepium*

Biomass production by trees of *G. sepium* is very much dependent on climate and soils, management, planting density, length of rotation and the provenance used. Studies have measured leaf biomass (dry matter) production under a range of climatic and edaphic conditions, and under various management regimes differing with respect to variables such as establishment methods (seedlings versus stakes of various sizes), plant spacing, lopping height and lopping frequency. Values reported for *G. sepium* annual leaf dry matter production generally range from about 2 t/ha/year (Wong and Sharudin, 1986) to 20 t/ha/year (Sriskandarajah, 1987).

In Tanzania, Chamshama *et al.* (2002) report yields up to 7.34 and 8.18 t ha^{-1} of foliage and wood respectively which is equivalent to 3.67 and 4.10 t/ha/year of foliage and wood in that order for a two year *G. sepium* fallow at Gairo, Morogoro (semi arid area). Salazar (1986) reports dry wood yields of up to 6.3 t/ha/year from trees in Costa Rica, whereas Wiersum (1982) quotes yields of 1520 m^3/ha/year. In the Philippines, where *G. sepium* is grown in woodlots on a three-year rotation to provide wood for tobacco curing, yields of up to 23-40 m^3/ha/year have been obtained (Wiersum and Dirdjosoemarto, 1987). In Nigeria, Cobbin *et al.* (1990) reports higher shoot dry weight of 84-day-old *G. sepium* in fertile soil (4.2 g/plant) than in poor soil (3.3 g/plant).

Table 1: Some reported results on variation in foliar nutrient concentrations among multipurpose trees and shrubs

Tree/shrub	N	P	K	Ca	Source
Alchornea cordifoliar	3.29	0.23	1.74	0.46	Kang *et al.* (1984)
Albizia lebbeck	2.30	0.12			Fasuluku (1998)
Cajanus cajan	3.60	0.2	-	-	Agboola (1982)
Cajanus cajan^{x}	2.58	0.18			Mgangamundo (2000)
Cajanus cajan^{y}	2.52	0.18			Mgangamundo (2000)
Cajanus cajan^{z}	2.45	0.15	-	-	Mgangamundo (2000)
Cassia siamea	2.52	0.27	1.35	-	Yamoa *et al.* (1986)
Dactyldenia barteria	2.57	0.16	1.78	0.96	Wilson *et al.* (1986)
Erthrina poeppigiana	3.30	0.18	1.16	1.52	Russo and Budowski (1986)
Gliricidia sepium	4.21	0.29	3.43	1.40	Kang *et al.* (1984)
Gliricidia sepium^{1}	2.87-3.99	0.13-0.17	-	-	Kwesiga (1994)
Gliricidia sepium^{1}	2.58-3.15	0.17-0.20	0.98-1.77	1.63-2.97	Ngulube (1994)
Gliricidia sepium	2.61-2.85	0.12-0.14	-	-	Kimaro (2000)
Gliricidia sepium	2.36	0.13			Fasuluku (1998)
Grevillea robusta^{1}	1.2	0.18	1.6	0.49	Hakizimana (1999)
Inga edulis	3.1	0.20	0.9	0.7	Szott *et al.* (1991)
Leucaena leucocephala	4.33	0.28	2.50	1.49	Kang *et al.* (1984)
Senna siamea	2.21	0.38			Fasuluku (1998)
Sesbania sesban	2.92	0.13			Fasuluku (1998)
Sesbania sesban^{x}	2.94	0.20	-	-	Mgangamundo (2000)
Sesbania sesban^{y}	2.80	0.18			Mgangamundo (2000)

^{1}Provenance trials; ^{x}Results at the age of 1 year; ^{y}Results at the age of 2 years; ^{z}Results at the age of 3 years.

Table 1: Continued.

Tree/shrub	N	P	K	Ca	Source
Sesbania sesban[z]	2.27	0.17			Mgangamundo (2000)
Tephrosia vogelii	2.56	0.19			Fasuluku (1998)
Tephrosia vogelii[x]	2.59	0.20	-	-	Mgangamundo (2000)
Tephrosia vogelii[y]	2.17	0.17	-	-	Mgangamundo (2000)
Tephrosia vogelii[z]	1.89	0.15	-	-	Mgangamundo (2000)

[1]Provenance trials; [x]Results at the age of 1 year; [y]Results at the age of 2 years; [z]Results at the age of 3 years.

Marked differences among *G. sepium* provenances with up to 500% differences in biomass production at some sites have been reported (Simons and Dunsdon, 1992). Sukanten *et al.* (1995) reported significant variation among *G. sepium* provenances in growth and fodder yield in Indonesia. They reported fodder yield ranging from 1,015 to 1,671 g dry weight /plant and wood yield from 792 to 1,662 g dry weight/plant. In Malawi, Ngulube (1994) reported variation in growth and yield between *G. sepium* provenances. He reported the variation in average above ground biomass ranging from 7.0 for poor performing provenance to 10.9 t ha^{-1} per year for best performing provenance. In Zambia, Kwesiga (1994) reports variation in above ground biomass production among *G. sepium* provenances ranging from 8 to 32 t ha^{-1} at 27 months and 9 to 33 t ha^{-1} at 39 months. According to Simons and Dunsdon (1992) and Kwesiga (1994), one provenance from Guatemala, Retalhuleu, showed stable and superior production for both leaf and wood production across a wide range of sites. Another provenance from Guatemala, Monterrico, showed poor growth in terms of wood production yet was outstanding for leaf production (Simons and Dunsdon, 1992). However, this can be expected to vary from one climatic region to another (Sukanten *et al.*, 1995). The existence of large variations among *G.sepium* provenances in terms of growth and yield necessitates the need to test the various *G.sepium* provenances in a wide range of climates before embarking on large-scale utilization of this important multipurpose tree in agroforestry systems in Tanzania.

2.6 Importance of species and provenance selection in agroforestry

Provenance trials are the logical continuation of the process of species' selection that begins with species' elimination trials, and so the two employ basically similar methodology (Nshubemuki, 1998). The chief difference is that whilst in species' trials attempts are made to determine accurately the comparative value of populations, which are known to be genetically different, provenance research is concerned with differences that at the beginning can only be "assumed" (Kemp, 1976). Therefore to establish whether real differences exist between populations as well as to determine their relative value for particular uses in different locations is one purpose of provenance research (Nshubemuki, 1998).

Exotic multipurpose tree/shrub species are often more vigorous and produce higher yields than indigenous species and in many regions they have made invaluable contributions. For example, it has been estimated that 150 to 200 million people use gliricidia worldwide, the majority of whom live outside its native range (Simons, 1996). *Leucaena leucocephala* is now naturalized in the Philippines, where it is the principal source of tree fodder and of fuelwood, and this species underpins a sustainable and highly productive beef cattle production system in northern Australia (Middleton *et al.*, 1995). However, only a small number of exotic tree/shrub species have dominated tree-planting activities in the AF sector with information on their performance creating an ever-increasing demand for seed. According to Zobel and Talbert (1984) and Krishan and Tocky (1995), success in the establishment and productivity of the introduced tree/shrub in AF systems will depend largely on the species and the sources of seed (provenance) within the species. Traditionally, links between tree breeders and small farmers have, however, been weak with the results that single ad hoc introductions have often formed the basis of the subsequent spread of a species throughout a country leading to the dangers of narrowly based populations. For example, the introduction of *Gliricidia sepium* from Trinidad to Sri Lanka was made with seed from one tree (Stewart *et al*., 1996). According to Hughes (1987), and Simons and Dunsdon (1992) the disadvantage of such a practice include the possibility of the threat of widespread destruction due to disease, and/or pests, lack of tolerance to a wide range of ecological conditions, erosion of the inherent genetic variation (in breeding depression) or possible dilution of desirable traits over time. Susceptibility of *Leucaena leucocephala* to Leucaena psyllid is an outstanding example in Tanzania. In addition, experience has shown that early introductions are inferior in terms of performance to other sources of seed from within the native range of the species in question. Also according to Simons and Dunsdon (1992) research results obtained from studies using material from narrow genetic base may not indicate the full potential of the species. Thus it is tempting to study provenance variations for introduced AF trees and shrubs in Tanzania such as *G. sepium*.

2.7 Provenance x site interaction

Provenance x site interaction refers to any inconsistency in the relative performance of provenances in different environments. This occurs when different environments (sites) do not have the same effect on different genotypes (Falconer. 1960). This interaction can be manifested in various ways but it is of practical importance only if the best population for one site is not necessarily the best for others (Barnes *et al.*, 1984).

Squillace (1970) and Wright (1973) reviewed the literature and revealed the existence of strong provenance x site interaction in tree species, particularly for growth rate.
In Tanzania provenance x site interaction has been reported by Nshubemuki (1983), and Sabasi and Nshubemuki (1987) for *Eucalyptus camaldulensis* Schlecht. in Dodoma and Mwanza, Tanzania respectively. Herbert *et al.* (2002) reported provenance x site interaction for *Calliandra calothysus*. On the other hand, the absence of such interaction has been reported in other studies. In Nigeria, Otegbeye (1990) and Otegbeye (1995) reported the absence of provenance x environment interaction for *Pinus oocarpa* Shiede & Schltdl and *Pinus caribaea* Morelct respectively while Otegbeye (1992) reported similar results for other tree species. In fact, the level at which interaction occurs varies with species and characteristics (variables) assessed (Barnes *et al.*, 1984). In addition, the interaction depends on the genetic make-up of the investigated material, strongest effect being expected on clonal material which provenances will buffer interactions more effectively.

Presence or absence of provenance x interaction has economic implications in genetic improvement programmes since it affects the costs involved in tree improvement programme. According to Otegbeye (1992), the presence of provenance x site interaction indicates that the expression of the assessed characteristics is little affected by genetic make-up so it is under the control of environments, and/or sites. Conversely, absence of provenance x site interaction implies that the expression of the assessed characteristics (variables) is under strong genetic control and environments have little effects (if any) on expression of the characteristics.

The absence of provenance x site interaction especially when the test sites are the true representatives of the different agro-ecological zones that exist in a given country or region gives a room for identification of the single best provenance for afforestation and genetic improvement programme for the whole country, and/or region. In addition, seeds of the species that do not display provenance x site interaction can be easily exchanged in the country without any fear of adverse effects. This in turn, greatly enhances the breeder's ability to develop the desired trees/shrubs of superior genetic constitution in a shorter period of time and at reduced cost since a genetic improvement programme for a single provenance can be developed to carter for the whole country or region. This is possible as there will be no need of maintaining different breeding populations for the different agro-ecological zones within the country or region.

CHAPTER THREE

3. MATERIALS AND METHODS

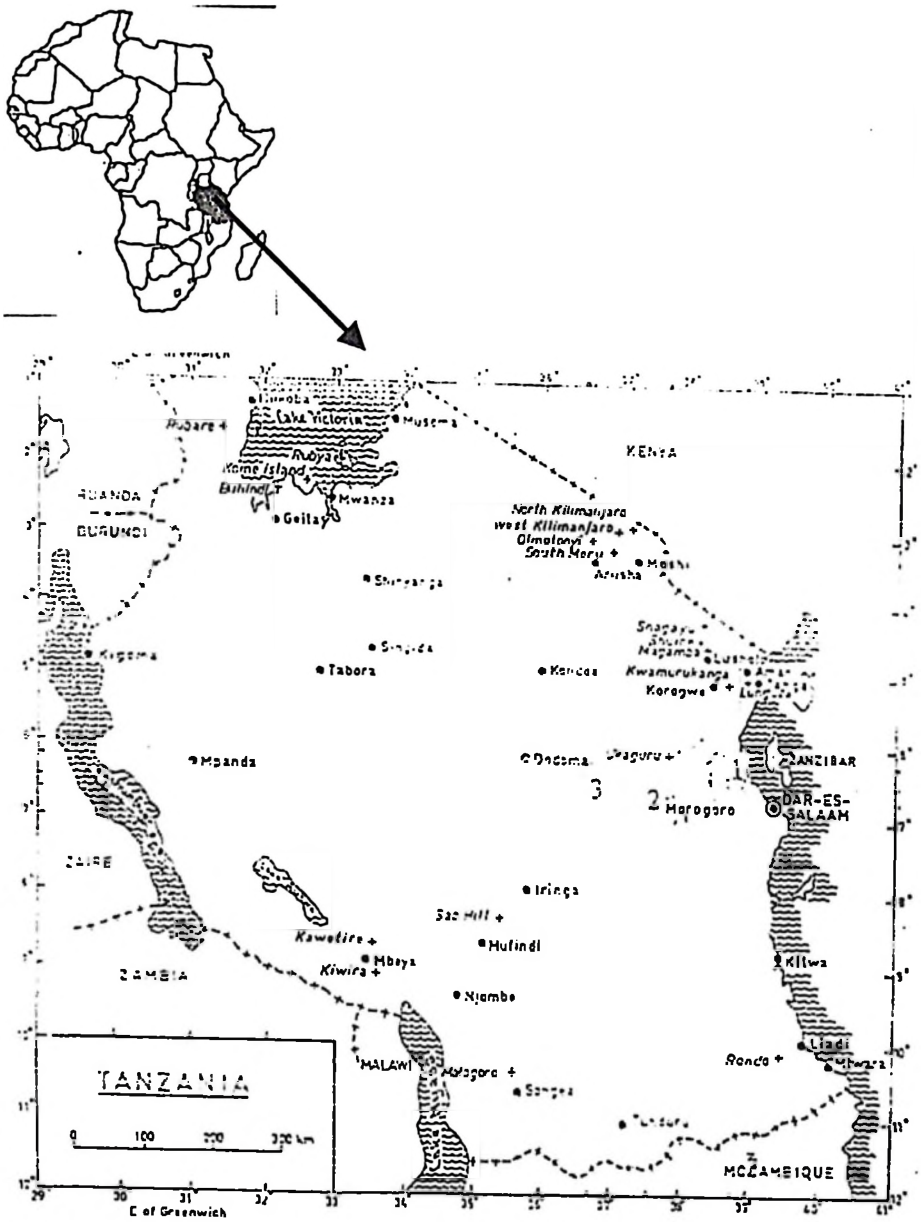
3.1 Description of study sites

The study was carried out at three sites i.e. SUA farm, Gairo and Kibaha, Tanzania Figure 1 shows location of the study sites.

3.1.1 Sokoine University of Agriculture (SUA) farm site

Sokoine University of Agriculture (SUA) farm site (37^0 38'E; 6^{0}50'S: 526 m a.s.l) in in Morogoro region, Tanzania is located along Iringa-Dar es salaam/Dodoma highway about 3 km from Morogoro town. The area experiences a sub-humid tropical climate with a bimodal rainfall pattern characterized by two rain peaks in a year with a definite dry season separating the short rains (October to December) and long rains (March to May). The long-term annual rainfall is 870 mm (Appendix 4), total annual evapontranspiration is about 1370 mm and the mean annual temperature is 24^{0}C. Figure 2 shows medium term (1970-2001) total rainfall for SUA farm site

Soils are classified as Acrisol (FAO, 1988). These soils are deep and well drained, predominantly clay loamy with very low OC and P contents, and low to very low total nitrogen contents (Fasuluku, 1998).



Source: Forest Division (1982)

Legend:

1 = Kibaha site

2 = SUA farm site

3 = Gairo site

Figure 1: A map of Tanzania showing location of the study sites

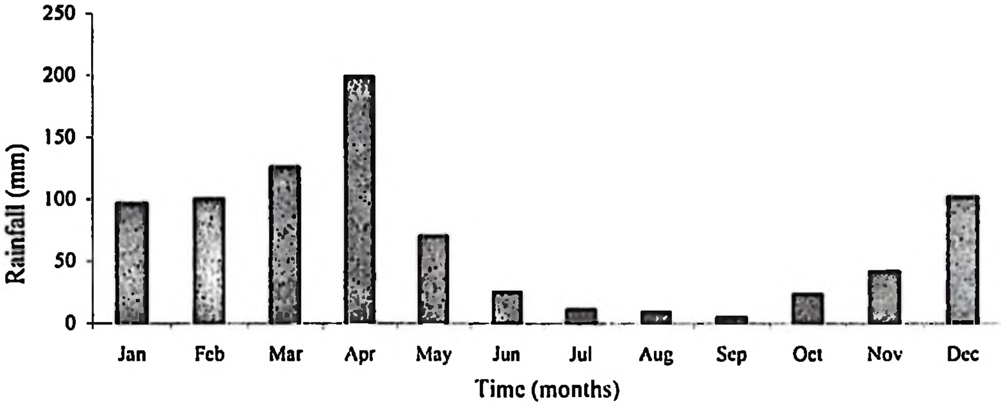


Figure 2: Mean monthly rainfall (1970-2001) for SUA Farm, Morogoro, Tanzania

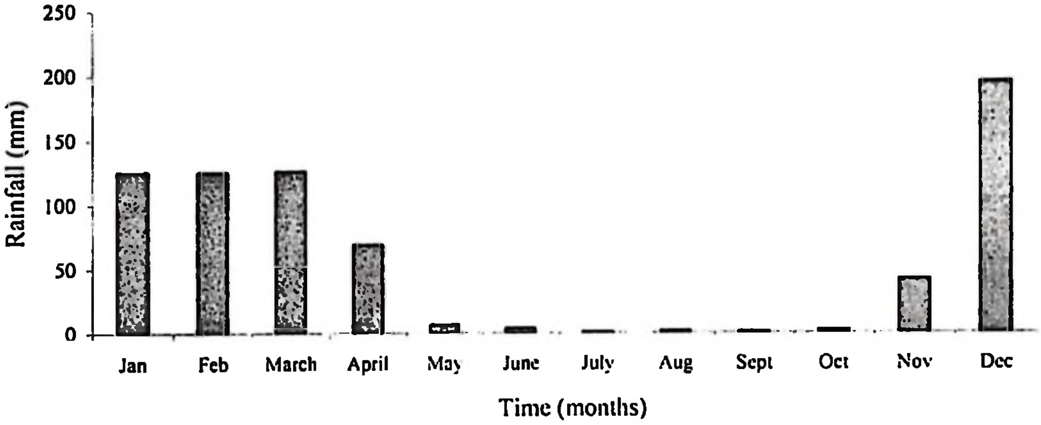


Figure 3: Mean monthly rainfall (1961- 1978) for Gairo, Morogoro, Tanzania

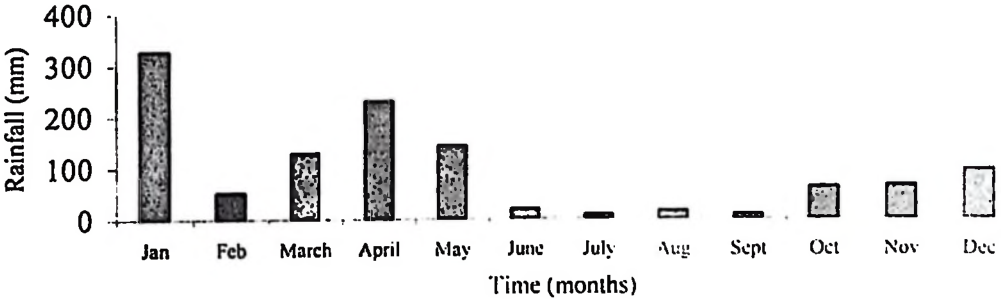


Figure 4: Mean monthly rainfall (1973- 1998) for Kibaha, Coast region, Tanzania

The overall inherent soil fertility is low. Soil bulk density is higher between 10-30 cm soil depth as compared to that of soil above and below this depth. This is related to soil compaction due to long term use of farm tractors during ploughing and harrowing. Table 2 shows some selected soil properties for SUA farm site.

3.1.2 Gairo site

Gairo ($36^0$45'E; $6^0$30'S; 1300 m a.s.l.) in Morogoro region. Tanzania is located along the Morogoro-Dodoma highway about 130 km from Morogoro town and 140 km from Dodoma. Rainfall is poorly distributed, and varies from year to year. The average annual rainfall is around 499 mm. most of which fall between November and May (Chamshama *et al.*, 1994). There is no weather station in the immediate vicinity of Gairo. The data (Appendix 5) from Kongwa Ranch (1961-1978) that is about 40 km from Gairo tend to show the general pattern. Figure 2 shows medium term (1961-1978) total rainfall for Gairo site. Selected soil properties are given in Table 3. The soil has low inherent fertility. The area is dominated by vegetation consisting mainly of shrubs and few scattered trees such as *Acacia, Brachystegia, Julbernadia* and *Isoberlinia.* The major activity of the population is arable farming, the most common crops being maize and sweet potato. In addition, livestock keeping is practiced.

Table 2: Some selected soil properties of the Soikoine University of Agriculture (SUA) farm, Morogoro, Tanzania

	Soil depth (cm)				
Soil properties	0-10	10-20	20-30	30-40	40-50
Textural class	Clay loam	Clay loam	Clay loam	Clay loam	Clay loam
Bulk density (g/cm^3)	1.25[1] (0.04)	1.39 (0.40)	1.31 (0.01)	1.24 (0.01)	1.18 (0.02)
pH	5.60 (0.22)	5.03 (0.27)	4.86 (0.23)	4.85 (0.24)	4.71 (0.13)
Electrical conductivity (dS/m)	0.043 (0.014)	0.023 (0.003)	0.023 (0.003)	0.030 (0.020)	0.023 (0.013)
Organic carbon (%)	0.99 (0.034)	0.84 (0.023)	0.59 (0.023)	0.49 (0.017)	0.34 (0.026)
Total nitrogen (%)	0.13 (0.014)	0.16 (0.016)	0.14 (0.008)	0.13 (0.006)	0.11 (0.007)
Total phosphorus (ppm)	305.56 (30.92)	241.67 (21.38)	275.00 (31.55)	243.06 (22.34)	176.39 (36.19)
Available phosphorus (ppm)	2.95 (0.197)	1.96 (0.134)	0.58 (0.076)	0.38 (0.030)	0.32 (0.190)
Exchangeable cations (cmol(+)kg^{-1} soil)					
Na	0.51 (0.002)	0.31 (0.001)	0.34 (0.002)	0.41 (0.006)	0.37 (0.001)
K	1.66 (0.020)	1.09 (0.021)	0.68 (0.021)	0.81 (0.045)	0.32 (0.003)
Ca	4.60 (0.017)	3.65 (0.032)	2.91 (0.026)	2.60 (0.020)	2.29 (0.022)
Mg	3.07 (0.004)	2.70 (0.016)	2.52 (0.018)	2.75 (0.022)	2.85 (0.015)

[1] Means of three replications followed by standard error in parentheses.

Source: Fasuluku (1998)

Table 3: Some soil properties of the experimental site at Gairo, Morogoro, Tanzania

	Soil depth (cm)				
Soil properties	0-10	10-20	20-30	30-40	40-50
Bulk density (g/cm^3)	1.45[1] (0.02)	1.43 (0.11)	1.57 (0.04)	1.56 (0.05)	1.55 (0.03)
pH	6.24 (0.10)	6.22 (0.03)	6.23 (0.09)	6.30 (0.15)	6.10 (0.0.07)
Electrical conductivity (dS/m)	0.07 (0.02)	0.04 (0.01)	0.02 (<0.01)	0.02 (<0.01)	0.01 (<0.01)
Organic carbon (%)	0.91 (0.06)	0.72 (0.06)	0.63 (0.05)	0.51 (0.03)	0.39 (0.03)
Total nitrogen (%)	0.16 (0.01)	0.13 (0.01)	0.13 (<0.01)	0.11 (0.02)	0.11 (<0.01)
Organic phosphorus (%)	305.56 (30.92)	241.67 (21.38)	275.00 (31.55)	243.06 (22.34)	176.39 (36.19)
Available phosphorus (ppm)	3.38 (0.93)	1.52 (0.41)	1.23 (0.17)	1.90 (0.54)	0.18 (0.09)
Exchangeable cations					
Ca	4.11 (0.02)	4.68 (0.84)	4.94 (0.21)	4.61 (0.12)	5.00 (0.50)
Mg	1.65 (0.15)	1.87 (0.21)	2.57 (0.13)	2.70 (0.11)	2.97 (0.04)
K	0.96 (0.08)	0.63 (0.15)	0.58 (0.15)	0.42 (0.13)	0.38 (0.04)
Na	0.29 (0.02)	0.27 (0.03)	0.38 (0.06)	0.30 (0.01)	0.31 (0.02)

[1] Means of four replications followed by standard error in parentheses.

Source: Mugasha *et al.* (2000)

Table 4: Some soil properties of the experimental site at Kibaha, Tanzania

	Soil depth (cm)				
Soil properties	0-10	10-20	20-30	30-40	40-80
pH	6.29 (0.29)	5.6 (0.18)	5.56 (0.17)	4.99 (0.26)	4.61 (0.26)
Electrical conductivity (mS/cm)	119.82 (20.8)	22.97 (2.2)	13.762 (2.35)	16.62 (1.27)	21.72 (4.06)
Organic carbon (%)	0.85 (0.25)	0.91 (0.09)	0.93 (0.06)	0.83 (0.23)	0.43 (0.03)
Total nitrogen (%)	0.105 (0.028)	0.059 (0.019)	0.054 (0.019)	0.045 (0.016)	0.037 (0.000)
Total phosphorus (%)	0.334 (0.056)	0.180 (0.024)	0.337 (0.041)	0.480 (0.055)	0.831 (0.014)
Available phosphorus (%)	0.0048 (0.0003)	0.0036 (0.0007)	0.0002 (0.0005)	0.0019 (0.0008)	0.0014 (0.0007)
Soil texture					
Sand (%)	91.45 (0.435)	90.55 (1.037)	88.2 (0.47)	89.6 (0.72)	87.95 (2.81)
Course silt (%)	5.15 (0.639)	3.5 (0.288)	5.5 (0.86)	3.05 (1.03)	4.15 (1.63)
Fine silt (%)	0.95 (0.75)	1.55 (0.67)	1.65 (0.81)	0.8 (0.14)	1.55 (0.46)
Clay (%)	2.45 (0.18)	4.4 (0.86)	4.65 (1.05)	6.55 (0.22)	6.35 (1.48)

[1] Means of four replications followed by standard error in parentheses.

Source: Mnyonga (2001)

3.1.3 Kibaha site

Kibaha experimental site (6°32' and 6° 43' S; 38° 48' and 39° 02' E; 70 m a.s.l.) in Coast region, Tanzania is located within Ruvu forest project along Morogoro-Dar es Salaam highway about 40 km west of Dar es Salaam city. The annual rainfall ranges between 700 to 1000 mm and the medium term rainfall in about 1175 mm/year (Appendix 6). October to May is the wet season while June to October is dry. Figure 3 shows medium term (1973-1998) total rainfall for Kibaha site. Mean annual average temperature for the coldest and hottest are 18°C and 30°C respectively. Selected soil properties are given in Table 4.

3.2 Experimental design and treatments

Provenances planted were 6, 5 and 13 at Gairo, Kibaha and SUA farm site respectively (Tables 5a and 5b). The trials were planted in a randomized complete block design with two, three and four replications for Gairo, SUA farm and Kibaha site respectively. Plots measured 6 x 12, 6 x 8, and 8 x 8 m for Gairo, SUA farm and Kibaha site respectively. Distances between plots and between blocks were 3 and 4 m respectively for each site. Trees were planted at a spacing of 2 x 2 m on each site and numbers of trees planted per plot were 28, 20 and 25 for Gairo, SUA farm and Kibaha sites respectively. For each site, each plot had one surrounding row of *Gliricidia sepium* planted at a spacing of 2 x 2 m.

3.3 Establishment, tending and assessment of the experiments

3.3.1 Site preparation, planting and tending

All sites were prepared by clearing all vegetation using a hand hoe followed by ploughing and pitting. Pit size was 20 cm x 30 cm. Planting was done in February 1996, March 1996 and March 1999 for Gairo, SUA farm and Kibaha site respectively. All experiments were kept clean weeded throughout. For Gairo and SUA farm sites, weeding was done twice during the rain season and once during the dry season. For Kibaha site, weeding was done three times during the rain season and twice during the dry season.

3.3.2 Assessments

Assessments were done at ages of 6, 18, 27, 42 and 70 months for Gairo site; 6, 16, 24, 41 and 69 months for SUA farm site; and 10, 29 and 33 months for Kibaha site. For Gairo and SUA, during the first two assessments root collar diameter (RCD) and height were measured while RCD, diameter at 30 cm above ground level (D30) and height were measured in the subsequent assessments but RCD was not measured at the SUA farm in the final assessment as it was found to have low correlation with biomass production. For Kibaha site, RCD, D30 and height were measured on each assessment date.

Table 5a: Seed sources for *Gliricidia sepium* provenances/landraces planted at SUA farm, Gairo and Kibaha, Tanzania

Provenance			*Seed lot/OFI No.	Latitude	Longitude	Altitude (m)	Rain fall (mm/yr)
No.	Locality	Country					
1	Cuyatenango	Guatemala	14504	14^{0}33'N	091^{0}39'W	330	3540
2	Taxisco	Guatemala	14507	13^{0}54'N	090^{0}29'W	1354	1714
3		Nigeria	10930				
5	Jutiapa	Guatemala	14503	14^{0}22'N	089^{0}46'W	950	
6	Ibadan	Nigeria	14501	07^{0}18'N	003^{0}50'E	200	
8	Gualan	Guatemala	14883	15^{0}08'N	089^{0}20'W	150	
9	Makhanga,	Malawi	2057/94				
10	Na	Malawi	1.2.13.13	na	na	na	na
11	Research Centre (Head Quarters)	Thailand	na	na	na	na	na
12	Belen Rivas	Nicaragua	na	11^{0}37'N	85^{0}48'W	75	1650
14	Playa Tamarindo	Costa Rica	12/86	10^{0}19'N	85^{0}54'W	0-10	1500
15	Monterrico	Guatemala	17/84	13^{0}54'N	90^{0}29'W	5	1650
16	Potezuelo Bolivar	Columbia	24/86	10^{0}35'N	75^{0}51'W	20-50	950
17	Retalhuleu	Guatemala	14/84	14^{0}33'N	91^{0}39'W	330	3500
18	Kihonda Mrorogoro	Tanzania	na	6^{0}50' S	37^{0}39' E	570	908

* Seed lot number applies from provenance 1 to 10; Oxford Forest Institute (OFI) number applies from provenance 13 to 17

Table 5b: Provenances of *Gliricidia sepium* represented on each site

Provenance	Country of origin	Study sites[1]		
		SUA Farm	Gairo	Kibaha
Cuyatenango	Guatemala	√	√	√
Taxisco	Guatemala	√	√	√
Na	Nigeria	-	-	√
Jutiapa	Guatemala	√	-	√
Ibadan	Nigeria	-	-	√
Gualan	Guatemala	√	-	-
Makhanga,	Malawi	√	-	-
Na	Malawi	√	-	-
Research Centre (Head Quarters)	Thailand	√	-	-
Belen Rivas	Nicaragua	√	√	-
Playa Tamarindo	Costa Rica	√	-	-
Monterrico	Guatemala	√	√	-
Potezuelo Bolivar	Columbia	√	-	-
Retalhuleu	Guatemala	√	√	-
Kihonda Mrorogoro	Tanzania	√	√	-

[1] √ = planted; - = not planted; Na = Not available

3.3.2.1 Survival, height and diameter growth

On each assessment date and for each plot, all surviving inner plot trees were measured for height, RCD and D30 and height as detailed in section 3.3.2 above. Height was measure to the nearest 0.01 m using a digital height-measuring pole while RCD and D30 were measured to the nearest 0.01 cm using a small caliper. The tally of height and RCD also gave the tree survival data.

3.3.2.2 Tree sampling for development of allometric equations

For each site, trees for development of allometric equations were sampled during the last assessment. Trees were randomly selected from each site to include all diameter classes. Numbers of trees felled were 60, 80 and 28 for Gairo, SUA farm and Kibaha sites respectively. Before felling, each tree was measured for RCD, D30 and total height as detailed in section 3.3.2. The sample trees were felled and portioned into tree components i.e. stems, branches and leaves/twigs, and each component immediately weighed to determine green (fresh) weight. Sub-samples of each component were brought into the laboratory, oven-dried (70^0C) to constant weight and weighed to determine each tree's component dry weight. Thereafter tree components sub-sample moisture content was determined which was later used to derive tree component dry weight. Tree components' dry weights were used to develop allometric equations for foliar biomass, wood biomass and total biomass as described in section 3.4.1.

3.3.2.3 Foliage sampling for determination of unit leaf mass and nutrients content and concentration

To evaluate the variation among provenances in foliar unit mass, N and P status, foliage samples were taken at 72, 73 and 36 months after planting at SUA Farm, Gairo and Kibaha site respectively. For each plot on each site, mature and unshaded foliage samples were taken from six trees randomly selected from the inner plot.

Foliage samples were taken from the top third of the crown of *Gliricidia sepium* plant, bulked, placed in paper bags, quickly sealed in airtight plastic bags and transported to the laboratory for chemical analyses and unit mass determination.

3.3.2.4 Laboratory procedures

(a) Unit leaf mass determination

In the laboratory, three sub-samples per plot each made up of 10 leaves were randomly selected from the bulk sample per plot and oven-dried (70^0C) to constant weight. The dry weights of each of the 10 leaves sub-samples were determined, and later on expressed as weight per unit leaf and averaged per plot.

(b) Analysis of foliar N and P concentration

In the laboratory, foliage sub-samples were oven-dried (70^0C) to constant weight. To determine total N and P concentrations, leaf sub-samples were ground in a Willy mill to pass through a 1 mm sieve. For each plot, two sub-samples of a ground composite sample each weighing 0.2 g were taken, digested using concentrated sulphuric acid followed by oxidation by hydrogen peroxide (Lowther, 1980). Total N in each digest was determined by semi-micro Kjeldahl procedure (Bremner and Mulvaney, 1982). Total P in each digest was determined calorimetrically as described by Anderson and Ingram (1993).

3.4 Data analysis

All statistical analyses were carried out using General Linear model (GLM) of Statistical Analysis Systems (SAS) (SAS Inst. Inc., 1991).

3.4.1 Development of tree allometric equations

Tree component oven-dry weights were used to develop tree allometric equations for foliage, wood and total biomass. Two forms of equations (see general forms of equation 1 and 2) were fitted.

$$y = b_0 + b_1*(d) + b_2*(ht) \quad (1)$$

$$\ln(y) = b_0 + b_1*\ln(d) + b_2*\ln(ht) \quad (2)$$

Where:

ln = base of natural logarithms

b_0 = intercept

y = dependent variables (wood biomass, foliar biomass or total biomass) (kg/tree)

d = diameter (root collar diameter (RCD) measured at 10 cm from ground (cm) or diameter at 30 cm height (D30) (cm))

ht = total tree height (m)

However, only equation 2 was selected for determination of biomass production (yield) of *Gliricidia sepium* foliage, wood and total biomass. Equation 2 was selected on the basis of its superiority as far as goodness of fit in terms of R^2 and lower standard error (SE). This equation is also simple to use. Table 11 shows coefficients of the selected allometric equations. These equations were used to derive the individual tree component (stem, wood, foliage and total) biomass. All intercepts were corrected for bias that occurs when converting from logarithmic units (Baskerville, 1972). Plot totals were then established and expanded to a hectare basis as described by Maghembe and Prins (1994).

3.4.2 Statistical analysis

For all statistical analysis, a fixed effect model was fitted (Equation 3) and a type III SS analysis was carried out. All data i.e. survival (%), height (m), RCD (cm), D30 (cm); foliar P and N concentrations (%), foliar P and N content (mg/leaf) and accumulation (kg ha^{-1}); foliage, wood and total biomass (t/ha) were subjected to analysis of variance (ANOVA) using plot means. Data for percentage survival were arcsine transformed prior to analysis to remove bias (Sokal & Rohlf, 1969). For significantly different provenance means, the Duncan's Multiple Range Test (DMRT) was used for grouping similar means (Gomez and Gomez, 1983).

$$Y = \text{replication} + \text{provenance} + \text{error} \tag{3}$$

Where Y is the measurement

CHAPTER FOUR

4. RESULTS

4.1 Survival

The results for tree survival for different *Gliricidia sepium* provenances planted at SUA Farm, Gairo and Kibaha sites are presented in Tables 6a, 6b and 6c respectively. For SUA Farm, although variation occurred in tree survival between provenances, the differences in survival were not significant (P>0.05) throughout the assessment period (Appendix 1). During the last assessment (69 months after planting), untransformed survival ranged between 75 (Pontezuelo) and 100% (Taxisco, Malawi, Thailand and Monterrico). At Gairo site, tree survival varied significantly (P< 0.05) among provenances on all assessment occasions except the last assessment occasion (Appendix 2). During the last assessment (70 months after planting), untransformed survival ranged between 75 (Retalhuleu and Kihonda) and 95% (Belen Rivas). For Kibaha site, survival did not differ significantly between provenances (P> 0.05) for the whole study period despite variation in survival between provenances (Appendix 3). On the final assessment date (34 months after planting) untransformed survival ranged between 81 (Ibadan) and 97% (Nigeria).

Table 6a: Transformed and untransformed survival of *Gliricidia sepium* provenances planted at SUA farm, Morogoro, Tanzania

Provenance	Transformed survival at...months					Untransformed survival at 69 months
	6	16	24	41	69	
Cuyatenango	81.96^x (8.04)	81.96 (8.04)	81.96 (8.04)	73.92 (8.04)	73.92 (8.04)	88.89 (5.55)
Taxisco	90.00 (0.00)	90.00 (0.00)	90.00 (0.00)	90.00 (0.00)	90.00 (0.00)	100.00 (0.00)
Jutiapa	90.00 (0.00)	90.00 (0.00)	90.00 (0.00)	81.96 (8.04)	81.96 (8.04)	94.44 (5.55)
Gualan	81.96 (8.04)	81.96 (8.04)	81.96 (8.04)	81.96 (8.04)	73.92 (11.75)	88.89 (11.11)
Makhanga	90.00 (0.00)	90.00 (0.00)	81.96 (8.04)	81.96 (8.04)	81.96 (8.04)	94.44 (5.55)
Malawi	90.00 (0.000)	90.00 (0.00)	90.00 (0.00)	90.00 (0.00)	90.00 (0.00)	100.00 (0.00)
Research Centre	90.00 (0.00)	90.00 (0.00)	90.00 (0.00)	90.00 (0.00)	90.00 (0.00)	100.00 (0.00)
Belen Rivas	81.96 (8.04)	81.96 (8.04)	81.96 (8.04)	81.96 (8.04)	81.96 (8.04)	94.44 (5.55)
Playa Tamarindo	90.00 (0.00)	90.00 (0.00)	90.00 (0.00)	73.92 (8.04)	73.92 (8.04)	88.89 (5.55)
Monterrico	90.00 (0.00)	90.00 (0.00)	90.00 (0.00)	90.00 (0.00)	90.00 (0.00)	100.00 (0.00)
Potezuelo Bolivar	72.00 (18.00)	67.50 (22.50)	67.50 (22.50)	67.50 (22.50)	67.50 (22.50)	75.00 (25.00)
Retalhuleu	72.38 (17.62)	72.38 (17.62)	72.38 (17.62)	72.38 (17.62)	72.38 (17.62)	83.34 (16.67)
Kihonda	90.00 (0.00)	90.00 (0.00)	90.00 (0.00)	70.21 (10.40)	78.25 (11.75)	88.89 (11.11)
P>F- Ratio	0.86	0.28	0.43	0.66	0.82	0.77
RMSE^y	14.31	19.90	10.44	14.66	15.37	13.67
CV^z	17.38	25.28	12.18	18.15	18.94	14.77

^{x}Mean of three replications, with standard error in parenthesis; ^{y}RMSE – root mean square error, ^{z}CV – coefficient of variation (%).

Table 6b: Transformed and untransformed survival of *Gliricidia sepium* provenances planted at Gairo, Morogoro, Tanzania

Provenance	Transformed survival at...months					Untransformed survival at 70 months
	6	18	27	42	70	
Cuyatenango	80.78a^{x}	80.78a	71.56a	71.56a	63.44	80.00
	(9.22)	(9.22)	(0.00)	(0.00)	(0.00)	(0.00)
Taxisco	67.50b	67.50b	67.50a	67.50a	67.50	85.00
	(4.06)	(4.06)	(4.06)	(4.06)	(4.06)	(5.00)
Belen Rivas	71.56ab	71.56ab	71.56a	71.56a	71.56	90.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Monterrico	64.18b	64.18b	60.12b	60.12b	64.18	80.00
	(7.39)	(7.39)	(3.33)	(3.33)	(7.39)	(10.00)
Retalhuleu	60.12b	60.12b	60.12b	60.12b	56.79	70.00
	(3.33)	(3.33)	(3.33)	(3.33)	(0.00)	(0.00)
Kihonda	60.12b	60.12b	60.12b	60.12b	56.79	70.00
	(3.33)	(3.33)	(3.33)	(3.33)	(0.00)	(0.00)
P>F- Ratio	0.04	0.04	0.02	0.01	0.10	0.09
RMSE^{y}	21.52	21.52	3.65	2.59	4.44	5.92
CV^{z}	6.89	9.87	4.47	3.98	7.00	7.47

^{x}Mean of two replications, with standard error in parenthesis; Values with the same latter(s) within the same column do not differ significantly ($P>0.05$); ^{y}RMSE – root mean square error, ^{z}CV – coefficient of variation (%).

Table 6c: Transformed and untransformed survival of *Gliricidia sepium* provenances planted at Kibaha, Tanzania

Provenance	Transformed survival at...months			Untransformed survival at 34 months
	14	29	34	
Cuyatenango	90.00[x]	85.135	73.24	88.89
	(0.00)	(4.865)	(8.53)	(7.86)
Taxisco	90.00	80.270	73.24	88.89
	(0.00)	(5.618)	(5.95)	(4.54)
Nigeria	90.00	85.135	85.14	97.22
	(0.00)	(4.865)	(4.87)	(2.78)
Jutiapa	90.00	80.270	73.24	88.89
	(0.00)	(5.618)	(5.95)	(4.54)
Ibadan	90.00	69.298	67.52	80.56
	(0.00)	(7.618)	(8.37)	(8.34)
P>F- Ratio	-	0.44	0.59	0.52
RMSE[y]	0.00	12.59	13.56	11.52
CV[z]	0.00	15.95	17.94	12.89

[x] Mean of four replications, with standard error in parenthesis; [y] RMSE – root mean square error, [z] CV – coefficient of variation (%).

4.2 Height growth

Trends for height growth of *G. sepium* for SUA farm, Gairo and Kibaha sites are as shown in Tables 7a, 7b and 7c respectively. For SUA farm and Gairo sites, there was no significant variation ($P > 0.05$) in height development on all the assessment occasions (Appendices 1, 2). For Kibaha site significant variation ($P < 0.05$) in height development was observed only at 14 months after planting (Appendix 3). At SUA farm site, mean height ranged between 3.77 (Taxisco) and 4.85 m (Belen Rivas) at 24 months, and 5.37 (Kihonda, Morogoro) and 6.30 m (Cuyatenango) at 69 months after planting. It is interesting to note that at all assessment occasions, Cuyatenango Guatemala, Jutiapa Guatemala and Belen Rivas Nicaragua provenances showed superiority in height growth even if no one single provenance maintained one rank throughout this period. For Gairo site, mean height ranged between 2.57 (Monterrico) and 3.20 m (Cuyatenango) at 27 months, and 3.87 (Monterrico) and 4.39 m (Cuyatenango) at the final assessment (70 months after planting). Generally, Cuyatenango provenance showed superiority in height growth for both SUA farm and Gairo sites. For Kibaha site, mean height ranged between 4.32 (Nigeria) and 5.03 m (Jutiapa) at 29 months, and 4.45 (Nigeria) and 5.26 m (Jutiapa) at the final assessment (34 months after planting). At all assessment occasions at Kibaha site, the best provenance was Jutiapa while Nigeria was the poorest.

Table 7a: Mean height development (m) of *Gliricidia sepium* provenances planted at SUA farm, Morogoro, Tanzania

Provenance	Age (months)				
	6	16	24	41	69
Cuyatenango	1.26^x	3.09	4.22	5.29	6.30
	(0.04)	(0.09)	(0.02)	(0.54)	(0.19)
Taxisco	1.02	2.33	3.77	5.71	6.12
	(0.18)	(0.23)	(0.25)	(0.04)	(0.07)
Jutiapa	1.16	3.38	4.07	4.73	5.67
	(0.21)	(0.04)	(0.18)	(0.59)	(0.41)
Gualan	0.88	3.05	4.55	5.47	5.97
	(0.19)	(0.09)	(0.40)	(0.15)	(0.23)
Makhanga	0.94	2.80	4.34	5.12	5.73
	(0.12)	(0.50)	(0.40)	(0.74)	(0.34)
Malawi	1.12	3.19	4.00	5.01	5.82
	(0.20)	(0.39)	(0.15)	(0.60)	(0.51)
Research	1.00	2.96	4.21	5.60	5.58
Centre	(0.08)	(0.13)	(0.24)	(0.61)	(0.11)
Belen Rivas	1.07	3.21	4.85	5.71	6.02
	(0.03)	(0.33)	(0.21)	(0.22)	(0.18)
Playa	0.71	2.57	3.83	5.22	5.43
Tamarindo	(0.07)	(0.18)	(0.34)	(0.12)	(0.13)
Monterrico	0.82	2.40	4.13	5.07	5.69
	(0.01)	(0.10)	(0.23)	(0.20)	(0.31)
Potezuelo	0.96	3.10	4.64	5.55	5.80
Bolivar	(0.29)	(0.23)	(0.14)	(0.43)	(0.5)
Retalhuleu	1.12	3.00	4.37	5.51	5.98
	(0.12)	(0.02)	(0.08)	(0.05)	(0.17)
Kihonda	0.93	2.81	3.92	4.89	5.37
	(0.22)	(0.11)	(0.13)	(0.63)	(0.34)
P>F- Ratio	0.18	0.19	0.15	0.79	0.50
$RMSE^y$	0.20	0.41	0.41	0.60	0.44
CV^z	20.44	13.94	9.65	11.32	7.59

^{x}Mean of three replications, with standard error in parenthesis; ^{y}RMSE – root mean square error, ^{z}CV – coefficient of variation (%).

Table 7b: Mean height development (m) of *Gliricidia sepium* provenances planted at Gairo, Morogoro, Tanzania

Provenance	Age (months)				
	6	18	27	42	70
Cuyatenango	0.68^x (0.05)	1.79 (0.03)	3.20 (0.26)	3.62 (0.19)	4.39 (0.29)
Taxisco	0.54 (0.05)	1.60 (0.06)	3.02 (0.17)	3.25 (0.19)	4.14 (0.19)
Belen Rivas	0.55 (0.01)	1.72 (0.05)	2.71 (0.22)	3.14 (0.09)	4.22 (0.08)
Monterrico	0.61 (0.04)	1.57 (0.07)	2.57 (0.12)	2.99 (0.05)	3.87 (0.08)
Retalhuleu	0.52 (0.01)	1.85 (0.02)	2.91 (0.07)	3.04 (0.12)	3.99 (0.18)
Kihonda	0.53 (0.10)	1.77 (0.07)	2.82 (0.15)	3.25 (0.19)	4.15 (0.01)
P>F- Ratio	0.27	0.08	0.28	0.23	0.48
RMSE^y	0.07	0.08	0.24	0.22	0.25
CV^z	11.37	4.56	8.38	6.97	6.03

^{x}Mean of two replications, with standard error in parenthesis; ^{y}RMSE – root mean square error, ^{z}CV – coefficient of variation (%).

Table 7c: Mean height (m) development of *Gliricidia sepium* provenances planted at Kibaha, Tanzania

Provenance	Age (months)		
	14	29	34
Cuyatenango	3.94[x] (0.14)	4.78 (0.38)	4.86 (0.20)
Taxisco	2.770 (0.0.20)	4.79 (0.46)	4.96 (0.16)
Nigeria	2.90 (0.34)	4.32 (0.35)	4.46 (0.30)
Jutiapa	3.47 (0.17)	5.03 (0.20)	5.26 (0.11)
Ibadan	3.16 (0.11)	4.58 (0.19)	4.67 (0.16)
P>F- Ratio	0.02	0.16	0.12
RMSE[y]	0.39	0.36	0.28
CV[z]	12.55	7.73	6.44

[x] Mean of four replications, with standard error in parenthesis; [y] RMSE – root mean square error, [z] CV – coefficient of variation (%).

4.3 Root collar diameter and diameter at 30 cm from the ground

The results of tree RCD and D30 for SUA Farm. Gairo and Kibaha sites are presented in Tables 8a, 8b and 8c respectively.

4.3.1 Root collar diameter

At SUA farm site, provenances differed significantly ($P < 0.05$) in RCD at 6 months assessment occasion only (Appendix 1). The variation among provenances in RCD was not significant ($P > 0.05$) at all assessment occasions at Gairo site (Appendix 2). At Kibaha site, provenances differed significantly ($P < 0.05$) in RCD at 14 months only (Appendix 3). For SUA farm site, root collar diameter ranged between 1.73 (Makhanga) and 2.53 cm (Cuyatenango) at 6 months and 5.68 (Playa Tamarindo) and 6.51 cm (Cuyatenango) at 41 months after planting. At Gairo site, RCD ranged between 3.47 cm (Belen Rivas) and 4.15 cm (Cuyatenango) at 27 months and 5.70 cm (Retalhuleu) and 6.67 cm (Cuyatenango) at the final assessment occasion (70 months after planting). For Kibaha site. RCD ranged between 6.30 cm (Taxisco) and 7.24 cm (Ibadan) at 29 months and 6.58 cm (Taxisco) and 7.66 cm (Ibadan) at the final assessment occasion (34 months after planting).

4.3.2 Diameter at 30 cm from ground

Provenances did not differ significantly ($P > 0.05$) in D30 at SUA farm and Gairo site at all assessment occasions (Appendices 1 and 2). At Kibaha site, provenances differed significantly in D30 ($P < 0.05$) at 14 months assessment occasion only (Appendix 3). For SUA farm, D30 ranged between 3.52 (Thailand) and 4.42 cm (Cuyatenango) at 24 months, and 4.70 (Kihonda) and 6.37 cm (Cuyatenango) at the final assessment occasion (69 months after planting). At Gairo site, D30 ranged between 3.77 (Retalhuleu) and 4.67 cm (Cuyatenango) at 42 months, and 4.91 (Retalhuleu) and 5.69 cm (Cuyatenango) at final assessment occasion (70 month after planting). For Kibaha site, D30 ranged between 3.63 (Ibadan) and 3.84 cm (Cuyatenango) at 29 months and 3.69 (Nigeria) and 4.24 cm (Jutiapa) at the final assessment occasion (34 months after planting).

4.4 Leaf mass and foliar nutrients concentration and nutrient content and accumulation

Results of unit leaf mass, foliar nutrient (N and P) concentration and content and accumulation are presented in Tables 9a, 9b and 9c for SUA farm, Gairo and Kibaha site respectively.

4.4.1 Leaf mass

For all sites, provenances did not differ significantly ($P > 0.05$) in unit leaf mass (Appendices 1, 2 and 3). Unit leaf mass ranged between 0.37 (Kihonda) and 0.71 g per leaf (Malawi), 0.45 (Retalhuleu) and 0.83 g per leaf (Taxisco), and 0.68 (Cuyatenango) and 0.81 g per leaf (Taxisco) for SUA farm, Gairo and Kibaha site respectively.

4.4.2 Foliar N and P concentrations

Provenances did not differ significantly ($P>0.05$) in foliar N and P concentrations for SUA farm and Kibaha site (Appendices 1, 3) while they differed significantly ($P<0.05$) in foliar N concentration only at Gairo site (Appendix 2). Foliar N and P concentrations did not differ significantly ($P > 0.05$) among provenances for all sites (Appendices 1, 2 and 3). For SUA farm site, foliar N concentration ranged between 3.58 (Taxisco) and 4.24% (Thailand) whereas P ranged between 0.16 (Playa Tamarindo) and 0.19% (Gualan). At Gairo site, foliar N concentration ranged between 3.68 (Kihonda) and 4.38% (Cuyatenango) whilst P ranged between 0.26% (Kihonda and Taxisco) and 0.30 (Belen Rivas). For Kibaha site, foliar N concentration ranged between 3.69 (Ibadan) and 3.93% (Jutiapa) alongside P ranged between 0.20 (Ibadan) and 0.24% (Taxisco).

Table 8a: Root collar diameter (cm) and diameter at 30 cm height from the ground (cm) development of *Gliricidia sepium* provenances planted at SUA farm, Morogoro, Tanzania

Provenance	Age (months						
	6	16	24		41		69
	RCD (cm)	RCD (cm)	RCD (cm)	D30 (cm)	RCD (cm)	D30 (cm)	D30 (cm)
Cuyatenango	2.38^x	4.99	6.45	4.42	6.51	5.28	6.37
	(0.07)	(0.31)	(0.46)	(0.39)	(0.12)	(0.39)	(0.56)
Taxisco	2.05	4.23	5.76	3.69	6.20	5.23	5.26
	(0.01)	(0.12)	(0.10)	(0.24)	(0.11)	(0.18)	(0.22)
Jutiapa	2.23	4.59	5.73	3.76	5.70	4.48	5.29
	(0.30)	(0.27)	(0.53)	(0.21)	(0.58)	(0.49)	(0.18)
Gualan	2.15	4.97	5.67	3.91	6.08	5.17	5.34
	(0.19)	(0.42)	(0.17)	(0.06)	(0.10)	(0.16)	(0.28)
Makh-anga	1.73	3.90	5.66	3.81	5.97	4.80	5.36
	(0.28)	(0.44)	(0.72)	(0.39)	(0.94)	(0.90)	(0.35)
Malawi	2.05	3.97	5.58	3.67	5.93	4.61	5.28
	(0.23)	(0.43)	(0.59)	(0.45)	(0.73)	(0.83)	(0.58)
Research Centre	2.05	3.90	5.66	3.52	6.01	4.86	4.90
	(0.12)	(0.35)	(0.21)	(0.058)	(0.37)	(0.75)	(0.10)
Belen Rivas	2.53	5.20	6.49	4.283	6.38	5.23	5.80
	(0.12)	(0.09)	(0.24)	(0.16)	(0.32)	(0.21)	(0.30)
Playa Tamar-indo	2.12	4.31	5.55	3.59	5.68	4.93	5.22
	(0.17)	(0.24)	(0.62)	(0.22)	(0.27)	(0.14)	(0.32)
Monterrico	1.85	8.73	5.66	3.96	6.23	5.30	5.47
	(0.17)	(0.48)	(0.14)	(0.07)	(0.30)	(0.14)	(0.14)
Potezuelo Bolivar	2.05	5.19	5.58	3.98	6.03	5.06	5.41
	(0.13)	(0.16	(0.93)	(0.26)	(1.04)	(0.71)	(0.68)

^{x}Mean of three replications, with standard error in parenthesis; ^{y}RMSE – root mean square error, ^{z}CV – coefficient of variation (%).

Table 8a: Continued…

Provenance	Age (months)						
	6	16	24		41		69
	RCD (cm)	RCD (cm)	RCD (cm)	D30 (cm)	RCD (cm)	D30 (cm)	D30 (cm)
Retalh-uleu	2.29	4.52	5.40	3.91	6.00	5.33	5.42
	(0.06)	(0.30)	(0.78)	(0.22)	(0.02)	(0.21)	(0.16)
Kihon-da	1.87	4.29	5.59	3.81	6.10a	4.68	4.70
	(0.34)	(0.16)	(0.45)	(0.32)	(0.24)	(0.42)	(0.28)
P>F- Ratio	0.05	0.69	0.90	0.42	0.89	0.89	0.17
RMSE^y	0.26	2.53	0.83	0.43	0.62	0.64	0.55
CV^z	12.30	52.14	14.39	10.99	10.23	12.91	10.27

^{x}Mean of three replications, with standard error in parenthesis; ^{y}RMSE – root mean square error, ^{z}CV – coefficient of variation (%).

Table 8b: Root collar diameter (cm) and diameter at 30 cm height from the ground (cm) development of *Gliricidia sepium* provenances planted at Gairo, Morogoro, Tanzania

Provenance	Age (months)				
	27	42		70	
	Root collar diameter (cm)	Root collar diameter (cm)	D30 (cm)	Root collar diameter (cm)	D30 (cm)
Cuyatenango	4.15[x]	5.90	3.93	6.67	5.69
	(0.12)	(0.43)	(0.50)	(0.57)	(0.45)
Taxisco	3.87	4.72	3.77	5.76	4.98
	(0.11)	(0.05)	(0.03)	(0.18)	(0.29)
Belen Rivas	3.47	4.68	4.14	5.77	5.03
	(0.40)	(0.41)	(0.40)	(0.49)	(0.46)
Monterrico	3.70	4.98	4.67	5.94	5.05
	(0.19)	(0.10)	(0.38)	(0.40)	(0.21)
Retalhuleu	3.56	4.60	4.01	5.70	4.91
	(0.04)	(0.15)	(0.04)	(0.02)	(0.09)
Kihonda	3.81	5.29	4.22	6.08	5.38
	(0.07)	(0.14)	(0.30)	(0.15)	(0.15)
P>F- Ratio	0.28	0.21	0.61	0.47	0.36
RMSE[y]	0.26	0.35	0.51	0.508	0.36
CV[z]	6.95	7.018	12.25	8.29	6.90

[x]Mean of two replications, with standard error in parenthesis; [y]RMSE – root mean square error, [z]CV – coefficient of variation (%).

Table 8c: Root collar diameter (cm) and diameter at 30 cm height from the ground (cm) development of *Gliricidia sepium* provenances planted at Kibaha, Tanzania

Provenance	Age (months					
	14		29		34	
	Root collar diameter (cm)	D30 (cm)	Root collar diameter (cm)	D30 (cm)	Root collar diameter (cm)	D30 (cm)
Cuyatenango	5.35	3.22a	6.77abc	3.84	7.35	4.12ab
	(0.32)	(0.14)	(0.39)	(0.1)	(0.47)	(0.23)
Taxisco	3.53	2.60b	6.30c	3.81	6.58	3.91abc
	(0.39)	(0.20)	(0.41)	(0.21)	(0.19)	(0.15)
Nigeria	3.92	2.65b	6.37bc	3.59	6.78	3.69c
	(0.50)	(0.29)	(0.716)	(0.29)	(0.50)	(0.34)
Jutiapa	4.30	3.21a	7.10ab	4.02	7.41	4.24a
	(0.14)	(0.0.15)	(0.40)	(0.10)	(0.12)	(0.08)
Ibadan	4.22	2.82b	7.24a	3.63	7.66	3.88abc
	(0.18)	(0.13)	(0.29)	(0.05)	(0.18)	(0.15)
P>F- Ratio	<0.01	0.01	0.10	0.16	0.17	0.06
RMSE^y	1.27	0.24	0.48	0.22	0.52	0.24
CV^z	28.78	8.59	7.30	5.98	9.85	6.00

^{x}Mean of four replications, with standard error in parenthesis; Values with the same letter(s) within the same column do not differ significantly (P>0.05); ^{y}RMSE – root mean square error, ^{z}CV – coefficient of variation (%).

4.4.3 Foliar N and P content and accumulation

For all sites, provenances did not differ significantly (P>0.05) in foliar N and P content and accumulation (Appendices 1, 2 and 3). At SUA farm site, foliar N content ranged between 14.51 (Kihonda) and 25.71 mg/leaf (Malawi) while P content ranged between 0.59 (Kihonda) and 1.18 mg/leaf (Malawi); foliar N accumulation ranged between 667.47 (Retalhuleu) and 1084.95 kg ha^{-1} (Belen Rivas) while foliar P accumulation ranged between 30.42 (Retalhuleu) and 50.06 kg ha^{-1} (Belen Rivas).

For Gairo site, foliar N content ranged between 18.29 (Kihonda) and 36.21 mg/leaf (Taxico) while foliar P content ranged between 1.27 (Kihonda) and 2.24 mg/leaf (Taxico); foliar N accumulation ranged between 558.99 (Kihonda) and 809.50 kg ha^{-1} (Cuyatenango) whereas foliar P accumulation ranged between 37.64 (Kihonda) and 51.48 kg ha^{-1} (Cuyatenango). For Kibaha site, foliar N content ranged between 25.93 (Cuyatenango) and 3.58 mg/leaf (Taxisco) while foliar P content ranged between 1.48 (Ibadan) and 1.94 mg/leaf (Taxisco); foliar N accumulation ranged between 587.48 (Ibadan) and 665.27 kg ha^{-1} (Jutiapa) whereas foliar P accumulation ranged between 32.22 (Ibadan) and 38.32 kg ha^{-1} (Cuyatenango). Overall, mean foliar N and P contents found in this study were19.53 N mg leaf and 0.87 P mg/leaf; 25.85 N mg/leaf and 1.67 P mg/leaf; and 30.03 N mg/leaf and 1.72 P mg/leaf for SUA farm, Gairo and Kibaha site respectively. Mean foliar N and P accumulation were 852.18 N kg ha^{-1} and 37.83 P kg ha^{-1}, 645.52 N kg ha^{-1} and 41.80 P kg ha^{-1}, and 609.46 N kg ha^{-1} and 34.43 P kg ha^{-1} for SUA farm, Gairo and Kibaha in that order.

Table 9a: Leaf mass and foliar nutrients concentration and content and accumulation of 72 months old *Gliricidia sepium* provenances planted at SUA farm, Morogoro, Tanzania

Provenance	Nutrient concentration (%)		Nutrient content (mg/leaf)		Nutrient accumulation (kg ha^{-1})		Unit leaf (g/leaf)
	P	N	P	N	P	N	
Cuyatenango	0.17[x]	3.84	0.95	20.76	39.74	903.55	0.54
	(0.01)	(0.07)	(0.13)	(0.83)	(2.41)	(141.87)	(0.03)
Taxisco	0.18	3.58	0.82	16.40	38.74	781.90	0.46
	(0.01)	(0.38)	(0.05)	(0.02)	(6.05)	(164.94)	(0.05)
Jutiapa	0.17	3.72	1.02	22.71	41.47	937.14	0.60
	(0.00)	(0.24)	(0.15)	(3.86)	(9.40)	(252.71)	(0.07)
Gualan	0.19	3.67	0.84	16.72	40.14	790.11	0.46
	(0.01)	(0.21)	(0.09)	(2.86)	(1.26)	(81.07)	(0.06)
Makhanga	0.18	3.76	0.73	15.22	37.68	766.36	0.40
	(0.01)	(0.14)	(0.14)	(2.97)	(6.67)	(86.30)	(0.07)
Malawi	0.16	3.67	1.18	25.71	35.90	773.39	0.71
	(0.00)	(0.39)	(0.04)	(1.96)	(5.33)	(74.36)	(0.03)
Research Centre	0.18	4.24	0.91	21.56	42.15	1009.48	0.50
	(0.02)	(0.43)	(0.16)	(4.03)	(7.98)	(230.79)	(0.05)
Belen Rivas	0.18	3.85	(0.95	20.60	50.06	1084.95	0.54
	(0.01)	(0.37)	(0.08)	(3.23)	(6.33)	(179.53)	(0.06)
Playa Tamarindo	0.16	3.77	0.78	19.34	33.17	809.93	0.49
	(0.00)	(0.31)	(0.33)	(9.30)	(2.82)	(121.99)	(0.20)

[x] Mean of three replications, with standard error in parenthesis; [y] RMSE – root mean square error, [z] CV – coefficient of variation (%).

Table 9a: Continued…

Provenance	Nutrient concentration (%)		Nutrient content (mg/leaf)		Nutrient accumulation (kg ha^{-1})		Unit leaf (g/leaf)
	P	N	P	N	P	N	
Monterrico	0.16	3.77	0.80	19.07	36.95	884.49	0.50
	(0.00)	(0.21)	(0.04)	(1.94)	(5.38)	(175.32)	(0.03)
Potezuelo	0.18	3.98	0.83	18.24	36.34	815.77	0.46
Bolivar	(0.015)	(0.10)	(0.15)	(2.14)	(2.65)	(7.18)	(0.04)
Retalhuleu	0.18	3.89	1.11	24.90	30.42	667.47	0.64
	(0.01)	(0.15)	(0.90)	(0.09)	(10.05)	(170.14)	(0.02)
Kihonda	0.16	3.98	0.59	14.51	33.31	817.76	0.37
	(0.18)	(0.18)	(0.13)	(3.73)	(3.70)	(127.60)	(0.10)
P>F- Ratio	0.33	0.30	0.32	0.34	0.61	0.68	0.23
RMSE^{y}	0.02	0.27	<0.01	0.01	8.65	192.00	0.13
CV^{z}	8.81	7.16	27.41	27.77	22.53	22.40	26.19

^{x}Mean of three replications, with standard error in parenthesis; ^{y}RMSE – root mean square error, ^{z}CV – coefficient of variation (%).

Table 9b: Leaf mass and foliar nutrients concentration and content and accumulation of 73 months old *Gliricidia sepium* provenances planted at Gairo, Morogoro, Tanzania

Provenance	Nutrient concentration (%)		Nutrient content (mg/leaf)		Nutrient accumulation (kg ha^{-1})		Unit leaf (g/leaf)
	P	N	P	N	P	N	
Cuyatenango	0.26[x]	4.38a	1.83	28.83	51.48	809.50	0.67
	(0.08)	(0.22)	(0.88)	(4.47)	(24.97)	(131.92)	(0.14)
Taxisco	0.26	4.36a	2.24	36.21	45.08	734.79	0.83
	(0.08)	(0.04)	(0.91)	(4.44)	(17.42)	(73.91)	(0.11)
Belen Rivas	0.30	4.14a	1.92	26.79	44.54	621.00	0.65
	(0.02)	(0.22)	(0.24)	(3.23)	(1.59)	(25.41)	(0.05)
Monterrico	0.29	4.30a	1.83	27.07	38.74	571.02	0.63
	(0.00)	(0.06)	(0.21)	(2.46)	(9.80)	(132.40)	(0.07)
Retalhuleu	0.29	4.14a	1.30	18.34	40.27	567.72	0.45
	(0.01)	(0.06)	(0.03)	(0.51)	(2.83)	(11.64)	(0.01)
Kihonda	0.26	3.68b	1.27	18.29	37.64	558.99	0.50
	(0.05)	(0.00)	(0.00)	(0.00)	(1.63)	(75.81)	(0.02)
P>F- Ratio	0.97	0.02	0.86	0.14	0.92	0.07	0.10
RMSE[y]	0.07	0.14	<0.01	<0.01	14.59	72.14	0.10
CV[z]	25.83	3.24	40.50	17.75	33.97	11.20	16.83

[x]Mean of two replications, with standard error in parenthesis; Values with the same latter(s) within the same column do not differ significantly (P>0.05); [y]RMSE – root mean square error, [z]CV – coefficient of variation (%).

Table 9c: Leaf mass and foliar nutrients concentration and content and accumulation of 36 months old *Gliricidia sepium* provenances planted at Kibaha, Tanzania

Provenance	Nutrient concentration (%)		Nutrient content (mg/leaf)		Nutrient accumulation (kg ha^{-1})		Unit leaf (g/leaf)
	P	N	P	N	P	N	
Cuyatenango	0.22	3.84	1.56	25.93	38.32	653.09	0.68
	(0.03)	(0.08)	(0.35)	(2.15)	(7.94)	(84.23)	(0.07)
Taxisco	0.24	3.91	1.94	31.58	37.61	638.66	0.81
	(0.03)	(0.10)	(0.35)	(1.12)	(3.67)	(48.76)	(0.04)
Nigeria	0.22	3.82	1.66	28.41	32.75	592.45	0.75
	(0.03)	(0.08)	(0.26)	(2.84)	(3.99)	(107.60)	(0.08)
Jutiapa	0.21	3.93	1.60	29.61	35.90	665.27	0.75
	(0.02)	(0.21)	(0.18)	(4.08)	(2.92)	(73.71)	(0.08)
Ibadan	0.20	3.69	1.48	27.29	32.22	587.50	0.75
	(0.02)	(0.10)	(0.22)	(3.68)	(4.04)	(33.70)	(0.11)
P>F- Ratio	0.42	0.44	0.11	0.052	0.34	0.36	0.08
RMSE[y]	0.03	0.18	<0.01	<0.01	7.76	95.23	0.12
CV[z]	12.50	4.75	15.32	15.99	22.87	15.60	15.41

[x] Mean of four replications, with standard error in parenthesis; [y] RMSE – root mean square error, [z] CV – coefficient of variation (%).

4.5 Stem number and biomass production

The coefficients of allometric equations used to estimate foliage, wood and total biomass production per tree (kg/tree) are shown in Table 10. Results for stem number (stems ha^{-1}) and biomass production (t ha^{-1}) are presented in Tables 11a, 11b and 1c for SUA farm, Gairo and Kibaha site respectively.

4.5.1 Multiple stems production

Provenances did not differ significantly ($P>0.05$) in multiple stems production for the three sites and at all assessment occasions (Apendices 1, 2 and 3). At SUA farm site, stem number ranged between 22500 (Retalhuleu) and 44583 stems ha^{-1} (Thailand provenance) at 24 months after planting, and 15000 (Cuyatenango) and 28750 stems ha^{-1} (Thailand) at 69 months after planting. At Gairo site, stem number ranged between 28750 (Monterrico) and 36250 stems ha^{-1} (Retalhuleu), and 27500 (Cuyatenango and Monterrico) and 33438 stems ha^{-1} (Retalhuleu) at 27 and 70 months after planting respectively. For Kibaha site, stem number ranged between 17813 (Jutiapa) and 21250 stems ha^{-1} (Cuyatenango), and 16563 (Jutiapa) and 22031 stems ha^{-1} (Nigeria) at 14 and 34 months after planting.

Table 10: Coefficients of allometric equations[u] and their goodness of fit for *Gliricidia sepium* grown at SUA farm. Gairo and Kibaha sites, Tanzania.

Dependent variable	Regression estimator[v,w]				
	b_0	b_1	b_2	R^2	SE
	SUA Farm site (n = 80)				
Foliar biomass	-3.8349	2.5677	-0.2711	0.86	0.03
(kg tree^{-1})	(0.159)	(0.119)	(0.163)		
Wood biomass	-3.7663	2.5466	0.4985	0.92	0.02
(kg tree^{-1})	(0.130)	(0.098)	(0.130)		
Total biomass	-3.1593	2.5455	0.2769	0.93	0.03
(kg tree^{-1})	(0.120)	(0.090)	(0.130)		
	Gairo site (n = 60)				
Foliar biomass	-4.2523	2.1303	-	0.84	0.05
(kg tree^{-1})	(0.172)	(0.122)			
Wood biomass	-4.4466	2.5956	0.5766	0.94	0.04
(kg tree^{-1})	(0.186)	(0.126)	(0.213)		
Total biomass	-3.7538	2.4871	0.3681	0.94	0.03
(kg tree^{-1})	(0.175)	(0.118)	(0.200)		
	Kibaha site (n = 28)				
Foliar biomass	-3.9301	2.2209	0.4310	0.83	0.42
(kg tree^{-1})	(0.633)	(0.3458)	(0.611)		
Wood biomass	-3.2208	2.1131	0.6482	0.93	0.26
(kg tree^{-1})	(0.387)	(0.211)	(0.374)		
Total biomass	-3.0284	2.3317	0.7416	0.93	0.28
(kg tree^{-1})	(0.413)	(0.226)	(0.398)		

[U] Equations follow the general form as defined in equation 2. [v] d= root-collar diameter for Gairo site; d = diameter measured at 30 cm from ground for SUA Farm and Kibaha sites. [w] Numbers in parentheses are standard errors of the regression coefficients, n = number of sample trees.

Table 11a: Multiple stems production (stems ha^{-1}) and biomass production (t ha^{-1}) of 24, 41 and 69 months old *Gliricidia sepium* provenances planted at SUA farm, Morogoro, Tanzania

Provenance	Age (months)							
	24				41			
	Stems	Foliage	Wood	Total	Stems	Foliage	Wood	Total
Cuyatenango	25000^x	17.20	57.65	75.09	14166	18.20	87.53	109.37
	(2500)	(2.49)	(8.02)	(10.59)	(1502)	(0.81)	(19.87)	(24.11)
Taxisco	23750	12.81	40.76	53.99	22500	21.61	86.17	106.92
	(1250)	(0.00)	(0.01)	(0.01)	(0.00)	(1.91)	(7.79)	(9.58)
Jutiapa	28333	12.65	40.57	53.53	25416	17.10	62.49	79.35
	(1816)	(2.10)	(8.24)	(10.25)	(3005)	(3.50)	(18.918)	(21.77)
Gualan	28750	14.47	50.32	64.69	22500	21.11	83.65	103.92
	(722)	(0.64)	(2.08)	(2.27)	(1909)	(0.63)	(3.73)	(3.96)
Makhanga	26250	12.18	41.10	53.32	21666	18.00	70.06	87.42
	(2602)	(2.08)	(8.72)	(10.56)	(2320)	(5.03)	(23.59)	(28.07)
Malawi	34166	13.77	44.60	58.61	24583	19.08	73.81	92.07
	(7784)	(1.59)	(5.77)	(7.29)	(2917)	(4.29)	(21.43)	(25.12)
Research Centre	44583	17.27	57.15	74.54	31666	22.41	85.29	107.14
	(2205)	(0.74)	(3.48)	(4.02)	(7372)	(4.18)	(18.22)	(22.11)
Belen Rivas	27083	16.68	60.61	77.03	25000	24.56	99.64	122.95
	(1102)	(0.99)	(2.15)	(3.14)	(2602)	(3.62)	(16.81)	(19.91)
Playa Tamarindo	40833	15.67	46.77	62.91	24166	20.23	75.95	95.90
	(6305)	(1.83)	(4.81)	(6.62)	(3560)	(1.95)	(8.02)	(9.84)
Monterrico	32916	17.84	59.86	77.61	19583	16.49	61.78	77.96
	(2205)	(1.60)	(6.76)	(7.95)	(1502)	(3.83)	(14.28)	(17.98)
Potezuelo Bolivar	25625^x	12.76	46.84	59.40	21875	18.00	72.52	89.63
	(6875)	(1.29)	(1.63)	(3.30)	(8125)	(0.61)	(2.36)	(1.08)
Retalhuleu	22500	11.40	39.02	50.48	17500	18.28	71.33	88.97
	(0.00)	(1.59)	(5.05)	(6.77)	(2500)	(4.41)	(16.82)	(21.06)
Kihonda	35000	19.34	61.78	81.53	25000	24.18	85.95	109.69
	(11614)	(5.95)	(18.42)	(24.46)	(4330)	(3.55)	(8.75)	(12.40)
P>F- Ratio	0.19	0.51	0.42	0.46	0.13	0.83	0.90	0.89
RMSE^y	8762.80	4.08	13.33	17.33	5259.70	5.94	27.17	32.97
CV^z	28.36	26.93	26.45	26.38	22.95	29.70	34.70	33.64

^{x}Mean of three replications, with standard error in parenthesis; ^{y}RMSE – root mean square error, ^{z}CV – coefficient of variation (%).

Table 11a: Continued...

Provenance	Age (months)			
	69			
	Stems	Foliage	Wood	Total
Cuyatenango	15000	23.41	104.16	124.92
	(1443)	(3.26)	(16.86)	(19.35)
Taxisco	22500	21.60	92.10	112.03
	(0.00)	(2.32)	(8.14)	(10.52)
Jutiapa	24166	24.53	102.41	125.10
	(4229)	(5.09)	(25.56)	(29.68)
Gualan	21666	21.44	91.52	111.20
	(2083)	(1.29)	(7.36)	(8.21)
Makhanga	19583	20.41	84.09	102.69
	(1816)	(2.21)	(11.85)	(13.57)
Malawi	22500	21.60	93.39	112.90
	(3819)	(3.35)	(19.24)	(21.57)
Research Centre	28750	23.29	93.13	115.40
	(5052)	(3.16)	(12.38)	(15.37)
Belen Rivas	22500	27.73	118.54	143.79
	(2602)	(2.21)	(10.99)	(12.75)
Playa Tamarindo	22500	21.28	82.76	103.03
	(4507)	(2.09)	(9.43)	(11.04)
Monterrico	20833	23.18	97.74	118.98
	(2732)	(3.77)	(16.96)	(20.09)
Potezuelo Bolivar	20625	20.515	87.69	106.35
	(6875)	(0.335)	(6.380)	(4.87)
Retalhuleu	16250	17.37	73.00	89.10
	(3750)	(5.055)	(22.940)	(27.40)
Kihonda	27916	20.53	82.14	101.68
	(5221)	(3.118)	(15.807)	(18.38)
P>F- Ratio	0.16	0.798	0.794	0.80
RMSE[y]	4843.20	4.697	23.063	26.81
CV[z]	21.93	21.106	24.796	23.58

[x]Mean of three replications, with standard error in parenthesis; [y]RMSE – root mean square error, [z]CV – coefficient of variation (%).

Table 11b: Multiple stems production(stems ha^{-1}) and biomass production (t ha^{-1}) of 27, 42 and 70 months old *Gliricidia sepium* provenances planted at Gairo, Morogoro, Tanzania

Provenance	Age (months)							
	27				42			
	Stems	Foliage	Wood	Total	Stems	Foliage	Wood	Total
Cuyatenango	35000[x]	10.64	36.16	47.26	28125	13.75a	55.69a	69.47
	(1250)	(0.30)	(0.80)	(1.22)	(0.00)	(1.30)	(6.72)	(8.10)
Taxisco	37500	9.58	30.70	40.86	34688	11.79a	42.00b	54.42
	(4376)	(0.53)	(1.62)	(2.11)	(3438)	(1.30)	(7.86)	(9.73)
Belen Rivas	39688	8.35	25.21	34.07	35625	11.97a	41.62b	54.31
	(1563)	(2.35)	(9.93)	(12.31)	(0.00)	(0.72)	(5.16)	(5.81)
Monterrico	28750	6.91	20.91	28.42	25000	9.63a	33.53b	43.95
	(5625)	(2.05)	(7.04)	(9.27)	(7500)	(2.46)	(8.35)	(10.98)
Retalhuleu	36250	7.96	23.85	32.32	28125	10.03a	32.64b	43.53
	(3750)	(1.14)	(4.22)	(5.35)	(1875)	(0.33)	(1.08)	(0.58)
Kihonda	30937	7.66	23.74	31.90	28750	9.64a	39.56b	49.25
	(3438)	(0.61)	(3.27)	(3.73)	(3125)	(0.38)	(3.58)	(3.62)
P>F- Ratio	0.137	0.16	0.15	0.160	0.20	0.09	0.04	0.05
RMSE[y]	3442.2	1.21	4.88	6.11	3960.40	1.23	4.95	6.05
CV[z]	9.92	14.19	18.23	17.07	13.15	11.07	12.12	11.53

[x] Mean of two replications, with standard error in parenthesis; Values with the same latter(s) within the same column do not differ significantly ($P>0.05$); [y] RMSE – root mean square error, [z] CV – coefficient of variation (%).

Table 11b: Continued...

Provenance	Age (months)			
	70			
	Stems	Foliage	Wood	Total
Cuyatenango	27500	18.68	95.15	110.64
	(1875)	(4.00)	(23.36)	(26.43)
Taxisco	33125	16.87	76.22	91.70
	(0.00)	(1.85)	(11.20)	(12.40)
Belen Rivas	28750	15.08	69.27	82.79
	(1250)	(1.41)	(9.92)	(10.78)
Monterrico	27500	13.32	60.76	72.90
	(7499)	(3.27)	(14.90)	(17.62)
Retalhulcu	33438	13.72	61.93	74.46
	(938)	(0.48)	(4.36)	(4.32)
Kihonda	30625	15.19	70.89	84.56
	(4375)	(2.06)	(10.67)	(12.35)
P>F- Ratio	0.70	0.16	0.08	0.10
RMSE[y]	4860.70	1.78	8.98	10.53
CV[z]	16.12	11.49	12.41	12.21

[x]Mean of two replications, with standard error in parenthesis; Values with the same latter(s) within the same column do not differ significantly (P>0.05); [y]RMSE – root mean square error, [z]CV – coefficient of variation (%).

Table 11c: Multiple stems production(stems ha^{-1}) and biomass production (t ha^{-1}) of 14, 29 and 34 months old *Gliricidia sepium* provenances planted at Kibaha, Tanzania

Provenance	Age (months)							
	14				29			
	Stems	Foliage	Wood	Total	Stems	Foliage	Wood	Total
Cuyatenango	22188^x	10.65a	25.39a	46.33a	20781	17.89	45.05	92.34
	(1313)	(1.04)	(2.55)	(5.08)	(1260)	(2.18)	(5.84)	(12.46)
Taxisco	21250	5.70c	13.06c	22.18c	22188	16.78	41.89	83.00
	(2150)	(1.25)	(2.90)	(5.29)	(1409)	(1.70)	(4.75)	(10.75)
Nigeria	21875	6.51bc	15.17bc	26.67bc	22188	15.61	38.56	75.96
	(1112)	(1.36)	(3.273)	(6.25)	(1155)	(2.24)	(5.79)	(13.00)
Jutiapa	17812	8.33b	19.615b	35.90b	17969	16.86	42.49	86.25
	(972)	(0.63)	(1.49)	(3.23)	(1260)	(0.96)	(2.67)	(3.23)
Ibadan	20625	7.05bc	16.53bc	29.10bc	22187	15.68	39.37	78.09
	(1296)	(0.75)	(1.77)	(3.33)	(2824)	(1.63)	(4.56)	(6.07)
P>F- Ratio	0.22	0.001	0.001	0.001	0.38	0.30	0.28	0.17
RMSE^y	2717.90	1.441	3.49	6.67	3332.00	2.68	7.01	14.54
CV^z	12.92	19.83	20.53	22.14	16.03	16.69	17.49	18.19

^{x}Mean of four replications, with standard error in parenthesis; Values with the same letter(s) within the same column do not differ significantly (P>0.05); ^{y}RMSE – root mean square error, ^{z}CV – coefficient of variation (%).

Table 11c: Continued...

Provenance	Age (months)			
	34			
	Stems	Foliage	Wood	Total
Cuyatenango	18438	20.19	49.15	96.34
	(2289)	(2.25)	(5.57)	(11.61)
Taxisco	20313	18.18	44.19	85.20
	(1210)	(1.00)	(2.48)	(5.46)
Nigeria	22031	17.62	41.76	79.06
	(1641)	(2.76)	(6.81)	(15.29)
Jutiapa	16563	18.76	44.59	88.25
	(786)	(1.38)	(3.44)	(7.50)
Ibadan	20313	17.74	42.47	81.09
	(2373)	(1.10)	(2.69)	(5.34)
P>F- Ratio	0.19	0.46	0.46	0.35
RMSE[y]	2911.50	2.70	6.61	13.85
CV[z]	15.03	17.02	17.20	18.26

[x]Mean of four replications, with standard error in parenthesis; Values with the same letter(s) within the same column do not differ significantly (P>0.05); [y]RMSE – root mean square error, [z]CV – coefficient of variation (%).

4.5.2 Foliar biomass

For SUA farm and Gairo site, provenances did not differ significantly ($P>0.05$) in foliar biomass production at all assessment occasions (Appendices 1 and 2). At Kibaha site, provenances differed significantly ($P < 0.05$) in foliar biomass production only at 14 months after planting (Appendix 3). At SUA farm site. foliage biomass ranged between 11.40 (Retalhuleu) and 19.34 t ha^{-1} (Kihonda), and 17.37 (Retalhuleu) and 27.73 t ha^{-1} (Belen Rivas) at 24 and 69 months after planting respectively. At Gairo site, foliar biomass ranged between 6.91 (Monterrico) and 10.64 t ha^{-1} (Cuyatenango), and 13.72 (Monterrico) and 18.68 t ha^{-1} (Cuyatenango) at 27 and 70 months after planting respectively. For Kibaha site. the ranges in foliar biomass were between 5.70 (Taxisco) and 10.65 t ha^{-1} (Cuyatenango), and 15.45 (Nigeria) and 20.19 t ha^{-1} (Cuyatenango) at 14 and 34 months after planting respectively.

4.5.3 Wood biomass

For SUA farm, provenances did not differ significantly ($P>0.05$) in wood biomass at all assessment occasions (Appendix 1). At Gairo site, provenances differed significantly ($P<0.05$) in wood biomass only at 42 months after planting (Appendix 2) while for Kibaha site significant variation ($P<005$) among provenances in wood biomass was detected only at 14 months after planting (Appendix 3). At SUA farm site, wood biomass ranged between 39.02 (Retalhuleu) and 61.78 t ha^{-1} (Kihonda), and 72.99 (Retalhuleu) and 118.54 t ha^{-1} (Belen Rivas) at 24 and 69 months after planting respectively. At Gairo site, wood biomass ranged between 20.91 (Belen Rivas) and 36.16 t ha^{-1} (Cuyatenango), and 60.76 (Monterrico) and 95.15 t ha^{-1} (Cuyatenango) at 27 and 70 months after planting respectively. For Kibaha site, wood biomass ranged between 31.01 (Taxisco) and 25.39 t ha^{-1} (Cuyatenango), and 37.26 (Nigeria) and 49.15 t ha^{-1} (Cuyatenango) at 14 and 34 months after planting respectively.

4.5.4 Total biomass

At SUA farm and Gairo site, provenances did not differ significantly ($P>0.05$) in total biomass at all assessment occasions (Appendices 1 and 2). For Kibaha site, provenances differed significantly ($P<0.05$) in total biomass only at 14 month after planting (Appendix 3). At SUA farm, total biomass ranges were between 50.48 (Retalhuleu) and 81.53 t ha^{-1} (Kihonda), and 89.10 (Retalhuleu) and 143.79 t ha^{-1} (Belen Rivas) at 24 and 69 months after planting respectively. For Gairo site, total biomass ranged between 28.42 (Monterrico provenance) and 47.26 t ha^{-1} (Cuyatenango), and 72.90 (Monterrico) and 110.64 t ha^{-1} (Cuyatenango) at 27 and 70 months after planting respectively. For Kibaha site, total biomass ranged between 22.18 (Taxisco) and 46.33 t ha^{-1} (Cuyatenango), and 72.77 (Nigeria) and 96.34 t ha^{-1} (Cuyatenango) at 14 and 34 months after planting respectively.

CHAPTER FIVE

5. DISCUSSION

5.1 Survival

In all sites, tree survival was generally good. Transformed data of mean tree survival for SUA farm and Kibaha site showed no significant differences between the provenances tested while significant differences in survival among provenances at Gairo site were evident. The significant differences in survival at Gairo site could be attributable to low rainfall in the area. In this case Balen Rivas provenance appears to tolerate dry conditions than Retalhuleu and Kihonda provenances. The high provenance survival in the present case conforms to results reported in Malawi (Ngulube and Mwabumba, 1991; Ngulube, 1994). The effect of site on provenances performance was not analyzed due to age differences but generally the overall mean tree survival was higher at SUA farm site (93%) as compared to Gairo (79%) and Kibaha site (89%). The relatively higher survival at SUA farm site than Kibaha and Gairo site could suggest better adaptation to the site conditions at SUA farm than the other two sites. SUA farm site has relatively lower soil pH and lower Ca content (Tables 2, 3 and 4). *Gliricidia sepium* has been reported to be adapted to acid soils with high Al saturation (Dierolf and Yost, 1989; Shelton, 1994; Roshetko *et al.*, 1996) and it is known to be well adapted to low Ca soils (Whiteman *et al.*, 1986) and suitable for infertile acidic soils (Szott *et al.*, 1991). However, it can neither tolerate severe acidity (pH less than 4.5) nor high Al saturation (greater than 60%) (Dierolf and Yost, 1989; MacDicken *et al.*, 1997). Although acid soils are known to cause Al toxicity that can be detrimental to plants, this is only apparent at pH 5.0 (Coleman, 1959; Brady, 1984). Thus soil at SUA farm does not appear to cause any Al toxicity to *G. sepium* (Table 2).

Lack of significant differences in tree survival at SUA farm and Kibaha implies that if the tree-planting objective is rehabilitation of degraded land, most of the provenances tested at SUA farm and Kibaha site are suitable for the respective sites and areas with similar conditions. However, planting multipurpose trees for satisfying a single objective is not a customary AF practice, and is more unlikely in Morogoro, Kibaha and similar sites in Tanzania where soil fertility and fuelwood are the serious problems (Mugasha *et al.*, 2000; Herbert *et al.*, 2002). Similarly, multipurpose trees are preferred among others for their foliages that are used as mulch to improve soil fertility as well as animal fodder. Attention should therefore be focused on provenance productivity and other attributes.

The survival recorded in the present study is higher than the ones reported by Herbert *et al.* (2002) for *Calliandra calothyrsus* and Chamshama *et al.* (2000) for *Sesbania macrantha.* The higher survival of *G. sepium* provenances compared to *C. calothyrsus* and *S. macrantha* provenances could be attributable to termite resistance (Kathiravetpillai, 1990). *G. sepium* is reported to be termite resistant as a result of toxic properties of its roots. This property has been used to reduce termite damage in tea plantations in Sri Lanka by mixed intercropping of tea with *G. sepium* (Silvapalan *et al.*, 1977). Very high survival of these *G. sepium* provenances is a good indication of the potential the species may have in the miombo woodland areas where termites have caused considerable damage to other exotic species such as *Eucalyptus*, *Casuarina* and *Leucaena* (Kwesiga, 1994).

5.2 Height, root collar diameter and diameter at 30 cm from ground

This study indicates superior height growth at Kibaha and poor height growth at Gairo site. Herbert *et al.* (2002) attributed poor height growth of *Calliandra calothyrsus* at SUA farm to soil compaction and low soil pH. Fue *et al.* (2000) reported impaired diameter and height growth in seedlings of *Pinus patula* Shiede & Deppe and that the compaction by farm tractor had no marked effect while compaction by Skidder had marked effects. For *G. sepium* in this study, soil compaction due to long-term tractor use at SUA farm site does neither impair diameter nor height growth.

The poor growth recorded at Gairo site is probably due to differences in amount of rainfall, altitude and edaphic factors. *Gliricidia sepium* grows well at an altitude between 0 and 750 m a.s.l. (AFNETA, 1992). Gairo receives relatively less rainfall and it is at higher altitude (499 mm/year, 1300 m) while Kibaha receives relatively higher rainfall and is at lower altitude (700-1000mm/year, 70 m) (Appendices 4, 5 and 6). According to Hughes (1987), Whiteman *et al.* (1986) and ICRAF (1992), *G.*

sepium is suitable for acid, infertile soils. These could explain the better performance at Kibaha and SUA farm site with relatively low soil pH and lower altitude than Gairo site. However, all sites recorded lower height growth than those reported by Simons and Dunsdon (1992) for *G. sepium*. This could be attributed to differences in management regimes (Glover, 1987; Nitis *et al.*, 1989), topography, land utilization, climatic zones (Nitis *et al.*, 1980), and genotypes (Nitis *et al.*, 1991).

5.3 Foliage N and P concentrations and content and accumulation

Most soils in Tanzania are inherently low in fertility and exhibit deficiencies in N and P (Mugasha *et al.*, 2000). *G. sepium* foliages are used in AF as mulch for soil fertility improvement and fodder in various places in the tropics including Tanzania (Nair, 1997; Mbuya *et al.*, 1994; Ngulube, 1994; Herbert *et al.*, 2002). Therefore, in addition to biomass production as a criterion for multipurpose tree/shrub provenances selection, information on foliar nutrient concentration is essential if the foliage is to be used as green manure and/or fodder. Also, nutrient concentration can facilitate early selection of best-adapted provenances (Steinbeck, 1966).

Foliage nutrient concentrations of the *Gliricidia* provenances in this study fall within the ranges reported elsewhere for *G. sepium* (Budelman, 1989; Glover, 1989; Ngulube, 1994; Lehmann *et al.*, 1995; Kimaro, 2000). Besides, these concentrations are generally comparable to other legumes foliage (Maghembe *et al.*, 1986; Budelman, 1989; Lulandala and Hall, 1990; Maghembe and Prins, 1994).

Variations in nutrient values may exist because of differences in sampling procedures as well as site conditions. Ngulube (1994) emphasized the need for standardization of sampling and laboratory procedures for proper comparisons of nutrient concentration values of the multipurpose trees recommended for AF in the Miombo ecozone.

The overall foliar N and P concentrations and contents found in this study are higher (about two folds) than those reported for 36 months old *Sesbania* sesban (2.73 % N, 0.17% P), *Tephrosia vogelii* (1.89%N. 0.15% P) and *Cajanus cajan* (2.45%N. 0.15%P) in Gairo, Tanzania (Mgangamundo, 2000). This suggests the superiority of this species for soil fertility improvement when the foliage is used as mulch. This is supported by Chamshama *et al.* (2002) who reported highest maize grain yield in a two-year improved fallow by *G. sepium* (3.36 t ha^{-1}) in comparison with *Cajanus cajan* (1.91 t ha^{-1}), *Sesbania macrantha* (2.22 t ha^{-1}), *S. sesban* (2.72 t ha^{-1}) and natural fallow (1.56 t ha^{-1}) at Gairo, Tanzania. Similar results have been reported elsewhere (Kwesiga and Coe, 1994; ICRAF, 1994).

On the other hand, the higher foliage N and P concentrations and contents and accumulation shade some lights on the substantial amount of nutrients that could be lost if leaves of *G. sepium* are removed from the field during tree harvesting as in cut-and-carry-fodder system. Such high nutrient export through foliage harvesting might lead to further nutrient depletion and so jeopardizing the whole practice of multipurpose tree planting for soil fertility improvement in AF. Thus, it is important that all leaves and twigs be retained in the field and used as mulch so that nutrients contained in the biomass component can be released into the soil after decomposition. Similarly, when the foliages are used for fodder, animal remains such as dung should be returned to the field to ensure sustainability of the system. Nutrient concentrations and contents and accumulation in wood biomass were not examined in this study. However, the necessity to remove woody component from AF systems due to firewood demand is likely to result into substantial nutrient export from the AF systems. Mgangamundo (2000) reported the estimates for amount of N and P export due to wood harvesting for 36 months *Sesbania sesban* and *Cajanus cajan* planted at Gairo, Tanzania to be 83.81 kgN/ha and 7.53 kgP/ha, and 16.88 kgN/ha and 2.51 kgP/ha respectively. This implies that in future external nutrient supplies in AF systems such as inorganic fertilizers will be needed to recover nutrients removed during harvesting of woody components for firewood.

In this study, site influence was not statistically analyzed due to age differences between the sites. However, variation was noted in foliage N and P concentrations and content between sites. Nutrient concentrations within species can be attributed to a number of factors, including differences in provenances, soil fertility, climate, aeration (oxygen), season and age of leaves or plant (Vitousek, 1982; Palm, 1995; Mgangamundo, 2000). In fact, it has been suggested that soil nutrient status is the most important factor influencing nutrient concentrations within species although the magnitude of the effect varies among the species (Palm, 1995).

There are studies, which have shown that soil fertility status influences among others foliar N and P concentrations. Even in leguminous trees/shrubs including *G. sepium* foliar N and P concentrations have been found to be affected by soil fertility status. The study by Cobbina *et al.* (1992) in Nigeria showed that both *Leucaena leucocephala* and *G. sepium* had lowest shoot N content on poor soil (total N 0.053%, pH 6.6) in comparison to the fertile soil (total N 0.100%, pH 7.0) the differences being 3 and 2 folds for *L. leucocephala* and *G. sepium* respectively. In Tanzania, Hakizimana (1999) reported similar results for *Grevillea robusta* growing in three sites differing in soil fertility status. In addition, the amount of N fixed by legumes such as *G. sepium* and so the amount contained in the foliage is correlated to population of rhizobia (Cobbina *et al.*, 1992). A slightly higher soil N status appears to enhance the legume/rhizobia symbiosis. Besides, low soil pH (pH<6) can sometimes cause a deficiency in Molybdenum (Mo), a micronutrient critical for the N-fixing process (Anonymous, 2002). Although Mo deficiency symptoms were not observed in this study, it is likely that the quantity of Mo available in different sites was influenced by soil pH. Thus differences observed in nutrient concentrations in this study are probably due to edaphic factors.

Low foliar nutrient concentration of a particular nutrient signifies high nutrient use efficiency for the nutrient in question and it suggests that the nutrient is relatively scarce at a site (Vitousek, 1982). SUA farm and Gairo site had almost equal soil total N and higher than Kibaha site. Thus soil fertility status alone does not appear to explain the differences observed in foliar N content among sites. Higher foliar N and

P concentrations at Gairo than Kibaha and SUA farm site can be explained by soil pH. The soil pH for the three sites was in the order SUA farm<Kibaha<Gairo (Tables 2, 3 and 5). Nitrogen is made available for plant use through mineralization and amount of N fixed in the soil by leguminous trees/shrubs such as *G. sepium*. Mineralization process proceeds at high rate in a well-drained aerated soil with plenty of basic cations present i.e. at high pH (Brady, 1984) although some other factors influence the process (Mugendi and Nair, 1997). The relatively high soil pH at Gairo site could have resulted into more N availability through mineralization therefore favoring its uptake by the trees besides its positive effects on N fixation leading to high concentration of N in the foliage at Gairo site. At SUA farm, compacted soils limit root proliferation and are poorly aerated due to long term tractor use (Herbert *et al*., 2002). In such poorly aerated soils both N-fixation and mineralization rate is low. This factor probably contributed to low N in foliages at SUA farm. Similarly, according to Brady (1984) the activity of P is directly related to soil pH. As soil acidity increases (pH decreases), there is a rise in the activity of the iron, Al, and manganese that precipitate P as insoluble phosphates making it unavailable. This fixation is most serious when the soil pH is below 5 and this can also be associated with Al toxicity. The prevailing low soil pH at SUA farm is probably responsible for fixation of P leading to lower concentration of P in the foliages at SUA farm. The high foliar N accumulation at SUA farm (Tables 10a, 10b and 10c) observed in this study was due to high foliage biomass at SUA farm rather than high foliar N concentration.

5.4 Multiple stems and biomass production

Generally, multiple stems production decreased with age for all sites indicating that the species is sensitive to competition. Kwesiga (1994) reported similar observations after 27 months of age for some *G. sepium* provenances grown in Malawi. In addition, sensitivity to competition has been reported for other fast growing multipurpose trees/shrubs (Mugasha *et al.*, 2000; Chamshama *et al.*, 2000). Rotation ages for various AF technologies for *G. sepium* have not been established in Tanzania. Chamshama *et al.* (2002) reported that 2 years was found to be the best fallow period for improved fallow utilizing *G. sepium* implying that after that age the effects of competition could become disadvantageous. In the Philippines, *G. sepium* is grown on three-year rotation (Wiersum and Dirjosoemarto, 1987). At the ages well below three years, the number of stems was highest at SUA farm and lowest at Kibaha site indicating that the species shows high multiple stems production at SUA farm site. This is probably due to variation in soil acidity and different rainfall (Bray *et al.*, 1993). Herbert *et al.* (2002) reported high stem number at SUA farm than Gairo in *C. calothyrsus* provenances. According to Simons (1996) and Glover (1989) *G. sepium* grows in areas receiving at least 600 mm of rainfall per year. All the three sites receive rainfall that is enough for *G. sepium*. Thus soil acidity and other edaphic factors may be the most important factors determining multiple stem production in *G. sepium*.

At the ages of 24 months (SUA farm), 27 months (Gairo) and 14 months (Kibaha) variation in biomass yield between best and poorest provenances for each of the three sites was roughly two folds. Differences in biomass production up to 500% have been reported elsewhere (Simons and Dunsdon, 1992). This provides an opportunity for exploitation of genetic variability within *G. sepium* for more effective AF technologies.

Biomass yields in this study are higher than those reported by Salazar (1986) for *G. sepium* in Costa Rica and those reported by Chamshama *et al.* (2002) for two-year *G. sepium* planted at Gairo, Tanzania. However, they are within the range reported for the same species by other authors (Wong and Sharudin, 1986; Sriskandarajah, 1987; Ngulube, 1994) and comparable with those reported in the literature for other fast growing fuelwood species (Gueverra *et al.*, 1978; Wittwer and Inimel, 1980; Maghembe *et al.*, 1986; Ahimana and Maghembe, 1987; Maghembe and Prins, 1994). On the other hand, there are other studies that have reported biomass levels higher than those reported in this study. Examples include irrigated *Acacia nilotica* in Pakistan, which produced 35-41 t ha^{-1} per year (Maguire *et al.*, 1990), and *Prosopis juliflora* DC. growing in a cement quarry in Kenya that produced 36 t ha^{-1} per year (Maghembe *et al.*, 1983). Thus comparisons of biomass yield should be made taking into account the differences between species, site, age, stocking density and management.

Differences in *G. sepium* biomass production are affected to a varying degree by management regimes (Glover, 1987; Nitis *et al.*, 1989), topography, land utilization and climatic zones (Nitis *et al.*, 1980), and genotypes (Nitis *et al.*, 1991; Simons and Dunsdon, 1992). This can also explain the highest foliar biomass at Kibaha site and highest wood biomass at SUA farm site. AFNETA (1992) reported that *G. sepium* is successful at lower to medium altitudes while Whiteman *et al.* (1986) and ICRAF (1992) reported that the species does well in acidic soils. SUA farm and Kibaha sites have relatively acidic soils with high Al saturation and they are at lower altitude compared to Gairo site (Tables 2, 3 and 4). Aluminum is known to be toxic to plants at pH less than 5 (Brady, 1984) but pH at SUA farm and Kibaha site are above 5 (Table 2). Thus climate at SUA farm and Kibaha site probably favoured high biomass production observed in these sites.

Mechanisms by which trees improve soil fertility and sustain productivity in improved fallow, rotational woodlots and hedgerows include nutrient cycling and enhancement of soil OM through litter fall and application of green manure (Young, 1989; Kang, 1993). According to Young (1989) the estimated aboveground plant biomass required for the maintenance of soil organic matter could be about 8.4, 4.2 and 2.1 t ha^{-1} year^{-1} for humid, sub humid, and semi arid climatic zones respectively.

In view of these results and the high coppicing ability of *G. sepium* reported by Stewart *et al.* (1992), Maghembe and Prins (1994) and ICRAF (1997), it could be suggested that if appropriate residue management systems are developed to incorporate above ground biomass including coppice regrowth, provenances such as Balen Rivas, Cuyatenango and Jutiapa with higher foliar biomass productivity and nutrient concentration for AF technologies that involve periodic pruning for green manure such as improved fallows, relay cropping and rotational woodlots can be suitable at SUA farm and similar sites. Since these provenances also showed high wood biomass productivity they can be used for fuelwood production. Similarly, Cuyatenango, Taxico and Balen rivas with high foliar and wood biomass productivity can be suitable for nutrient cycling and fodder and fuel wood production at Gairo and similar sites. A similar argument applies for Cuyatenango and Jutiapa for both nutrient cycling and fodder, and fuelwood production at Kibaha and similar sites.

The present study showed that Belen Rivas and Jutiapa provenances ranked first and second in foliage biomass yield while Balen Rivas and Cuyatenago ranked first and second in wood biomass yield at SUA farm; Cuyatenago and Taxico ranked first and second in both foliage and biomass yields at Gairo; and Cuyatenango and Jutiapa ranked first and second in both foliage and wood biomass yield at Kibaha. On the other hand, studies in Ibadan (Nigeria) by Cobbina and Atta-Krah (1992) showed that Retalhuleu and Monterrico provenance ranked second in leaf yield while in Utchee Creek (Australia) and Sie Putith (Indonesia), Bray *et al.* (1993) reported that Retalhuleu and Monterrico and Retalhuleu and Belen Rivas provenance were respectively ranked first and second in leaf yield. In addition, Simons and Dunsdon (1992) reported that Retalhuleu, showed stable and superior production for both leaf and wood production across a wide range of sites while Monterrico showed poor growth in terms of wood production but outstanding for leaf production. Such discrepancies might be due to different managements, edaphic and climatic factors (Sukanten *et al.*, 1994 cited in Sukanten *et al.*, 1995). Equally, however, such discrepancies may constitute provenance x site interaction.

According to Barnes *et al.* (1984), one way in which provenance x site interaction can be manifested is the situation where best population for one site is not necessarily the best for other sites. As noted earlier, in the present study, the influence of site was not analyzed statistically due to age differences between sites. However, for most of the characteristics evaluated the ranking changed from one site to another indicating presence of provenance x site interaction in *G. sepium*. Similar results have been reported for *Calliandra calothysus* at SUA farm and Gairo in Tanzania (Herbert *et al.*, 2002). This implies that the assessed characteristics are little affected by genetic make-up so it is under the control of environments, and/or sites. This has important bearing in genetic improvement of the study species in Tanzania since it might be of necessity to establish more than one seed stand of *G. sepium* to cater for the different agro-ecological zones within the country.

CHAPTER SIX

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Although not significant, the growth and productivity variations between provenances of *Gliricidia sepium* showed by this study suggest the importance of appropriate provenance selection for particular desirable products.

Of paramount importance is a statement on future seed sources. Taking into account age differences between site, survival and productivity of the provenances were highest at SUA farm and lowest at Gairo site. The most productive provenances were Balen Rivas, Cuyatenango and Jutiapa; Cuyatenango and Taxico; and Cuyatenango and Jutiapa for SUA farm, Gairo and Kibaha site respectively. However, this should be treated as a preliminary indication of promising seed sources since the number of provenances used in each of the three experiments is limited particularly for Gairo and Kibaha site.

There is still a room for development of appropriate management techniques in different AF technologies for the promising provenances in particular sites. In addition, the gain from the provenances could be further improved through singletree progenies and selecting elite trees from such populations.

6.2 Recommendations

If fire wood production is the primary objective, provenances Balen Rivas and Cuyatenango are the most appropriate at SUA farm on the basis of their high wood biomass yield. On the other hand, where foliage production for use as green manure for soil fertility enhancement and/or fodder for animals is the major objective, provenances Balen Rivas and Jutiapa are the most appropriate based on high foliage biomass yield and foliage nutrient concentrations and contents. Using the same interpretation, Cuyatenango and Balen Rivas are the most appropriate at Gairo site for soil fertility improvement and fodder production while Cuyatenango and Taxico are most appropriate for fire wood production. Conversely, Cuyatenango and Jutiapa appear to be the most appropriate provenances at Kibaha site for both purposes.

In this study, the best performing provenances varied between sites implying existence of provenance/site interaction. Thus future afforestation and genetic improvement programme should use different best provenances for different agro-ecological zones. In addition, exchange of the seeds within the country for *G. sepium* should be done with care as this might result into taking one provenance into a region in which it is not adapted.

In this study, out of fifteen provenances under trial only two provenances were replicated over the three sites owing to shortage of seedlings due to the fact that mice in the nursery destroyed seeds. Thus future research should compare performance of other *G. sepium* provenances in these sites. Kwesiga (1994) reported variation in coppicing ability among provenances of *G. sepium*. In the present study this aspect was not assessed. Therefore future research should evaluate this aspect.

The effects of the different *G. sepium* provenances on crop yield and soil amelioration aspects were not assessed in the present study. It is therefore recommended that future research should also address these aspects as well as nutritional factors, fodder quality and digestibility. In addition, nitrogen fixing potentials and nodulation ability that are important factors determining nitrogen fixation were not assessed in the present study. Thus future research should also focus on these two aspects.

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APPENDICES

Appendix 1: Summaries of ANOVA results for SUA Farm site

Age (months)	Dependent variable	Source	Df	Sum of square	Mean Square	F value	Pr>F
6	Survival (transformed)	Provenance	12	1424.4661	118.7055	0.70	0.7327
		Block		61.2413	30.6207	0.18	0.8356
		Error	21	3550.0365	169.0494		
		Total	35	5154.4384			
	Survival (untransformed)	Provenance	13	1329.8730	110.8228	0.54	0.8633
		Block	2	26.1259	13.0629	0.06	0.9384
		Error	21	4300.8432	204.8021		
		Total	35	5746.5498			
	Height	Provenance	12	0.7831578	0.0652632	1.57	0.1768
		Block	2	0.5605965	0.2802983	6.74	0.0055
		Error	21	0.8735868	0.0415994		
		Total	35	2.2112222			
	RCD	Provenance	12	1.7801579	0.1483465	2.22	0.0531
		Block	2	0.4086128	0.7043064	10.53	0.0007
		Error	21	1.4048205	0.0668962		
		Total	35	4.5288222			
16	Survival (transformed)	Provenance	12	6250.1340	520.8445	1.32	0.2778
		Block	2	842.5671	421.2835	1.06	0.3621
		Error	22	8708.0481	395.8204		
		Total	36	15826.5713			
	Survival (untransformed)	Provenance	12	8499.1990	708.2666	1.46	0.2148
		Block	2	1417.0966	708.5483	1.46	0.2548
		Error	22	10705.9102	486.6323		
		Total	36	20648.7852			
	Height	Provenance	12	3.0208783	0.2517399	1.53	0.1936
		Block	2	0.5444446	0.2722223	1.65	0.2164
		Error	20	3.2918054	0.1645903		
		Total	34	6.8749886			
	RCD	Provenance	12	57.999580	4.833298	0.76	0.6858
		Block	2	22.805474	11.402737	1.78	0.1939
		Error	20	127.946143	6.397307		
		Total	34	207.235954			

Appendix 1: Continued...

Age (months)	Dependent variable	Source	Df	Sum of square	Mean Square	F value	Pr>F
24	Survival (transformed)	Provenance	12	1406.8247	117.2354	1.07	0.4262
		Block	2	506.1511	253.0756	2.32	0.1229
		Error	21	2290.8265	109.0870		
		Total	35	4365.3264			
	Survival (untransformed)	Provenance	12	1441.1876	120.0990	1.30	0.2870
		Block	2	426.2987	213.1494	2.31	0.1236
		Error	21	1934.9235	92.1392		
		Total	35	3950.6791			
	Height	Provenance	12	3.3248063	0.2770672	1.67	0.1464
		Block	2	0.6577471	0.3288735	1.98	0.1627
		Error	21	3.4834529	0.1658787		
		Total	35	7.4775889			
	RCD	Provenance					
		Block	2	1.0352978	0.5176489	0.75	0.4836
		Error	21	14.4496688	0.6880795		
		Total	35	19.2682			
	D30	Provenance	12	2.3657562	0.1971463	1.09	0.4159
		Block	2	0.9351962	0.4675981	2.58	0.0992
		Error	21	3.7998538	0.1809454		
		Total	35	7.0725889			
	Stem number	Provenance	12	1409000000	117400000	1.53	0.1903
		Block	2	63250000	31620000	0.41	0.6677
		Error	21	1613000000	76790000		
		Total	35	3174000000			
	Foliar biomass	Provenance	12	192.92619	16.07718	0.97	0.5069
		Block	2	23.58116	11.79058	0.71	0.5034
		Error	21	349.10756	16.62417		
		Total	35	583.91390			
	Wood biomass	Provenance	12	2301.1768	191.7647	1.08	0.4231
		Block	2	347.8964	173.9482	0.98	0.3922
		Error	21	3731.5191	177.6914		
		Total	35	6504.5111			
	Total biomass	Provenance	12	3718.4298	309.8691	1.03	0.4571
		Block	2	519.1192	259.5596	0.86	0.4357
		Error	21	6304.8397	300.2305		
		Total	35	10785.0567			

Appendix 1: Continued...

Age (months)	Dependent variable	Source	Df	Sum of square	Mean Square	F value	Pr>F
41	Survival (transformed)	Provenance	12	2028.1621	169.0135	0.79	0.6587
		Block	2	98.5822	49.2911	0.23	0.7969
		Error	21	4511.0396	214.8114		
		Total	35	6672.5694			
	Survival (untransformed)	Provenance	12	1712.9704	142.7475	0.89	0.5675
		Block	2	114.6687	57.3343	0.36	0.7029
		Error	21	3357.7759	159.8941		
		Total	35	5247.1236			
	Height	Provenance	12	2.6959650	0.2246638	0.63	0.7934
		Block	2	7.5176612	3.7588306	10.55	0.0007
		Error	21	7.479989	0.356190		
		Total	35	18.399256			
	RCD	Provenance	12	2.3533672	0.1961139	0.51	0.8853
		Block	2	7.3960182	3.6980091	9.61	0.0011
		Error	21	8.0809651	0.3848079		
		Total	35	17.4300306			
	D30	Provenance	12	2.4980737	0.2081728	0.50	0.8892
		Block	2	8.8839278	4.4419639	10.75	0.0006
		Error	21	8.678856	0.413279		
		Total	35	20.375789			
	Stem number	Provenance	12	580268429	48355702	1.75	0.1267
		Block	2	305252404	152626202	5.52	0.0119
		Error	21	580945513	27664072		
		Total	35	1503125000			
	Foliar biomass	Provenance	12	246.05448	20.50454	0.58	0.8330
		Block	2	17.45459	8.72730	0.25	0.7830
		Error	21	740.53268	35.26346		
		Total	35	999.448			
	Wood biomass	Provenance	12	4378.0036	364.8336	0.49	0.8953
		Block	2	1647.6043	823.8021	1.12	0.3462
		Error	21	15497.3076	737.9670		
		Total	35	21312.7772			
	Total biomass	Provenance	12	6503.4230	541.9519	0.50	0.8927
		Block	2	1931.4482	965.7241	0.89	0.4263
		Error	21	22832.6816	1087.2706		
		Total	35	30951.5358			

Appendix 1: Continued...

Age (months)	Dependent variable	Source	Df	Sum of square	Mean Square	F value	Pr>F
69	Survival (transformed)	Provenance	12	1679.6210	139.9684	0.59	0.8241
		Block	2	270.2855	135.1428	0.57	0.5727
		Error	21	4958.2014	236.1048		
		Total	35	6986.3660			
	Survival (untransformed)	Provenance	12	1475.4022	122.9502	0.66	0.7709
		Block	2	286.6375	143.3187	0.77	0.4772
		Error	21	3926.2885	186.9661		
		Total	35	5802.3828			
	Height	Provenance	12	2.2596479	0.1883040	0.98	0.5004
		Block	2	1.9280900	0.9640450	4.99	0.0168
		Error	21	4.0542267	0.1930584		
		Total	35	8.4209000			
	D30	Provenance	12	5.8210112	0.4850843	1.60	0.1683
		Block	2	1.7184663	0.8592331	2.83	0.0819
		Error	21	6.3848504	0.3040405		
		Total	35	13.8563889			
	Stem number	Provenance	12	459421074	38285089	1.63	0.1572
		Block	2	407141426	203570713	8.68	0.0018
		Error	21	492598157	23457055		
		Total	35	1396875000			
	Foliar biomass	Provenance	12	165.58253	13.79854	0.63	0.7977
		Block	2	183.85792	91.92896	4.17	0.0299
		Error	21	463.28417	22.06115		
		Total	35	842.61948			
	Wood biomass	Provenance	12	4019.4804	334.9567	0.63	0.7942
		Block	2	4514.6484	2257.3242	4.24	0.0283
		Error	21	11169.8507	531.8977		
		Total	35	20119.8708			
	Total biomass	Provenance	12	5404.5554	450.3796	0.63	0.7969
		Block	2	6075.6415	3037.8207	4.23	0.0287
		Error	21	15097.702	718.938		
		Total	35	27233.282			

Appendix 1: Continued...

Age (months)	Dependent variable	Source	Df	Sum of square	Mean Square	F value	Pr>F
72	Unit leaf mass	Provenance	12	0.3063037	0.02553	1.42	0.231
		Block	2	0.0666188	0.03331	1.86	0.181
		Error	21	0.3770478	0.01795		
		Total	35	0.7429000			
	Foliar P concentration	Provenance	12	0.0033935	0.0002828	1.23	0.3279
		Block	2	0.0007317	0.0003658	1.59	0.2277
		Error	21	0.0048	0.0002		
		Total	35	0.0090222			
	Foliar N concentration	Provenance	12	1.1485805	0.0957150	1.28	0.3010
		Block	2	3.4102985	1.7051492	22.74	0.0001
		Error	21	1.5744349	0.07497		
		Total	35	5.9590556			
	Foliar P accumulation	Provenance	12	0.0000009	0.0000001	1.23	0.329
		Block	2	0.0000002	0.0000001	1.69	0.208
		Error	21	0.0000012	0.0000001		
		Total	35	0.0000023			
	Foliar N accumulation	Provenance	12	0.0004307	0.0000359	1.20	0.342
		Block	2	0.0003871	0.0001936	6.49	0.006
		Error	21	0.0006265	0.0000298		
		Total	35	0.0014136			

Appendix 2: Summaries of ANOVA results for Gairo site

Age (months)	Dependent variable	Source	Df	Sum of square	Mean Square	F value	Pr>F
6	Survival (transformed)	Provenance	5	625.75814	125.15163	5.82	0.0379
		Block	1	248.70307	248.70307	11.56	0.0193
		Error	5	107.57987	21.51597		
		Total	11	982.04109			
	Survival (untransformed)	Provenance	5	666.66667	133.33333	6.67	0.0288
		Block	1	300.00000	300.00000	15.00	0.0117
		Error	5	100.00000	20.00000		
		Total	11	1066.66667			
	Height	Provenance	5	0.0371417	0.0074283	1.77	0.2724
		Block	1	0.0004083	0.0004083	0.10	0.7675
		Error	5	0.0209417	0.0041883		
		Total	11	0.0584917			
18	Survival (transformed)	Provenance	5	772.07954	154.41591	3.34	0.1058
		Block	1	444.93541	444.93541	9.63	0.0268
		Error	5	231.0971	46.2194		
		Total	11		1448.1121		
	Survival (untransformed)	Provenance	5	741.66667	148.33333	5.24	0.0466
		Block	1	408.33333	408.33333	14.41	0.0127
		Error	5	141.6667	28.3333		
		Total	11	1291.6667			
	Height	Provenance	5	0.1204667	0.0240933	3.94	0.0793
		Block	1	0.0008333	0.0008333	0.14	0.7271
		Error	5	0.0305667	0.0061133		
		Total	11	0.1518667			
27	Survival (transformed)	Provenance	5	327.50334	65.50067	9.74	0.0130
		Block	1	65.66041	65.66041	9.76	0.0261
		Error	5	33.64054	6.72811		
		Total	11	426.80429			
	Survival (untransformed)	Provenance	5	566.66667	113.33333	8.50	0.0174
		Block	1	133.33333	133.33333	10.00	0.0250
		Error	5	66.66667	13.33333		
		Total	11	766.66667			
	Height	Provenance	5	0.4991667	0.0998333	1.73	0.2817
		Block	1	0.0705333	0.0705333	1.22	0.3197
		Error	5	0.2890667	0.0578133		
		Total	11	0.8587667			

Appendix 2: Continued...

Age (months)	Dependent variable	Source	Df	Sum of square	Mean Square	F value	Pr>F
27	RCD	Provenance	5	0.5868750	0.1173750	1.72	0.2826
		Block	1	0.1102083	0.1102083	1.62	0.2594
		Error	5	0.3407417	0.0681483		
		Total	11	1.0378250			
	Stem number	Provenance	5	169531250	33906250	2.86	0.1366
		Block	1	102083333	102083333	8.62	0.0324
		Error	5	59244792	11848958		
		Total	11	330859375			
	Foliar biomass	Provenance	5	18.573467	3.714693	2.54	0.1
		Block	1	16.147200	16.147200	11.06	0.0209
		Error	5	7.300200	1.460040		
		Total	11	42.020867			
	Wood biomass	Provenance	5	316.31124	63.26225	2.66	0.1535
		Block	1	240.75521	240.75521	10.12	0.0245
		Error	5	118.96844	23.79369		
		Total	11	676.03489			
	Total biomass	Provenance	5	483.37888	96.67578	2.59	0.1599
		Block	1	384.76687	384.76687	10.31	0.0237
		Error	5	186.66708	37.33342		
		Total	11	1054.81282			
	Survival (transformed)	Provenance	5	327.50334	65.50067	9.74	0.0130
		Block	1	65.66041	65.66041	9.76	0.0261
		Error	5	33.64054	6.72811		
		Total	11	426.80429			
	Survival (untransformed)	Provenance	5	566.66667	113.33333	8.50	0.0174
		Block	1	133.33333	133.33333	10.00	0.0250
		Error	5	66.66667	13.33333		
		Total	11	766.66667			

Appendix 2: Continued...

Age (months)	Dependent variable	Source	Df	Sum of square	Mean Square	F value	Pr>F
42	Height	Provenance	5	0.5127667	0.1025533	2.05	0.2253
		Block	1	0.0133333	0.0133333	0.27	0.6280
		Error	5	0.2505667	0.0501133		
		Total	11	0.7766667			
	RCD	Provenance	5	1.2988667	0.2597733	2.15	0.2100
		Block	1	0.1976333	0.1976333	1.64	0.2568
		Error	5	0.6033667	0.1206733		
		Total	11	2.0998667			
	D30	Provenance	5	0.9690667	0.1938133	0.76	0.6144
		Block	1	0.0108000	0.0108000	0.04	0.8450
		Error	5	1.2743000	0.2548600		
		Total	11	2.2541667			
	Stem number	Provenance	5	174381510	34876302	2.23	0.1991
		Block	1	84667969	84667969	5.43	0.0673
		Error	5	78027344	15605469		
		Total	11	337076823			
	Foliar biomass	Provenance	5	27.357767	5.471553	3.60	0.0929
		Block	1	16.803333	16.803333	11.06	0.0209
		Error	5	7.594467	1.518893		
		Total	11	51.755567			
	Wood biomass	Provenance	5	689.85347	137.97069	5.64	0.0404
		Block	1	311.71213	311.71213	12.74	0.0161
		Error	5	122.3769	24.4754		
		Total	11	1123.9425			
	Total biomass	Provenance	5	917.92954	183.58591	5.01	0.0507
		Block	1	472.38201	472.38201	12.90	0.0157
		Error	5	183.1223	36.6245		
		Total	11	1573.4339			
70	Survival (transformed)	Provenance	5	342.75704	68.55141	3.48	0.0985
		Block	1	43.66267	43.66267	2.22	0.1965
		Error	5	98.38097	19.67619		
		Total	11	484.80069			
	Survival (untransformed)	Provenance	5	641.66667	128.33333	3.67	0.0901
		Block	1	75.00000	75.00000	2.14	0.2031
		Error	5	175.00000	35.00000		
		Total	11	891.66667			

Appendix 2: Continued...

Age (months)	Dependent variable	Source	Df	Sum of square	Mean Square	F value	Pr>F
70	Height	Provenance	5	0.3271417	0.0654283	1.06	0.4756
		Block	1	0.0168750	0.0168750	0.27	0.6235
		Error	5	0.3088750	0.0617750		
		Total	11	0.6528917			
	RCD	Provenance	5	1.3265417	0.2653083	1.08	0.4676
		Block	1	0.3104083	0.3104083	1.26	0.3121
		Error	5	1.2289417	0.2457883		
		Total	11	2.8658917			
	D30	Provenance	5	0.8937417	0.1787483	1.41	0.3591
		Block	1	0.4920750	0.4920750	3.87	0.1064
		Error	5	0.6360750	0.127215		
		Total	11	2.0218917			
	Stem number	Provenance	5	71777344	14355469	0.61	0.7011
		Block	1	44563802	44563802	1.89	0.2280
		Error	5	118131510	23626302		
		Total	11	234472656			
	Foliar biomass	Provenance	5	40.336480	8.067296	2.55	0.1637
		Block	1	56.519821	56.519821	17.86	0.0083
		Error	5	15.822674	3.164535		
		Total	11	112.678975			
	Wood biomass	Provenance	5	1578.5127	315.7025	3.92	0.0801
		Block	1	1844.8720	1844.8720	22.89	0.0050
		Error	5	402.9735	80.5947		
		Total	11	3826.3582			
	Total biomass	Provenance	5	1912.8249	382.5650	3.45	0.1000
		Block	1	2345.5644	2345.5644	21.17	0.0058
		Error	5	553.8979	110.7796		
		Total	11	4812.2872			
73	Unit leaf mass	Provenance	5	0.1861667	0.0372333	3.44	0.1008
		Block	1	0.0208333	0.0208333	1.92	0.2242
		Error	5	0.0541667	0.0108333		
		Total	11	0.2611667			
	Foliar P concentration	Provenance	5	0.0037417	0.0007483	0.15	0.9715
		Block	1	0.0036750	0.0036750	0.73	0.4311
		Error	5	0.0250750	0.0050150		
		Total	11	0.0324917			

Appendix 2: Continued...

Age (months)	Source	Dependent variable	Df	Sum of square	Mean square	F value	Pr>F
73	Foliar N concentration	Provenance	5	0.6778667	0.1355733	7.43	0.0230
		Block	1	0.1200000	0.1200000	6.58	0.0503
		Error	5	0.0912000	0.0182400		
		Total	11	0.8890667			
	Foliar P content	Provenance	5	1.424	0.285	0.52	0.757
		Block	1	0.761	0.761	1.38	0.293
		Error	5	2.757	0.551		
		Total	11	4.942			
	Foliar N content	Provenance	5	464.082	92.816	4.79	0.55
		Block	1	16.609	16.609	0.86	0.397
		Error	5	96.984	19.397		
		Total	11	577.676			
	Foliar P accumulation	Provenance	5	265.7718	53.1544	0.25	0.923
		Block	1	1007.0504	1007.0504	4.73	0.082
		Error	5	1064.5418	212.9084		
		Total	11	2337.3641			
	Foliar N accumulation	Provenance	5	109063.81	21812.76	4.19	0.070
		Block	1	67827.40	67827.40	13.03	0.015
		Error	5	26017.77	5203.55		
		Total	11	202908.98			

Appendix 3: Summaries of ANOVA results for Kibaha site

Age (months)	Dependent variable	Source	Df	Sum of square	Mean Square	F value	Pr>F
14	Survival (transformed)	Provenance	4	0	0	-	-
		Block	3	0	0	-	-
		Error	12	0	0		
		Total	19	0			
	Survival (untransformed)	Provenance	4	0	0	-	-
		Block	3	0	0	-	-
		Error	12	0	0		
		Total	19	0			
	Height	Provenance	4	3.561	0.890	4.82	0.0150
		Block	3	0.317	0.106	0.57	0.645
		Error	12	2.217	0.185		
		Total	19	6.095			
	RCD	Provenance	4	7.359	1.840	9.60	0.001
		Block	3	4.384	1.461	7.62	0.0041
		Error	12	2.300	0.192		
		Total	19	14.044			
	D30	Provenance	4	1.428	0.357	4.97	0.0135
		Block	3	1.351	0.450	6.27	0.0084
		Error	12	0.863	0.072		
		Total	19	3.642			
	Stem number	Provenance	4	48906250	12226563	1.82	0.189
		Block	3	41406250	13802083	2.06	0.159
		Error	12	80468750	6705729		
		Total	19	170781250			
	Foliar biomass	Provenance	4	59.829	14.957	5.83	0.008
		Block	3	34.415	11.472	4.47	0.025
		Error	12	30.808	2.567		
		Total	19	125.053			
	Wood biomass	Provenance	4	367.517	91.879	6.10	0.0064
		Block	3	190.526	63.509	4.22	0.030
		Error	12	180.747	15.062		
		Total	19	738.790			

Appendix 3: Continued...

Age (months)	Dependent variable	Source	Df	Sum of square	Mean Square	F value	Pr>F
14	Total biomass	Provenance	4	1415.440	353.860	6.40	0.005
		Block	3	709.314	236.438	4.28	0.029
		Error	12	663.048	55.254		
		Total	19	2787.803			
29	Survival (transformed)	Provenance	4	669.694	167.423	1.02	0.438
		Block	3	44.188	14.729	0.09	0.965
		Error	12	1977.580	164.798		
		Total	19	2691.462			
	Survival (untransformed)	Provenance	4	530.758	132.690	1.59	0.239
		Block	3	49.373	16.458	0.20	0.896
		Error	12	999.800	83.317		
		Total	19	1579.931			
	Height	Provenance	4	1.123	0.281	2.00	0.158
		Block	3	4.943	1.648	11.75	0.001
		Error	12	1.683	0.140		
		Total	19	7.749			
	RCD	Provenance	4	2.858	0.715	2.48	0.100
		Block	3	9.509	3.170	10.99	0.001
		Error	12	3.462	0.289		
		Total	19	15.829			
	D30	Provenance	4	0.471	0.118	2.01	0.157
		Block	3	1.356	0.451	7.71	0.004
		Error	12	0.703	0.058		
		Total	19	2.530			
	Stem number	Provenance	4	53789063	13447266	1.15	0.378
		Block	3	33828125	11276042	0.97	0.440
		Error	12	139804688	11650391		
		Total	19	227421875			
	Foliar biomass	Provenance	4	14.309	3.577	0.46	0.764
		Block	3	101.013	33.671	4.32	0.028
		Error	12	93.451	7.788		
		Total	19	208.772			
	Wood biomass	Provenance	4	107.620	26.905	0.50	0.733
		Block	3	777.663	259.221	4.86	0.019
		Error	12	639.480	53.290		
		Total	19	1524.763			

Appendix 3: Continued...

Age (months)	Dependent variable	Source	Df	Sum of square	Mean Square	F value	Pr>F
29	Total biomass	Provenance	4	685.672	171.418	0.74	0.581
		Block	3	4078.270	1359.423	5.89	0.010
		Error	12	2768.795	230.733		
		Total	19	7532.737			
34	Survival (transformed)	Provenance	4	666.537	166.634	1.02	0.437
		Block	3	880.212	293.404	1.79	0.202
		Error	12	1965.039	163.753		
		Total	19	3511.789			
	Survival (untransformed)	Provenance	4	555.444	138.861	1.10	0.402
		Block	3	641.847	213.949	1.69	0.222
		Error	12	1518.215	126.518		
		Total	19	2715.506			
	Height	Provenance	4	0.838	0.209	2.28	0.121
		Block	3	1.209	0.403	4.39	0.027
		Error	12	1.103	0.093		
		Total	19	3.150			
	RCD	Provenance	4	2.333	0.583	1.92	0.172
		Block	3	3.003	1.001	3.30	0.058
		Error	12	3.646	0.304		
		Total	19	8.982			
	D30	Provenance	4	0.730	0.183	2.91	0.067
		Block	3	1.819	0.606	9.68	0.0016
		Error	12	0.752	0.063		
		Total	19	3.302			
	Stem number	Provenance	4	69921875	17480469	2.01	0.157
		Block	3	83496094	27832031	3.20	0.062
		Error	12	104296875	8691406		
		Total	19	257714844			
	Foliar biomass	Provenance	4	6.782	1.696	0.22	0.919
		Block	3	110.397	36.799	4.87	0.019
		Error	12	90.597	7.550		
		Total	19	207.776			
	Wood biomass	Provenance	4	49.481	12.373	0.27	0.889
		Block	3	689.679	229.893	5.10	0.017
		Error	12	541.345	45.112		
		Total	19	1280.514			

Appendix 3: Continued...

Age (months)	Dependent variable	Source	Df	Sum of square	Mean Square	F value	Pr>F
34	Total biomass	Provenance	4	347.265	86.816	0.44	0.779
		Block	3	3418.036	1139.345	5.75	0.011
		Error	12	2377.904	198.159		
		Total	19	6143.205			
36	Foliar N concentration	Provenance	4	0.144	0.036	1.15	0.381
		Block	3	0.552	0.184	5.89	0.010
		Error	12	0.375	0.031		
		Total	19	1.070			
	Foliar P concentration	Provenance	4	0.003	0.001	0.86	0.516
		Block	3	0.033	0.011	14.25	<0.001
		Error	12	0.009	0.001		
		Total	19	0.45			
	Foliar N content	Provenance	4	75.007	18.752	0.69	0.612
		Block	3	203.260	67.753	2.50	0.109
		Error	12	325.630	27.136		
		Total	19	603.897			
	Foliar P content	Provenance	4	0.499	0.125	1.63	0.231
		Block	3	3.755	1.252	16.32	<0.001
		Error	12	0.920	0.077		
		Total	19	5.174			
	Foliar N accumulation	Provenance	4	20143.42	5035.86	0.54	0.707
		Block	3	220159.89	733386.63	7.91	0.004
		Error	12	111279.01	9273.25		
		Total	19	351582.32			
	Foliar P accumulation	Provenance	4	123.108	30.777	0.45	0.773
		Block	3	580.290	193.430	2.81	0.085
		Error	12	825.902	68.825		
		Total	19	1529.300			
	Unit leaf mass	Provenance	4	0.036	0.009	0.53	0.718
		Block	3	0.165	0.055	3.18	0.063
		Error	12	0.208	0.017		
		Total	19	0.409			

Appendix 4: Monthly means of rainfall data (1970 - 2001) for SUA farm, in Morogoro Region, Tanzania

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall (mm)	97	101	127	200	70	26	12	10	6	24	43	103	820
Raindays (days)	8	5	12	18	9	6	3	2	2	3	5	8	82

Source: Tanzania Forestry Research Institute (TAFORI)

Appendix 5: Monthly means of rainfall data (1961 - 1978) for Kongwa Ranch in Dodoma Region, Tanzania

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

Source: Nshubemuki *et al.* (1978)

Appendix 6: Monthly means of rainfall data (1973 - 1998) for Kibaha in Coast Region, Tanzania

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall (mm)	32 9	53	131	232	145	21	10	17	11	64	67	97	1175
Raindays (days)	5	3	9	16	13	3	2	2	2	5	7	6	73

Source: TAFORI