CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the study

Agroforestry is receiving attention as an alternative land-use practice that is resource efficient and environmental friendly in Ghana (Owusu, 2002). Multiple outputs and the flexibility of having several options for management make agroforestry an attractive alternative to conventional agriculture and forestry for landowners in many parts of both the Temperate and Tropical regions of the world (Jose and Gordon, 2008).

Although design of these integrated tree-crop and /or tree-crop-livestock systems can be flexible, in order to meet the different objectives or constraints of farmers or landowners, there are many obstacles, in both ecological and economic terms, to overcome to make them attractive to landowners (Thevathasan and Gordon, 2004). Gordon and Newman, (1997) report that, the acceptability of agroforestry systems by landowners would be improved if interactions that exist between trees and crops and /or livestock remain largely beneficial so that productivity per unit area is increased while reducing environmental risks associated with monocultural systems (Jose and Gordon, 2008). However, this is not an easy task. These multistoried, multi – component systems are more complex than single-species cropping systems, and exhibit great variety in temporal and spatial ecological interactions; in fact, a number of positive and negative interactions have been postulated between different components of these systems (Jose and Gordon, 2008). Thevathasan and Gordon, (2004) report that in a biological context, the success of such a complex system will depend on minimizing the negative interactions associated with forcing crops (animals or plants) and trees to grow together spatially while enhancing the synergistic interactions between system components.

1.2 Agriculture and Forestry in Ghana

Ghana is naturally endowed with tropical forests. Forestry contributes to about 11%, whilst agriculture contributes to 38% Gross Domestic Products (GDP) (FAO, 2003). Deforestation rate is 112.54 km^2 per annum and is potentially attributed to poor agricultural practices as in slash and burn system that leads to large forest clearance for farming (FAO, 2003). The economy of Ghana is agro-based and agriculture provides employment for about 70% of the populace. About 60% practice subsistence farming (FAO, 1998). This situation has traditionally created a strong competition for land between the forestry and the agricultural sectors (Assabil, 1996). Typical examples are sighted in the Western Region where large areas of forest lands are cleared annually for agriculture.

Ghana Forestry Commission's approach to mitigating deforestation whilst making some lands available for agriculture has been reforestation employing the "Taungya System'. In this approach short rotational tree crops such as *Tectona grandis* (Teak), *Gmelina arborea* (Gmelina) and *Cedrella odorata* (Cedrella) are mostly used (Owusu, 2002). Teak plantations establishment started in the early 1960s but peaked in the early 1970s, when there was realization of the threat of serious deforestation and the inability of natural regeneration to keep up with the pace of deforestation (Assabil, 1996). Under this programme, about 120,000 ha of degraded forest lands have been put under teak plantations between the period of 1960-1972 (Forestry Department, 1995). The government of Ghana in 2001 invigorated the commitment to reforestation by providing US$ 40 million for the planting up of 20,000 hectares of degraded land per annum for ten years (Ghana Forestry Commission, 2001).

In all these reforestation programmes farmers have been involved in an intercropping system referred to as the 'Taungya System' (Owusu, 2002). Amanor (1996) reported that, the contribution of farming communities in forest development cannot be overemphasized. Whilst farmers assisted in reforesting degraded forest lands, they also benefited from two scenarios: access to land and availability of fertile soil to reduce cropping system inputs (Example fertilizer application).

According to Amanor, (1996), one of the reasons attributed to failure in most of these Taungya areas was the perceived loss of land by farmers to tree crops; as the trees grow and develop canopy, further cropping is hindered. This would usually occur between years three and five of the plantation establishment phase. This perception often led to unfortunate situation of some farmers either apparently refusing to plant up the tree crops or killing the tree crops gradually as they cultivated their crops (Owusu, 2002). Nevertheless, there have been several attempts recently to prevent this unfortunate situation. One such evolutionary measure is the ‘‘Modified Taungya System’’ (MTS) (Amanor, 1996). Under this improved system, farmers are paid for the labour (clearing, cutting of pegs and pegging; and planting). Seedlings are provided by Forestry Commission and farmers have 40% share of the final tree crop; if they assist in maintaining tree crops up to at least five years (Owusu, 2002). However improved this system is, it does not appeal so much to farmers as expected and has not induced enough impetus in farmers to participate keenly in the reforestation programmes (Amanor, 1996). This may be largely due to the long production (gestation) period of trees and the fact that farmers would have to wait for such a long time before benefiting substantially from such arrangement. Amanor, (1996) asserts that farmers would only be motivated to help manage trees when the design used to establish the tree components would promote higher productivity of their agricultural crops used in the intercropping technology.

1.2.1 Teak Plantations in Ghana

Teak in Ghana has proven to be potentially compatible tree species in this regard (Mawusime, 2005). Teak has relatively short rotation; 6 – 10 year teak can be harvested for poles, stakes, rafters etc.; teak of 10 – 15years can be used as small logs. Teak of more than 15 years can be considered for large timber logs (Mawusime, 2005). Teak wood has shown superior performance and workability successfully. It is substituting highly preferred and extinction-threatened indigenous woody species like *Millicia excelsa* (Odum), *Terminalia ivorensis* (Ofram), *Pericopsis elata* (Kokrodua), *Entandrophragma utile* (Efoobrodedwo), etc. (Amanor, 1996). Environmentally, teak has successfully acclimatized on the Ghanaian ecosystem (Assabil, 1996). Economically, teak is tremendously contributing to the economy of Ghana. Teak wood is extensively used in every part of the country and Ghana is among the key exporters of teak products to Europe, America and Asia (Mawusime, 2005). Socially, teak growing is providing employment sources for larger farming communities especially in the transition zone; from teak nurseries, planting and harvesting (Forestry Commission, 2004). This success story of teak has led to large areas of degraded forest being put under teak plantations. So far, about 100,000 ha of teak plantation have been established under the MTS (Forestry commission, 2007). In these programmes farmers were involved in most aspects of the plantation establishment phases but were 'kicked' out from the plantation sites as trees grew and their canopies closed.

Final harvesting has been undertaken in most of these plantations established earlier but no coppice management has been done in any of these plantations in Ghana. Ackah, (2005 personal communication) identifies high management costs and lack of expertise as contributing factors to the lack of management of these teak coppices. Thevathasan and

Gordon, (2004) suggest that stands raised from coppice can equally provide substantial wood source and at relatively lower cost to actual tree planting. However profitable tree coppices can be, the cost of coppice management can be very high, but Ackah, (2005 personal communication) also indicated that, the re-introduction of farmers to these harvested plantations sites for cropping can also provide relatively cheaper cost of coppice management.

According to Amanor (1996), farmers would only stay and participate fully in tree establishment and management if their preference (crops) would do well under the design being used. Ackah, (2005 personal communication) suggests teak coppice management with farmers as one potential approach to maintaining farmers on improved soil. This, he asserts, that a well planned and designed rotational wood based intercropping system would help provide fertile land for agricultural crop cultivation leading to increased and diversified farm products and at the same time present an alternatively cheaper cost for coppice management. This idea is supported by Thevathasan and Gordon, (2004). This concept, if well designed and pursued, can effectively be integrated into the rural development programmes at mitigating poverty and environmental problems through the reforestation programmes and thereby contributing to meeting the objectives of the Ghana Millennium Development Agenda.

1.3 Teak Plantations Coppice Management in Ghana

Coppice describes the many small stems that arise from dormant buds beneath the bark of a tree stump following removal of the trunk (Grove *et al* 2001). Most teak plantations in Ghana have reached clear-felling phase. No coppice management has been done in any of these finally harvested plantations, and this, is technically leaving most teak coppices to waste because stands that develop from coppice shoots have very poor quality (Thevathasan and Gordon, 2004).

Thevathasan and Gordon, (2004) asserts that, coppice stems grow at least twice faster than planted seedlings under the same growth conditions. This is explained by the fact that coppice shoots depend on already developed roots and stored food nutrients of old stump and does not use available resources for growth as in newly planted seedlings.

Owusu, (2002), recommended for the design of an intervention to keep farmers on plantation site to help manage trees and also assist farmers to have land for long period of farming as an integral rural development strategy. Ackah, (2005, personal communication), suggested that, if coppice management can be designed in an appropriate spatial and temporal sequence, it can help keep farmers on plantation sites for longer periods for continuous farming.

Mawusime, (2005) reports that, the poor soil conditions under some teak plantations may be due to poor component spatial arrangement, lack of general tree management by many teak growers and broad – leaf nature of teak that intercept rainfall and drops them heavily causing splash erosion. Teak trees incorporate about 90% of nutrients absorbed into their system back into the soil during harvesting but at a very slower pace due to slow microbial activity at decomposition. This may therefore provide the base that teak coppices can be used in a tree-based intercropping system. This hypothesis is supported by the fact that almost all teak plantations in Ghana were established through intercropping system (The Taungya system).

The kind of agricultural crops that could be effectively intercropped with teak coppices and which would be of interest to the farming communities is much needed. Lessons learnt from these successful plantation areas indicate that maize, cassava, cocoyam and plantain (staple food of the majority of the Ghanaian populace) were successfully and effectively intercropped with teak trees (Owusu, 2002). This is an indication of the probable success of effective intercropping of these crops in coppice plantations.

1.3.1 Potential of Teak Coppice Intercropping in the Brong Ahafo Region of Ghana

The Brong Ahafo Region of Ghana is in the Transition zone, separating the savanna from the forest zone. Most Teak plantations were concentrated here because of its geographic location, forest fires and the successful and quick acclimatization of the teak species (Owusu, 2002). The occupation of the larger population is farming, most of whom are into subsistence agriculture. Land scarcity, soil infertility, lack of wood and forest fires are some of the many constraints inhabitants face (Owusu, 2002).

There is a trend to set aside additional areas of indigenous forest for conservation. This is to reduce the harvest of wood from forest providing extra incentive to increase wood production on farmland. Agroforestry is one way to realize this and to potentially provide much of the nation's wood requirement in the future (Gordon and Newman, 1997).

1.4 The Study

This study was conducted to ascertain the effect of teak tree coppices spatial arrangement on the two staple food crops (Maize and Cocoyam) of three communities (Fiapre, Dumasua and Ayakomaso) in a tree based intercropping system. The study took a participatory on station approach with students and community farmers actively involved. This study aims to provide scientific basis for the choice of appropriate density per hectare and optimum number of coppices per stool for teak coppices arrangement in any tree-based intercropping system. This would eventually help determine the optimum planting distance to adopt in future planting of teak trees suitable for intercropping systems for sustainable cropping activities at a particular site. This information may also be used to maintain farmers on teak forest plantations to provide alternatively cheaper tree management cost option.

1.4.1 Research Perspective

The millennium development agenda of Ghana require that farming communities engage in sustainable agriculture which is environmentally conducive, ecologically stable and socio-economically viable. In this regard, tree-based intercropping systems remain a viable option (Thevathasan, 1998). The beneficial effects of trees in relation to soil fertility rejuvenation, productivity and nutrient cycling, and microclimate can be positively exploited, especially in the context of developing systems for both marginal and prime agricultural lands (Gordon and Newman, 1997). The success of intercropping hinges on the ability of the system components to maximize resource utilization while maintaining ‘complementary’ interactions between them (Rao, Nair, and Ong, 1997). When this occurs, productivity per unit area is often enhanced resulting in higher economic returns. When components of an intercropping system vary dramatically (e.g., woody and non-woody plants), the demand for limited resources is generally staggered in space and time, and resource capture and productivity per unit land area may be maximized (Thevathasan, 1997).

On a biological level, intercropping increases micro- and macro- faunal diversity, both above and below ground. The increased range of faunal activity gives clear indication of ecosystem 'health' within an intercropping system relative to that associated with conventional agricultural practices. From an ecological perspective, intercropping systems trap larger amounts of energy at different trophic levels, demonstrating higher energy utilization efficiency (Thevathasan, 1997). In relation to CO_2 sequestration and other greenhouse gases (e.g. N_2O) emission reductions, tree-based intercropping systems have the potential to greatly contribute to climate change mitigation (Gordon and Newman, 1998).

Farmers in the Fiapre, Dumasua and Ayakomaso communities mostly rely on the forest reserve areas for their agricultural activities mainly because of scarcity, unfavourable land tenure arrangements and poor soil fertility on private and communal lands.

1.4.2 Rationale

Forestry activities have always involved farmers in the initial tree establishment phases, but the management (Tending) phases have not always involved farmers; examples include pruning, thinning, harvesting and coppice management.

Again, coppice management in established teak plantations in Ghana is virtually non-existence. Re-introduction of farmers to harvested teak plantation areas after first rotation is to help manage the coppice whiles growing crops. This has not been practiced in Ghana.

It is against this background that this study was conducted to obtain base line information for capacity building in farmers for introduction and management of forest crops on private lands.

This work studied the above-ground effect of teak coppicing and density on two agricultural crops (maize and cocoyam). It was envisaged that, at the end of the study the optimum spacing and coppice density of teak coppices for the cultivation of maize and cocoyam in an intercrop system would be determined.

The study will provide information as basis for the incorporation of trees onto farmers' private lands. It is also envisaged that results from this study can help develop a model for managing teak coppices in forest plantations in Ghana. It will make forest lands available to landless farmers. It will contribute to the Government of Ghana's poverty reduction strategy by using Agroforestry technologies for socio – economic development in resource-poor communities.

1.4.3 Research Questions

The study sought to address the following unanswered questions in teak coppice management in Ghana:

1. What coppicing density (number of sprouts per stool) of teak coppices would promote optimum yield of cocoyam and maize in an intercrop system?
2. What spacing (planting distance between stools) of teak coppices would promote optimum yield of cocoyam and maize in an intercrop system?
3. What would be the effect of this teak coppices management and the intercropping of maize and cocoyam on soil nutrients and chemical properties (N, P, K, pH, and effective Cation Exchange Capacity (e. C. E. C) which has the tendency to influence yield of crops?

1.4.4 Hypotheses:

The study tested the following hypotheses:

The number of teak coppice shoots per stump/stool (coppice density) does not affect the yields of cocoyam and maize as sole crops or mixture in an intercropping system

The planting distance (spacing) of teak coppices does not affect yields of cocoyam and maize as sole crops or mixture in an intercropping system.

1.5 Objectives

The specific objectives were:

i. To determine the effect of teak coppice spacing on the yield of cocoyam and maize.
ii. To determine the effect of teak coppice density on the yield of cocoyam and maize.
iii. To determine the interactive effect of density and spacing of teak coppice shoots on maize and cocoyam.
iv. To determine nutrient status of soils under teak coppice forest / plantation with intercropping of cocoyam and maize.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 What is Agroforestry

Agroforestry is an integrated land use management system where trees or shrubs are deliberately cultivated on the same piece of land as crops and / or livestock (Killough *et al*, 2002). Perennials that were left over from forest or woodland may also be retained as parts of the system.

Rising human population is a serious threat to the continued use of traditional shifting cultivation practices. These are gradually failing to meet the people's food and energy needs. Efforts to increase agricultural production to overcome food shortages have brought in their wake environmental degradation: deforestation, soil erosion and soil fertility losses. Agroforestry technologies offer possible solutions to both types of problems: they improve farm production at the same time as combating environmental degradation. They are especially suited to small- scale farmers in the tropics.

2.1.1 Characteristics of trees

Certain characteristics of perennial woody plants are common considerations in any type of land-use system. For example, and rather obviously, woody perennials have lengthy actual and economic life cycles; thereby influencing investment patterns and restricting cropping system flexibility (Huxley, 1983). They are often dominated plants in plant associations in their juvenile phase, in an intercropping sense; whilst becoming dominant when mature. Compared with many common agricultural crops, seed dormancy are more prevalent and, because many woody perennial species are out-breeding, germplasm is often highly heterozygous. The permanent woody structure of trees, with dormant buds, affords a wide choice of management techniques – training, lopping, browsing, pruning-with which to modify their shape and growth patterns, and flowering and fruiting behaviour. Relatively large organs (branches, trunks and large roots) facilitate the storage of carbohydrate and nutrient reserves, thereby modifying nutrient requirements, and assisting survival during adverse environmental periods. Characteristics of trees which are generally considered to be environmentally beneficial are: a continuity of plant cover, implying amongst other things, with some species at least, an ability to utilize incoming solar radiation which might otherwise be lost by seasonally sown plants; the capacity to enrich the microsite by depositing litter in the top soil, which can then be exploited by more shallowly rooted species; and a capacity to modify the microclimate, which can bring about favourable effects on the soil and associated plants species. Offsetting these are strong plant competitive attributes, such as the capacity to shade understorey plants, and a tendency to dominate the water economy at the microsite (Huxley, 1983).

2.1.2 Experimental evidence about tree/crop mixtures

In practice, the net effect of mixing trees with herbaceous crops (or grass) will depend not only on the 'richness' of the environment, and the ways in which the various plant types can share environmental resources, but also on characteristics, partly modifiable by man, such as the geometry of the system and various temporal relationships with regard to the phenology of the separate plant components (Huxley, 1983). Two examples give the extremes. First, a temporal advantage in the tree/crop mixture is clearly shown by *Acacia albida*, a soil-enriching, leguminous tree of African savanna regions, which loses its leaves in the wet season. Associated crops of sorghum, millets, groundnuts, and so on, can thus, gain the advantages of the enriched site whilst avoiding the worst effects of competition from the tree for light and water (Felker, 1978). Second, the canopy architecture of a plot of well-spaced, mature coconut palms readily permits light penetration to lower storey crops. Hence this ligneous species is useful with a large number of other plant associations.

Except for a few clear-cut examples like those above, we have as yet very little experimental evidence on tree/crop combinations that tells us whether the species mixtures will interact with mutual inhibition, co-operatively, or through one form or another of compensation (Willey, 1979). Even if a particular tree/crop association were to be mutually inhibitory the mixture might, in practice, be encouraged by planners because of the long-term beneficial environmental effects of the tree components. However, such an association would prove even more difficult to promulgate than many agroforestry systems because of a poor productivity cost/benefit ratio during the early years.

2.1.3 Choice of agricultural crops

The agricultural crop components in any existing agroforestry system, or in any postulated one, will be largely restricted to species which satisfy existing consumer and market preferences in any particular region (Huxley, 1983). Introducing completely new food or cash crops is generally a lengthy business; an exception to this might be in relatively infertile, semiarid ecozones where agricultural cropping is not generally considered viable, yet possibilities of nutrient transfer and improved water economy exist if trees are planted and the litter and mulch materials from them are carried to adjacent strips to support agricultural crops (Nair, 1993).

2.1.4 How many trees of the chosen kind

An inherent feature of many agroforestry land use systems is the trade-off between requirements for productivity and the sustainability of the system (Huxley, 1983). Trees can impart environmental benefits to a system but often, and certainly in their early years this may be at the expense of productive outputs (Nair, 1993). If the intension is to replace some proportion of an existing agricultural cropping scheme with trees, then what sacrifice will have to be made in existing outputs? What new mixture of outputs can be expected later? What happens to the sustainability of the system during the course of time? And what exact proportion of species is needed to achieve any particular set of requirements? A precise answer to these questions can only be evaluated site-specifically.

2.1.5 How trees are to be arranged

Once the kinds and numbers of trees required have been decided upon, in relation both to the land user's objectives and resources, then the question of optimizing their spatial arrangement has to be considered. There are three main factors: management considerations, soil and water conservation aspects, and theoretical aspects of optimizing biomass and /or particular plant products.

2.2 Management Decisions

The first is whether to adopt a mixed or a zonal agroforestry system. This basic choice is an important one which will depend on both technical and social considerations. Zonal agroforestry is likely to simplify management procedures because each tree or crop component can be dealt with largely as a sole cropping enterprise within the system. According to Kang *et al*. (1981), alley cropping, a form of zonal agroforestry, is one convenient way to arrange the plants. In zonal agroforestry the extent of plant-to-plant interactions will depend on the species involved as well as the overall land unit size and the site, shape and arrangement of zones within it. Between-species interactions, as found in the more intimately associated mixed cropping systems, will occur only at the interfaces between zones. The transfer of materials (litter or mulch) can easily become part of the management procedures in zonal systems. Where there is already some information about the potential for introducing a suitable agroforestry tree species, but little or nothing is known of the interactions with agricultural crops, then a zonal system may offer a less committed, and more flexible approach, than that of more intimately mixed alternatives.

2.2.1 Soil and water conservation considerations

Information about the use of trees for soil conservation is available from various sources. Although more quantitative data are required, especially for many of the new multipurpose species which are now attracting attention. Trees can actually encourage soil erosion in some circumstances, for example, if the wrong species are used and/or they are planted in the wrong places (Wenner, 1981). Thus an important aspect of agroforestry planning must be a consideration of the spatial arrangement of trees in relation to soil and water conservation.

2.2.2 Optimizing the product

Finally, it is possible to draw on a vast body of information from a range of different plant science studies concerning the theoretical aspects of optimizing productivity through proper spatial arrangement and management of the component plant species. Because trees and shrubs lend themselves to easy modification of shape and size there will be many opportunities to manipulate the growth of trees in agroforestry systems by training, pruning and lopping (Huxley, 1983). The extensive knowledge we already possess about these procedures for existing tree crop species, both temperate and tropical, can form a useful basis from which to start. What is immediately required for all aspects of tree arrangement and management is a new synthesis of existing information.

2.2.3 Land equivalent ratio

The concept of land equivalent ratio (LER) has been developed to deal with this aspect of non-agroforestry intercropping (International Rice Research Institute, 1975; Trenbath, 1976; Willey, 1979), and it is equally applicable to agroforestry systems. Assuming equivalent levels of management, LER may be defined as the relative land area under sole crops that is required to produce the yields achieved by intercropping (Willey, 1979). When LER is experimentally assessed on the basis of uniform planting density of intercrop and sole crops, the resulting LER figure is equivalent to the relative yield total (RYT) of de Wit and Van den Bergh (1965). When intercropping gives a yield advantage, however, the total optimum intercrop density may be higher than that of either sole crop optimum (Willey, 1979). It has been suggested; therefore, that calculation of LER and other indices of yield advantage should be made on the basis of the optimum, rather than constant density in order not to distort the true practical potential of intercropping (Huxley and Maingu, 1978). In any case, the practice of intercropping is assumed to be beneficial when LER > 1, of neutral value when LER = 1, and detrimental to yields when LER < 1. LERs of as much as 1.6 have been reported for traditional farmers' fields (Norman, 1973) and up to 2.0 for experimental plots (Andrews and Kassam, 1976). The ratio should prove useful in agroforestry applications', providing some additional means is used to assess differences in duration of the production period.

2.2.4 The optimum number of trees

Supplementary product relationships should be taken advantage of by increasing production at least to the point where the products become competitive. In the case of complementary products, resources should be transferred from one product to the other as long as doing so increases the production of both (Flinn, 1979). Increasing the transfer of fixed resources (land) beyond the range of complementarity into the range of competition will decrease the production of one of the products (Huxley, 1983). How far into the competitive range it is profitable to go will depend on the relative prices of the products in general, maximum profit is obtained at the point which the rate of transfer of resources from one product to the other ($\Delta Y_2/\Delta Y_1$) is equal to the rate at which the products exchange in the market, that is the price ratio (P_1/ P_2) (Flinn, 1979). All of this follows from the fact that the rational producer will continue to transfer resources (land in this case) from one product (Y_1) to another product (Y_2) as long as the value of increased production of the one ($\Delta Y_2.P_2$) is greater than the cost in decreased production of the other ($\Delta Y_1.P_1$), that is $\Delta Y_2.P_2 > \Delta Y_1.P_1$. If the value added to the one is less than the cost of decreased production in the other ($\Delta Y_2.P_2 < \Delta Y_1.P_1$), the resources should be transferred in the opposite direction. The optimum resource allocation is reached when the value of the last increment of the one product is equal to its cost in terms of the other, that is when $\Delta Y_2.P_2 = \Delta Y_1.P_1$, or equivalently, when $\Delta Y_2/\Delta Y_1 = P_1/P_2$. This is the principle of equimarginality.

2. 3 Agroforestry Systems Component Interactions

Component interactions refer to the influence of one component of a system on the performance of the other components as well as the system as a whole (Nair, 1983). Historically, different groups of scientists have described these interactions differently. For example, in the ecological literature, the types of interactions in two-species populations have often been described on the basis of net effect of interactions, by such terms as *commensalistic* (positive, “+”, effect on species one and no observable effect, “0”, on species two), *amensalistic* (-, 0), *monopolistic, predatory* or *parasitic* (+,-), and *inhibitory*(-,-) (Hart, 1974; Trenbath, 1976; Pianka, 1988). To these, synergistic(+,+) could be added as an interaction where the net effects are positive for both species. These concepts of observable net effects can also be expressed by terms such as *Complementary, Supplementary*, and *Competitive*; they are used to describe economic interactions as well.

Agronomists and , of late, agroforestry researchers, have used the terms "below-ground" and "above-ground" as adjectives to describe interactions (mostly competitive) between components for growth factors absorbed through roots (nutrients and water), and those absorbed/intercepted through leaves (radiant energy) (Singh *et al*., 1989; Monteith *et al.*,1991; Ong *et al*.,1991). Partitioning the interactions into above- and below-ground groups provides a sound basis for studying the processes involved as well as suggesting improved management options for components and systems. However, the net effects of interactions, which are the ultimate research goals due to their practical significance, often cannot be separated into above- and below-ground effects (Nair, 1993). For example, in agroforestry systems involving animal components, it is meaningless to separate the net effects into above- and below-ground segments. Therefore, it is appropriate to consider these interactions based on their net results as positive (beneficial or production-enhancing) and negative (harmful or production decreasing) (Huxley, 1983). These positive or negative effects can be direct or indirect. For example, with respect to the herbaceous component, direct effects may result from the physical presence of the woody component in the system, which causes microclimate amelioration or nutrient additions via litter fall and root decay (Nair, 1993). Indirect effects may result from management practices connected with or necessitated by the presence of woody perennials, e.g., weeding, pruning, irrigation, or fertilization.

Since the woody perennials (trees) are important components of all agroforestry systems, these interactions can be referred to, for practical purposes, as tree-crop interactions and tree-animal interactions. From an academic point of view, these interactions can be said to present processes at the tree-crop interface (TCI) (Huxley, 1985) and tree-animal interface (TAI). Therefore, component interactions are treated as positive (beneficial) and negative (harmful) interactions that occur at the tree-crop and tree-animal interfaces. The balance between these positive and negative effects determines the overall effect of the interactions on a given agroforestry combination; an understanding of where and how interactions occur indicates possible system-modification domains that can be addressed through management activities (Nair, 1993). It needs to be emphasized, however, that such a separation of the interactions is arbitrary, because the processes are interdependent, and the manifestation of their effects will be influenced to a great extent by the environmental conditions.

Table 2.1 The major positive and negative effects at the tree-crop interface (TCI) and tree-animal interface (TAI)

At the TCI		At the TAI
Positive	- shading trees (stress reduction)	- shading
	- biomass contribution	- manure deposition
	- water conservation	
	- soil conservation	
Negative	- light competition	- phytotoxins
	- nutrient competition	- browsing damage
	- water competition	- trampling
	- allelopathy and shading	- disease/ pest hosts

Adopted from Nair, 1993.

2.3.1 Positive (production-enhancing) interactions

This is the consideration of beneficial effects of one component on another, but also the manipulation of negative effects to minimize their influence on the productivity of the overall system.

2.3.2 At the tree-crop interface

The major types of positive or complementary interactions at the tree-crop interface (TCI) are those relating to microclimate amelioration and nutrient balance. Here it is limited to the major factor, microclimate amelioration.

In agroforestry systems, microclimate amelioration involving soil moisture and soil temperature relations results primarily from the use of tree for shade, or as live supports, live fences, or windbreaks and shelterbelts. The provision of shade causes a net effect of complex interactions, which extend far beyond the mere reduction of heat and light (Willey, 1975). Temperature, humidity, and movement of air, as well as temperature and soil moisture of the soil, directly affect photosynthesis, transpiration, and the energy balance of associated crops (Rosenberg *et al*., 1983), the net effect of which may translate into increased yields.

The innumerable practices that traditional farmers have developed to attain this goal attest to the importance attributed to microclimate management (Wilken, 1972; Stigster, 1988; Reifsnyder and Darnhofer, 1989).

In general, shading causes a reduction of temperature and temperature fluctuations as well as the vapour pressure deficit (VPD) under tropical conditions. For example, comparing shaded versus open-grown coffee plantations in Mexico, Barradas and Fanjul (1986) found that, in a coffee plantation under the shade of *Inga jinicuil* (205 trees/ha; average tree height: 14 m), the average maximum temperature was 4.5^0C lower and the minimum temperature 1.5^0 C higher, and that both VPD and Piche evaporation were substantially reduced as compared to open-grown coffee. The smaller temperature fluctuations under shade were attributed to reduced radiation load on the coffee plants during the day and to reduced heat loss during the night. The lower VPD was probably caused by a higher water input through the trees' transpiration stream in combination with lower the temperatures. Similar results, indicating a buffering effect of the trees on the microclimate beneath them, were also reported for a combination of coconut and cacao India (Nair and Balakrishnan, 1977) and for an alley cropping system of millet and *Leaucaena* in India (Corlett *et al*., 1989). A reduction of VPD will cause a corresponding reduction in transpiration and, hence, less likelihood of water stress for the shaded crop (Willey, 1975; Rosenberg *et al*., 1983). This could be especially beneficial during short periods of drought and may result in production increases, as in the case of increased tea yields under shade in Tanzania during the dry season (Willey, 1975). Similarly, Neumann and Pietrowicz (1989) reported that bean plants associated with *Grevillea robusta* trees in Rwanda showed no signs of wilting in hot afternoons, whereas those grown on a field without trees did.

The presence of tree may have both positive and negative overall effects on the water budget of the soil and crops growing in between or beneath them. Examining the water content of the top 0.1 m of soil on farm in Turriaba, Costa Rica, Bronstein (1984) found higher moisture content under *Erythrina poepipigiana* than in open fields or under *Cordia alliodora* during the dry season. The light transmission through the canopy of the *Erythrina* was only 40%, while *Cordia* was leafless at that time. Therefore, the higher soil moisture under *Erithrina* may have been partly due to lower evaporative water losses as a function of lower soil temperatures. Properties of different litter layers may have also affected evaporation. Generally, a mulch or litter layer under shade trees may be seen as a one-way barrier to moisture flow, since it increases the infiltration of rain water while simultaneously reducing evaporation from soil (Wilken, 1972; Muller – Samann, 1986). However, in some situations, especially in semiarid regions, the transpiration of the shade trees may actually increase water stress to the associated crops. Soil temperature will generally be affected in the same manner as air temperature i.e., shade tends to exert a buffering effect on temperature fluctuations and extremes.

Another potentially positive interaction in agroforestry systems is related to weeds. The effect of shade is more severe for light-demanding plants than for shade-tolerant plants; this could be an avenue to suppress some light demanding weeds. A reduction of weeds due to the presence of trees has been reported from many ecological zones. For example, in alley-cropping systems in Nigeria, Yamoah *et al*. (1986) found that weed yield was positively correlated with available radiation. *Cassia (Senna siamea)* was reported to control weeds better than *Gliricidia sepium* or *Flemingia macrophylla*. This was attributed to the greater shade under *Cassia.* Similarly, Jama *et al*. (1991) attributed weed reduction under closely spaced *Leucaena* alleys in Kenya to shading. In an alley-cropping trial in Costa Rica, Rippin (1991) reported a reduction in weed biomass of over 50% in alleys of *Erythrina poepipigiana* and *Gliricidia sepium* as compared with non-alley cropped plots, although the mechanism involved was not clearly established. Szott *et al.* (1991) reported that weed suppression by pruning in alley cropping was related to mulch quality: slowly decomposing mulches such as *Inga* suppressed weeds more effectively than mulches that decomposed more rapidly.

Apart from shading, weed suppression is also determined by factors such as land-use history, weather, mulch quality and crop competitiveness.

For example, Szott *et al.* (1991) reported from studies on acid soils of the Peruvian Amazon that weed suppression was achieved in 3.5 to 4.5 years in most “managed fallow” treatments, i.e., the growing of mono-specific stands of acid-tolerant leguminous stoloniferous species such as *Centrosema macrocarpum* and *Pueraria phaseoloides* as well as leguminous trees and shrubs such as *Cajanus cajan*, *Desmodium ovalifolium*, and *Inga edulis* on abandoned shifting cultivation lands. It is important to note that weed suppression was achieved earlier in the plots with stoloniferous species. Although the mechanism of weed suppression or weed elimination is not evident in these weed-reduction studies, they clearly indicate the possibility of using agroforestry techniques in situations where weed control is a serious land-use problem, as in the vast areas of tropical humid lowlands infested with obnoxious weeds such as *Imperata cylindrica*.

2.3.3 Negative (production-decreasing) interactions

Because all members of a plant community utilize the same reserves of growth resources such as light, nutrients, water, and CO_2, negative interactions, often through competition, are likely to occur in every plant association (Etherington, 1975; Grime, 1979; Neuman, 1983). This competition can be separated into that caused by direct interference (real competition), and that caused by exploitation of shared resources which is mediated by other plants or shared predators (apparent competition).

2.3.4 At the tree- crop interface

The major yield decreasing effects at the Tree – Crop Interface (TCI) arise from competition for light, water, and nutrients, as well as from interactions via allelopathy.

2.3.5 Competition for light

Investigations on light interaction and competition in agroforestry systems are generally scarce. An additional problem is the difficulty to compare the available results because of the differences in methodologies used in the investigations. However, some insights originate from the few available studies, including some on intercropping of herbaceous species. Shading was found to be more important than below-ground competition in an intercropping study with pearl, millet and groundnut in India (Willey and Reddy, 1981). Similarly, Verinumbe and Okali (1985) showed that competition for light was a more critical factor than root competition for intercropped maize between teak trees (*Tectona grandis)* in Nigeria. In another Nigerian study, Kang et al. (1981) attributed low yields from maize rows adjacent to *Leucaena* hedgerows to shade. Neumann and Pietrowicz (1989), who studied competition in agroforestry combination of *Grevillea robusta*, maize, and beans in Rwanda, reported that the shade cast by *Grevillea* appeared more important than other effects of the trees.

While the availability of light may be the most limiting factor in many situations, particularly those with relatively fertile soils and adequate water availability, the relative importance of light will decrease in semiarid conditions as well as on sites with low fertility soils. Since crops differ in their responses to poor nutrition, competition for light or water may either be reduced or amplified by a shortage of nutrients. Generally, the shade tolerance of crop plants depends on the photosynthetic pathway and the product to be harvested. In comparison to leaf-yielding plants, fruit-and seed-yielding crops tend to be relatively shade-tolerant and should therefore be grown in open spaces where possible.

2.3.6 Competition for nutrients

There are innumerable studies indicating how competition for nutrients can reduce crop yields. In most cases, the yield of the agricultural crops is the criterion by which the merit of an agroforestry system is assessed; yield depressions of this component therefore receive more attention than those of the associated tree species. Furthermore, since the crop is usually the smaller component (when compared individually), its root system will usually be confined to soil horizons that are also available to the roots of the trees; but the tree can exploit soil volume beyond the reach of the crop. Therefore, the effect of nutrient competition will probably be more severe for the crop components. The theories and mechanisms of plant competition for nutrients have been reviewed by several workers e.g., Tilman (1990). However, direct evidence as to where, and how severely, nutrient competition occurs is limited due to difficulties of separating nutrient competition from competition for light, water, and from allelochemical interactions (Young, 1997). Additionally, soil and root studies are generally more difficult to conduct than above-ground studies.

2.3.7 Competition for Water

With the exception of areas with well-distributed rainfall, or azonal sites with a continuous supply of below-ground water, water competition is likely to occur in most agroforestry systems at some period of time; this period may be as short as a dry spell of one or two weeks. The effect of these events depends on the severity of the drought and drought tolerance of the plants. It also depends on the degree of competition for other resources, especially nutrients.

In alley-cropping trials of *Leucaena* with cowpea, castor, and sorghum under semiarid conditions in India, competition for water appeared more important than shading effects (Singh et al., 1989). Corlett *et al*. (1989), again in a semiarid study from India, reported similar results for an alley cropping mixture of *Leucaena* and millet. Examining soil moisture effects of 3.5 year-old *Eucalyptus tereticornis* on mustard and wheat yields next to the tree line in semiarid India, Malik and Sharma (1990) reported reductions of over 30% for the crops growing at a distance of less than 10 m from the tree line. Thus, despite the use of drought-adapted plants, water competition is likely to play a major role in the productivity of agroforestry systems, especially in dry areas.

2.3.8 Allelopathy

Allelopathy refers to the inhibition of growth of one plant by chemical compounds that are released into the soil from neighbouring plant (Nair, 1993). A large number of studies have been undertaken in recent years on such allelopathic interactions between plants. Although allelochemicals are reported to be present in all plant tissues, including leaves, flowers, fruits, stems, roots, rhizomes, and seeds, information on the nature of active chemicals and their mode of action is lacking. The effects of these chemicals on other plants are known to be dependent principally upon the concentration as well as the combination in which one or more of these substances is released into the environment (Putnam and Tang, 1986). There are several difficulties associated with rigorous research in allelopathy (Williamson, 1990). However, more studies are needed on these aspects in agroforestry. Given the present stage of agroforestry research, the priority should be to screen the commonly used plants in agroforestry systems for their allelopathic interactions, because it may be infeasible to explore the details of the mechanisms involved in each case.

2.3.9 Microclimate modification for pest/ diseases

The effect of plant associations on pest and disease incidence is a potentially important but rather unexplored area. Bacterial and fungal diseases may increase in shaded, more humid environments (Huxley and Greenland, 1989). For example the incidence of *Phytophthora palmivora* on cacao increases greatly under conditions of heavy shading (Alvim, 1977). The main reasons for these are probably greater relative humidity and decreased wind, both of which tend to favour fungal growth. This situation is likely to apply to other crop plants susceptible to *Phytophthora*. However, reduced temperature and humidity fluctuations under shade can also have a suppressing effect on pest and diseases. For example, these conditions tend to reduce the spread the spread of withes' broom disease (*Crinipellis perniciosa*) on cacao (Lass, 1985). It seems, then, that the balance between positive and negative effects will have to be assessed for each particular situation.

2.4 Component Management

The magnitude of interactive effects between trees and other components of agroforestry systems depends on the characteristics of the species, their planting density, and spatial arrangement and management of the trees (Huxley, 1983). Manipulating densities and arrangements is probably the most powerful method for capitalizing on beneficial effects of trees while reducing negative ones. However, in some cases, for example, when trees are used as supports for crop plants, the planting density of the trees is determined by the planting density of the crops. Therefore, in these cases, choosing wider plant spacing for trees with larger crowns may not be a valid option; under such conditions, knowledge of the light transmission characteristics of the tree crowns and of the options for tree management will become important.

Several characteristics could be identified as desirable attributes of trees in agroforestry systems; but often it is not possible to choose trees with all these characteristics, either because other plants are already established, or because production or protection goals favour the choice of other species. Whenever a tree species with all the desired characteristics is not available (which is most likely to be the case), tree crowns and roots can be manipulated through management operations, mainly by pruning and thinning. Other common management operations such as fertilization, application of mulch and manure, cut-and-carry fodder systems, and confinement or rotation of the animals can also be employed. The different manipulations can be grouped as growth-enhancing or growth-reducing according to their effect on the targeted component (Table 2)

Table 2.2 Summary of different management options to manipulate the growth of components in agroforestry systems

Management options to achieve:	
(1) Increased growth	(2) decreased growth
- Microclimate amelioration	- Pruning
- Fertilization	- Pollarding
- Application of mulch/manure	- Root pruning
- Irrigation	- Trenching
- Soil tillage	- Excessive shading
- Adapted species	- Herbicides
- Supplemental feeding	- Grazing/browsing

The goals of management practices should be to increase the production of the desired products and to decrease the growth and, hence, competition of undesired components. In many cases, one cultural treatment will accomplish both goals simultaneously, e.g., in the case of pruning trees in alley cropping and applying the biomass to the soil. While the removal of parts or the entire crown will obviously reduce the tree's competitive ability, it will automatically increase the growth of the associated intercrop by providing green manure and by allowing more light to penetrate to the crop. Below-ground competition may also be reduced as a result of pruning-induced root die-back (Cannell, 1983). These observations also apply to pruning or pollarding operations on trees grown for shade or as live supports, such as legumes of the genera *Erythrina, Inga*, or *Gliricidia*. Species such as *Erythrina berteroana*, which have large thick leaves and high rates of biomass production when grown as a shade tree, will require more intensive pruning than trees with a less dense canopy such as *Gliricidia* *sepium* (Muschler, 1991).Under conditions of severe below-ground competition, root pruning operations or trenching may eliminate, or at least strongly reduce, the negative effects of the trees on the intercrop. In an alley cropping system with *Leucaena leucocephala* in a semiarid area in India, Singh *et al*., (1989) demonstrated that the construction of a root barrier completely eliminated any yield reduction of cowpea, castor, and sorghum grown in the 10 m-wide alleys. Similar results were obtained in an alley cropping system with *Senna siamea* and *Leucaena leucocephala* in Togo, where the roots were cut biweekly to plowing depth; the growth of maize plants close to the hedgerows was less reduced than in treatments without root cutting (Schoth, 1989). However, these operations tend to be extremely labour-and cost-intensive and therefore may only be acceptable in unique settings.

2.4.1 Resource pools

For continued growth plants require continuous and balanced access to the resource pools of light, water and nutrients. Their growth responses must be adapted to the regional climate and to the behaviour of the cohabiting species (Nair, 1993). Growth implies resource use and hence a gradual diminution in the sizes of the pools. Opposing physical and chemical forces of the natural environment tend to replenish the pools although they may also, like plant growth, cause losses (Nair, 1993).

2.4.2 Light

Light is a resource that is instantaneously available and if not used immediately in the photochemical reduction of CO_2 is lost to all plants in the community. There is no storage. The resource level varies widely with both strong diurnal and, except at equatorial locations, seasonal fluctuations. Its level changes rapidly, in the order of minutes or hours, but at any location its diurnal and seasonal levels are usually highly predictable. Preferential access relies upon canopy display in which stature is the most advantageous attribute. Differential response exists and can be quantified in leaf photosynthesis versus light response functions. Efficient utilization of both high and low intensities confers competitive advantage.

2.4.3 Water

This is available to plant roots from the soil within their root zone. If it is not used immediately it remains in the soil for future use. Depending upon the soil depth and physical characteristics, the storage may be large (for example, 200mm m^{-1} depth) relative to the rate of use by even actively transpiring and growing plants for example, 8mm day^{-1}) (Huxley, 1983). The storage is not from the soil surface, and downwards to below the root zone even at no saturated water contents. Water below the root zone may become available by upward flow, when water potential gradients are appropriate, but more effectively by downward extension of the root zone. Changes in the level of soil water depend upon the pattern of rainfall but, by comparison with the hour by hour changes in the level of light, the changes are more appropriately measured in weeks. Preferential access relies upon the relative root profiles of the component species and differential volume. High root density and low root water potential both contribute favourably to this. In drying soils the resistance to flow of water to and across the soil-root surface interface increases dramatically. Consequently high root density is likely to be the more effective basis of improved access to soil water.

2.4.4 Nutrients

These, like water, are located in the soil and also, like water, are available for immediate use or may remain stored for the future. Once again, storage is not perfect with possible losses at the soil surface by volatilization and by erosion, and to depth by leaching. Additionally, nutrients may be rendered unavailable by chemical alteration. Nutrients located below the root zone can become available only by extension of the root system. In the absence of serious erosion, surface deposition or fertilization changes in overall fertility are slow, are measurable in years, and rely upon continued weathering of the parent material both within and below the root profile and the redistribution of nutrients to the upper soil layers by recycling via the litter of deeply rooted species. This resource pool is thus at any site, like light and unlike water, highly predictable. Preferential access depends upon relative profiles, principally root depth, whilst differential access is based upon more efficient absorbing power per unit rooting volume. Symbiotic nitrogen fixation, or mycorrhizal association effective in the uptake of other nutrients, provides extreme cases of differential ability in nutrient uptake.

2.5 Response to stress

The interest lies in the response of plants when confronted with suboptimal levels of one or more of the growth resources at any stage in the phonological development of their biomass or yield. Stress describes a condition of the environment that causes a reduction in the growth of plants or damage to particularly meristematic activity that leads to a subsequent reduction in the yield (Levitt, 1978). In the response to stress, the plant may or may not demonstrate changes in any of the various physiological indices, for example, water potential, nutrient content, and enzyme activity. That is it may or may not be internally affected. The extent of its adaptation to stress is measured by its growth or yield under stress relative to that in the absence of stress. According to Huxley (1983) this is an important relationship in the study of growth response of a plant under stress although, in the development of the productive systems, absolute yields under stress are likely to be more important than relative adaptability. Since the growth resources have such different characteristics it is difficult to say a great deal about the nature of resource use which is generally appropriate. There are, however, some general points relevant to agroforestry associations, which, in addition to their multispecific composition, are characterized by anatomically, and physiologically diverse plants, and are intended to persist at least tens of years. Appropriate adaptations to stress depend not only upon the severity and duration of the stress, but also upon its predictability (Huxley, 1983). Of the three resources, the most unpredictable is the level of available soil water. For light and nutrients the predictability at any site is high, although since the levels experienced by a particular component in an association depend also upon the growth of the cohabiting species, they may have an unpredictability entrained to the level of the water resource. Thus, for example, transient change in leaf area or display in the tree layer in response to water stress will alter the penetration of radiation to the lower canopy; or reduced growth in response to water stress will lower the current demand for nutrients. Conservative use of the storable resources, water and nutrients, is a well-established component of a successful adaptation for continued growth and for survival under stress. The value of this adaptation to an individual species clearly depends on the behaviour of cohabiting species.

Seasonal changes in light levels may cause a reduction in the reproductive yield of crops which is greater than the overall reduction of growth itself (Huxley, 1983). This arises because in the sequential processes that determines reproductive yield there are stages which are particularly sensitive to stress, including stress arising from low light levels. Determinate crops like wheat (Fischer, 1975) or maize (Gerakis and Papakosta-Tasopoulou, 1980) have little opportunity to compensate for stresses that operate to reduce the grain set. Fischer (1975), demonstrated experimentally the severity of shade in an attempt to explain the possible role of dull weather in the year-to-year variability in the yield of irrigated wheat in Mexico. Indeterminate crops have the potential to compensate by further flowering but the possibility of an exaggerated decrease in yield remains. Root crops may have better inherent yield stability in conditions of transient stresses, as would pasture species in which, except for the requirement of annuals to produce sufficient seed for the year survival, the major interest is in biomass production only.

Photomorphogenic and photoperiodic responses determine plant form and reproductive performance. Etiolation is a commonly observed reaction of plants growing in low light intensities and has been reported for oats and lupins grown singly in an agroforestry association with *Pinus radiata* (Anderson and Batini, 1979). Yield reduction was associated with reduced seed set but in this the relative roles of photosynthetic productivity and development responses were not separated. Extreme effects of light stress may occur if the flowering response of understorey plants in agroforestry systems is affected by shifts in light quality. It does, however, seem unlikely that these effects would dominate the response of the plants to light stress, that is, cause serious developmental problems, at least at light levels which allow acceptable levels of productivity.

2.6. Selection of agroforestry associations and their management to minimize light stress

The selection of the tree component of agroforestry associations should concentrate on those species that have high efficiency of utilization of captured radiation, so that acceptable levels of productivity can be maintained at the lowest possible levels of light capture. In this way the potential productivity of the substratum can be maximized. The trees are practically certain to be C_3 species, so the efficiency of utilization requires effective distribution of radiation over the foliage surfaces (Huxley, 1983). Trees with high leaf angles and high reflectivity will contribute to the construction of the most photosynthetically productive mixed canopy. Where tree are planted in rows east-west orientation will maximize the radiation reaching the herbaceous layer. If the trees are evergreen then they ought to be continuously productive, or replaced with deciduous trees probably at a closer spacing.

Continued productivity of the herbaceous stratum will require continued attention to the canopy of the tree layer so that by harvesting individuals, coppicing or pruning, it is possible to adjust light penetration to minimize the effects of light stress on the yield of the herbaceous component. By attention to the timing of such manipulations it should be possible to minimize the effects of light stress on the growth, development and yield of the herbaceous layer.

In selecting the herbaceous component particular care should be directed towards ensuring that the transient periods of more than usually extreme shade resulting, for example, from climate characteristics, or increases in tree leaf area, do not coincide with sensitive stages in the development of yield. In some areas it might be advisable to avoid determining crops and perhaps to choose the root or tuber crop alternative since they do appear to be less sensitive to transient severe stresses. Under deciduous trees it may be possible to devise a cropping programme in which there is no light limitation to the growth of the herbaceous component (for example, sorghum and millets associated with *Acacia albida*, El Houri Ahmed, 1980). Alternatively it may be necessary to start and/or finish the crop under shade. If there is a choice, then for determinate crops stress in the early stage is certain to have the least serious effect which, in many cases, may not be detectable in the final yield (for example Fischer, 1975).

2.6.1 Water stress in agroforestry associations

The water status, and hence metabolic activity, of the component organs of a plant-root, stem and leaves-through which water is drawn from soil to atmosphere, reflect not only the balance between the uptake by the roots, and the necessary loss from the canopy that must accompany an open pathway for the diffusion of CO_2 to the photosynthetic sites within the leaves They reflect also the resistance-capacitance characteristics of the internal pathway itself. The evaporative demand is determined by the ambient microclimate and the extent of the canopy, whilst leaf diffusion characteristics and responses determine their ability to withstand it. The root density profile determines the capacity of the plant to extract water from the soil, and the capacitance of the plant relative to the diurnal fluxes determines its ability to buffer diurnal deficits. Within agroforestry associations the potential interactions governing the relative success of the components when soil water levels are below optimum are considerable.

2.6.2 Water use

Faced with a shortage of water plants may either seek to evade the consequences of desiccation, or they may seek to tolerate them. These are the two extreme strategies of what is most likely a continuum of adaptation which is becoming well documented in the ecological, and more recently in the agronomic literature (Turner and Kramer, 1980). The appropriateness of any of adaptation must depend not only upon the severity and frequency of droughts but also upon the behaviour of cohabiting species. Thus plants which continue to transpire as soil water levels fall depend for success, in the absence of additional rainfall, on either increasing their water supply by expanding their root zone and/or by lowering their root water potential, or by completing their life cycle or current growth phase before the water supply is exhausted. By contrast, plants which begin to modulate transpiration at relatively high levels of soil water by stomatal control to reduce water loss per unit foliage area, or by reducing net radiation load through leaf movement or a real reduction in leaf area, have the potential to survive at low levels of metabolic activity for comparatively long dry periods. These plants also have the opportunity to employ diurnal patterns of stomatal activity which allow the most efficient use of transpired water.

Water stress will arise following periods when evapotranspiration exceeds rainfall but because of the nature of the association, the effect on either component may be unequal. Water stress will arise in agroforestry associations whenever there is insufficient water available to the root system of any plant component to meet the evaporative demand placed upon its canopy.

2.6.3 Canopy

The evaporative demand per unit leaf area of the tree canopy must exceed that of the herbaceous layer because, due to its position and structure, it is subjected to a higher radiation load, greater ventilation and lower vapour pressure deficits. Each of these factors works to increase the transpirational load. To offset these disadvantages a tree canopy in a mixed agroforestry system needs, in turn, to exercise greater control of water loss by any anatomical and stomatal adaptations which can increase the partition of its net radiation in favour of sensible heat and away from evaporation. The extent to which a tree canopy can affect this control, or the extent to which it can modify the disposition or extent of its leaf area to reduce it, will throw the balance of overall evaporative demand towards the herbaceous layer (Huxley, 1983). However, provided there are surfaces in the tree canopy to intercept radiation, even if they are evaporatively inactive, the demand on the herbaceous layer will be diminished.

The fact that the herbaceous layer growing in association with trees enjoys a lowered evaporative demand, and hence a potential for an improved water status, is the basis of the well-documented effect of shelterbelts of which agroforestry can seek to take advantage. The challenge is to arrange the association such that water supply to the herbaceous layer allows it to take advantage of any improved water status condition, and to overcome the serious effects of shading that will operate over at least some of the protected area. At least for strip associations, the available studies of the microclimatic and yield response to shelterbelts must afford explanation and direction to the formulation and management of agroforestry associations (Huxley, 1983).

Although there are probably trees with leaf water relationships comparable with those of herbaceous plants, on balance trees have more xeromorphic characteristics. From considerations of leaf reflectance, photosynthetic capacity, leaf diffusion characteristics and desiccation resistance tree leaves may show greater ability to control water use, and hence to persist actively in low rainfall environments.

Plant water status is not only under the control of cuticular and stomatal resistance but can also be effectively modulated by changes in the canopy display via leaf movements, or by reduction in the transpiring area itself. Whilst wilting has been interpreted (Rawson, 1979) as a positive, adaptive mechanism rather than simply a structural result of excessive water use, there are other well-documented leaf movements, especially in the leguminosae, which can reduce radiation load and which are functionally linked to leaf water status (Cruz, 1980). Modification to canopy area is probably the most effective means of reducing transpiration and this can be achieved by either a reduction in the expansion in the leaf area, or in an increased rate of senescence. The interpretation of the value of alternative adaptations to the reduction of water use in response to water stress must include a combined analysis of the efficiency of water use in producing new biomass, or in maintaining existing biomass which can remain productive for the future. In cassava, for example, water stress seriously restricts each aspect of leaf area development: apex division, leaf production per apex and leaf expansion itself.

2.6.4 Stems

Trees are distinct from herbaceous plants by the virtue of their greater investment in structural material which connects the photosynthesizing canopy to the absorbing roots. This material exists in substantial quantities both above and below ground and has important effects on their comparative water relationships (Huxley, 1983), and hence their differential response to stress of trees and herbaceous plants. Since the pathway of water transport is longer in trees than in herbaceous plants the resistance to flow also tends to be greater. Tree canopies tend to be internally drier than herbaceous canopies under similar conditions of evaporation and water uptake by the roots. Except in very tall trees (O'Connor *et al.*, 1977) the static component of 0.1 bar m^{-1} is not likely to contribute to excessively to this, but the flow related component, especially in trees in which vessel size is small, does become important. Higher internal stress and lower transpiration are the likely result of this increased resistance.

To offset this disadvantage, trees have a considerable internal water capacity, some of which may be released diurnally from the sapwood, or seasonally from the heartwood, to buffer the internal water deficits of metabolic active tissue, for example leaves and meristems. There are example of trees in which the storage capacity is enormous, for example the Australian bottle tree (*Brachychiton* spp.), baobabs and eucalypts with lignotubers (the 'mallee' group); but water reserves are important in trees of a more conventional design also.

2.6.5 Root systems

Gross differences between the root penetration of trees and associated herbaceous plants, provide for significant interaction between the water relations of associated plants and for the development of differential stresses (Cohen, 1970). By virtue of their greater root depth trees have access to soil water that is not available to the cohabiting herbaceous species. Whilst in the surface layer of the soil, to which the herbaceous component is morphologically restricted, both components may compete. The horizontal exploration by the roots of trees in the surface layers is a notable characteristic of trees, at least from water short environments (Kummerow, 1980). Canopy interception and subsequent stem flow in trees can substantially redirect water to their relative advantage. Whilst the water use characteristics of the herbaceous layer determine the penetration of non-intercepted rainfall into the subsoil from which trees have exclusive use. In many environments, trees clearly depend for their survival on water not available to the herbaceous stratum.

Models of plant water use adequate for soil water budgeting are now well developed enough to find a place in programming irrigation, optimizing sowing time of dry land crops (Fitzpatrick and Nix, 1979) and in explaining the distribution of natural vegetation. Long-term changes in the soil water profile are possible consequence of the implementation of agroforestry associations (Huxley, 1983). Short-term runs of above or below average rainfall may obscure the real stability, or otherwise, of the association.

2.6.6 Water stress and yield

Although carbon gain and water loss by plant canopies are only loosely connected, it turns out that the ratio between them – water use efficiency (WUE), or its reciprocal transpiration ratio (TR) – is sufficiently identifiable for any vegetation type to allow estimates of dry matter production from the more easy calculable water use. This analysis is improved if a separation is made the transpiration and the soil evaporation components of evapotranspiration, since the ratios best relate water loss by transpiration alone (Fischer and Turner, 1978). This technique allows for the calculation of productivity, particularly in water stressed environments, and it will provide a useful means of estimating the growth of the components and likelihood of differential stresses in agroforestry associations. It also draws attention to the possibilities that exist to exploit the inherently different water use efficiencies of the C_3, C_4 and CAM photosynthetic pathways (Ludlow, 1976; Christie, 1978).

As with trees due to light, it is once again important to emphasize that the sequential processes which determine the reproductive yield of plants are also differentially susceptible to water stress. This applies at floral initiation and around flowering and it is particularly potent in reducing seed set and hence, the potential yield. Stresses early in fruit filling are more important than those near fruit maturity in disrupting the supply of assimilate to meet the demands of this sink. A single comparatively short stress may have devastating effects on the yield of determinate crops. And also upon the fruit yield of tree species in which floral initiation occurs over a well-defined period, often the year before the fruit is filled (Begg and Turner, 1976). Indeterminate annuals have the capacity to compensate for single stresses and perhaps, root crops are best suited to withstand periodic stresses since their yield is apparently not determined by such a complex of processes and their storage organs persist to accept translocates when available.

2.6.7 Minimizing water shortage stresses

In order to minimize the effects of water stress in agroforestry associations, Huxley (1983) states that it is necessary to define, and then continue to pay attention to the levels of the storage pool available to either component relative to their water use behaviour and the differential sensitivity of the physiological processes that determine their yield. The more unpredictable is the rainfall, then the more conservative must be the management to ensure continuity of the perennial, and hence of the association. Yield stability must take second priority to this.

The most effective way to reduce transpiration, and hence reduce stress and prolong survival, is to reduce the area of the transpiring surface (Butcher, 1977). Reduction of the tree canopy will throw the evaporative balance of the community towards the herbaceous stratum which is generally dependent on upon a smaller store of water which it shares with the trees. Temporarily removing the trees/bush canopy (by coppicing) may eliminate competitive needs for water between the plant associates where these are sharing the same surface soil levels in some way. Pruning the roots of the trees will also allow the herbaceous stratum more complete control of its water resource. Reduction of the leaf area of the herbaceous stratum will not affect the immediate water balance of the trees but will favour a loss to the entire system by evaporation directly from the soil surface, and a preferential distribution of water to the trees by recharge to below the rooting depth of the herbaceous stratum. The losses to the system by soil evaporation can be considerable depending upon storm size distribution and ground cover, the latter including transpirationally inactive litter as well as transpiring leaf area.

Improved yields of annual crops in water short environments have been largely achieved by shortening the overall growing season and by sowing phenologically adapted cultivars into moist fallows when the subsequent and predictable critical stages in the development of yield are least affected (Huxley, 1983). There is little evidence that the substantial improvements in adaptation, which is in yield and yield stability, have yet included significant shifts in the physiological ability of the improved cultivars to tolerate stress. The same principles are likely to apply to the more constrained, competitive situation presented by agroforestry associations.

2.7 Nutrient stresses in agroforestry associations

One of the hopes of agroforestry is that it can capitalize upon the capacity of perennial plants to transfer nutrients from depth into upper soil layers where they are accessible to the companion shallowly rooted herbaceous plants. In this way, on one site, the system of 'shifting agriculture' is replicated in space rather than in time. As the association grows nutrients are fixed in the vegetation, especially in the perennial components. Nutrients are then removed from the site by harvesting. Whilst the pools available nutrients can be replenished by chemical conversions within the soil profile, and by accretion to the site, the nutrient content of the upper soil layer, to which the most intense root activity is restricted, will depend largely upon the external recycling system of the perennial component. From this description, it can be concluded that a successful agroforestry association will have, by nature or management, the following characteristics:

- A perennial component with a root system effective in nutrient uptake at depths below the rooting zone of the herbaceous layer.
- A highly productive perennial component with high nutrient return to the upper soil layer.
- A herbaceous component that can either compete with the perennial for nutrient enrichment in the upper soil layer, or which is managed still to take advantage of this.

Productivity will be restricted to sites in which the uptake of nutrients is less than that required by the vegetation as a whole to meet the growth potential determined by its access to the other environmental resources, that is, nutrient stress will occur (Huxley, 1985). Considering the number of plant nutrients, the intricacies of nutrient systems in vegetation and the anatomical and physiological differences between the perennial and herbaceous components of agroforestry associations it is unlikely that the same nutrient stress will be felt equally by either component (Nair, 1993). Selection of components of agroforestry associations and their management must account for issues of nutrient flow and hence productivity is to be maximized and differential stresses between the components minimized (Huxley, 1983). The characteristic feature of the nutrient resource at any site is its tendency to remain relatively constant, at least on a yearly time scale. Plants display a range of adaptations to such persistent nutrient shortages and the interest lies in what combinations of them are compatible with the objectives of agroforestry.

2.7.1 Nutrient uptake

Plants require a continuing supply of nutrients to meet the demand of growing tissues. The supply can be aided by efficient transport of nutrients from root system, by remobilization of nutrients already present in senescing tissue, that is by internal recycling, and the overall nutrient need can be minimized by genetic, environmental or management restrictions to the rate of growth (Huxley, 1983). Generally, however, unrestricted growth requires some level of continuing uptake by the root system.

Uptake at the root surface establishes a concentration gradient from the root surface to the bulk soil down which further supply diffuses to the root. If the root is also absorbing water then movement is aided by mass flow. Not all nutrients are equally mobile in soils and hence the rate at which they are replenished at the root surface differs. Of the major nutrients NO_3-N is highly mobile because it exists mainly in the solution phase, and the rate of supply is therefore critically affected by the soil water status. Phosphate-P, NH_4-N, and other cations, which are strongly associated with exchange surfaces, have limited mobility (Huxley, 1983) and rate of uptake is likely to be influenced by the time and extent of fine root extension.

Plants will compete for nutrients whenever the zones of depletion of their roots overlap and clearly this depends upon the nutrient in question, its concentration in the available pool, the rate at which this can be replenished, the soil water relationships and the nutrient uptake characteristics of the cohabiting species. Zones of depletion for mobile nutrients are wide and hence plant interaction can occur at relatively low rooting densities. By contrast for poorly mobile nutrients, with narrow zones of depletion, root systems of different plant associates may remain effectively independent to higher root densities. Whilst higher root density is relatively unimportant for the effective uptake of mobile nutrients by monocultured species (Barley, 1970), this is not necessarily true for mixtures (Trenbath, 1976). In the mutual zone of depletion nutrients will move to either species in approximate proportion to their overall root surface activity. High root surface density by one species serves to minimize its proportion of interspecific contacts. Intraspecific contacts are not competitively disadvantageous. In addition to this static description of nutrient uptake, root growth and exploration of new soil volume is an important part of the search for nutrients.

In the ecological (Mosse, 1973; Bowen, 1980) and forestry (Harley, 1970) literature, and more recently in the agronomic literature also, (for example, Khan, 1975; Hale and Armstrong, 1977; Asimi *et al*., 1980) the outstanding feature of nutrient uptake capacity is the range of symbiotic relationships with micro-organisms that plants have developed to improve nutrient uptake in nutrient-poor environments. Whilst rhizobial associations are restricted to the legumes, and these are the most important dinitrogen fixing systems, mycorrhizal associations of one type or another are almost universal in the roots of the components of natural vegetation and can be found in most agricultural crops and pastures. Mycorrhizal associations are known to increase the yield of the host plants under conditions of low fertility, and the nutrient most firmly implicated is P, although nutritional advantage with respect to N, Ca, Na, Mg, Fe, Mn, Cu, B and Al have also been recorded (Mosse, 1973). Since N and P are the important nutrients of the fertility syndrome it is important to explore the relevance of these symbiotic relationships to the development of successful agroforestry associations (Redhead, 1980).

The two types of symbiotic associations have important differences with respect to overall nutrient relationships. Rhizobial associations place at the disposal of the symbionts the enormous reserve of gaseous nitrogen which is unavailable directly to non-nodulated plants. Legumes are able to grow essentially independently of soil solution N, so that competition with non-legumes for this nutrient is not intensified by the symbiotic relationship. In fact the systems are generally quite 'leaky' so that associated non-legumes quickly benefit from raised levels of N in the soil solution.

2.8 Sociology and Social Forestry

The objective of Social forestry is to raise the standard of living of the rural dweller, to involve him in decision-making process, which affects his very existence, and to transform him into a dynamic citizen, capable of contributing to a wide range of activities than he was used to and of which he will be the direct beneficiary. Its ultimate objective is not physical but human. The physical goals, which will be set are really means towards achieving the objective of enhancing the lives of human beings. So it is the individual, whose all-round development is the goal in itself.

Since the inception of Forestry altogether a new kind of husbandry- the foresters have always treated trees as their friends at the cost of the society. Nowadays, the role of society in the forests is coming in the forefront and it seems that forestry is concerned with people as much as it is with trees.

The idea that forestry is nothing but a society-oriented activity has been clearly brought out in day-to-day life. Forestry is, therefore, incomplete if bereft of society. Society and forests are intertwined; they cannot be separated from each other. This association is there, from beginning of mankind (Vandermeer, 1989).

2.9 The basis for comparison

The problem of population density and planting design

Whatever method of evaluation, the underlying basis is always a comparison of the performance in intercrop to the performance in monoculture. The first complication arises when one must decide what monoculture production to figures should be used in the evaluation (Vandermeer, 1989).

2.9.1 Intercropping

Intercropping is the agricultural practice of cultivating two or more crops in the same space at the same time (Altieri, 1994). A practice often associated with sustainable agriculture and organic farming, intercropping is one form of polyculture, using companion planting principles. It is commonly used in tropical parts of the world and by various indigenous peoples (Altieri 1991), but in the mechanized agriculture of Europe, North America, and parts of Asia it is far less widespread. Intercropping may benefit crop yield or control of some kind of pest, or may have other agronomic benefits.

2.9.2 Intercropping Design

In intercropping, there is often one main crop and one or more added crops, with the main crop being the one of primary importance because of economic or food production reasons. The two or more crops used in an intercrop may be from different species and different plant families, or they may simply be different varieties or cultivars of the same crop species, such as mixing two kinds of wheat seed in the same field.

The most common goal of intercropping is to produce a greater yield on a given piece of land by making use of resources that would otherwise not be utilized by a single crop. Careful planning is required, taking into account the soil, climate, crops, and varieties. It is particularly important not to have crops competing with each other for physical space, nutrients, water, or sunlight. Examples of intercropping strategies are planting a deep-rooted crop with a shallow-rooted crop, or planting a tall crop with a shorter crop that requires partial shade.

When crops are carefully selected, other agronomic benefits are also achieved. Lodging-prone plants (those that are prone to tip over in wind or heavy rain) may be given structural support by their companion crop (Trenbath, 1976). Delicate or light sensitive plants may be given shade or protection, or otherwise wasted space can be utilized. An example is the tropical multi-tier system where coconut occupies the upper tier, banana the middle tier, and pineapple, ginger, or leguminous fodder, medicinal or aromatic plants occupy the lowest tier.

Intercropping of compatible plants also encourages biodiversity, by providing a habitat for a variety of insects and soil organisms that would not be present in a single crop environment. This biodiversity can in turn help to limit outbreaks of crop pests (Altieri, 1994) by increasing the diversity or abundance of natural enemies, such as spiders or parasitic wasps. Increasing the complexity of the crop environment through intercropping also limits the places where pests can find optimal foraging or reproductive conditions.

2.9.3 Intercropping types

The degree of spatial and temporal overlap in the two crops can vary somewhat, but both requirements must be met for a cropping system to be an intercrop. Numerous types of intercropping, all of which vary the temporal and spatial mixture to some degree, have been identified (Andrews and Kassam 1976). These are some of the more significant types:

Mixed intercropping, as the name implies, is the most basic form in which the component crops are totally mixed in the available space.

Row cropping involves the component crops arranged in alternate rows. This may also be called alley cropping. A variation of row cropping is strip cropping, where multiple rows (or a strip) of one crop are alternated with multiple rows of another crop.

Intercropping also uses the practice of sowing a fast growing crop with a slow growing crop, so that the fast growing crop is harvested before the slow growing crop starts to mature. This obviously involves some temporal separation of the two crops.

Further temporal separation is found in relay cropping, where the second crop is sown during the growth (often near the onset of reproductive development or fruiting) of the first crop, so that the first crop is harvested to make room for the full development of the second.

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CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

The Study was conducted in the Tain II Forest Reserve teak plantation. Tain II plantation lies between latitude $4^0$5' N and latitude 27^0 8' N. The vegetation is Dry semi-deciduous fire-zone forest type. The forest has *Chlorophora – Antiaris* association (Hall and Swaine, 1981).

The Soil is classified as alfisol, according to USAID classification system. The experimental plots were laid in compartments 263, 279 and 299. Tain II Forest Reserve is located 2 km off the Sunyani – Berekum /Dormaa trunk road near Ayakomaso community, which is also 15 km from Sunyani. The mean annual rainfall ranges between

800 – 1000 mm.

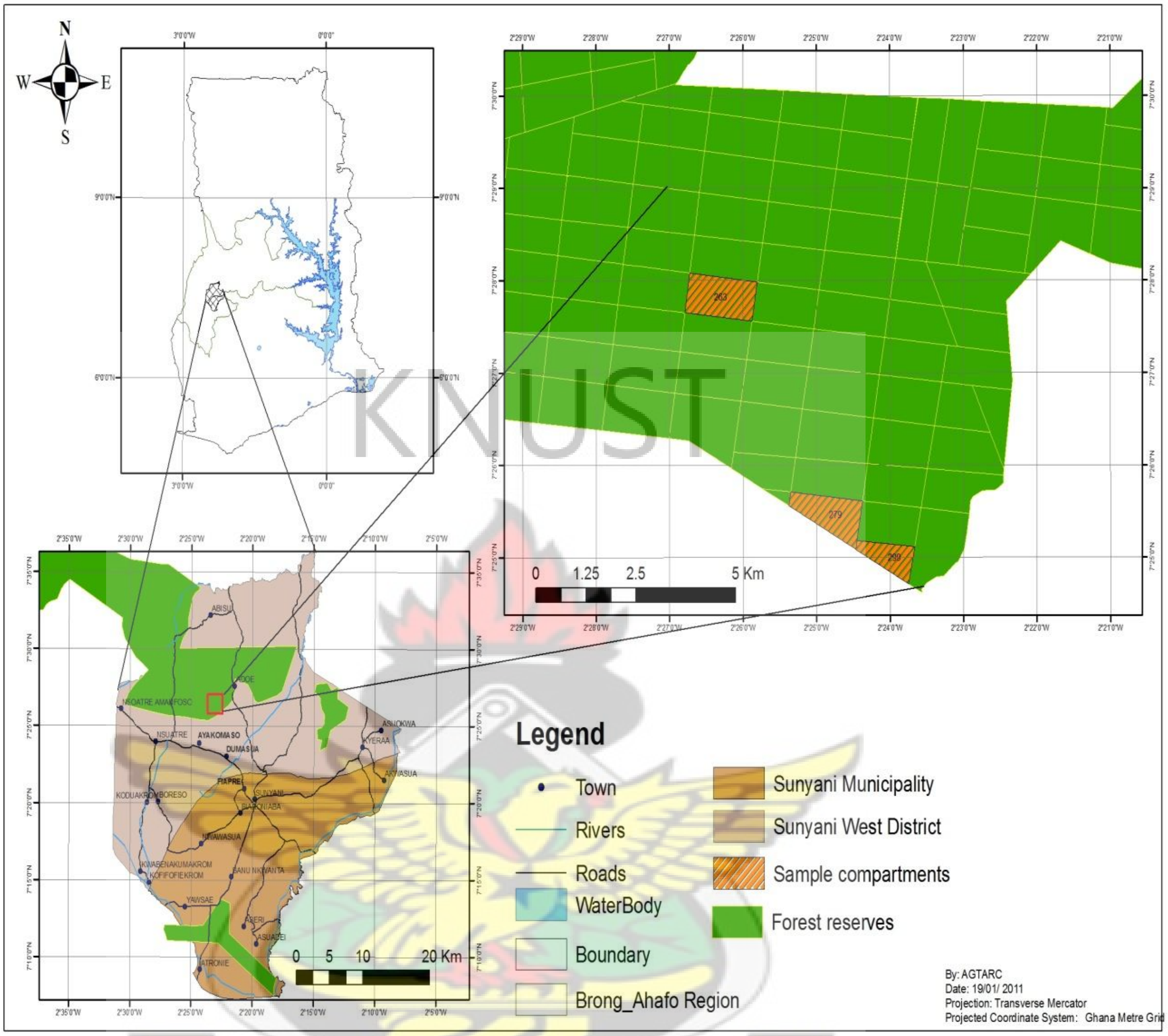


Figure 3.1 Map of Study Area (Tain II Forest Reserve)

3.2 Research Methods

3.3 Site (Compartments) Selection

All compartment numbers of the Tain II teak plantation were written on pieces of paper. These papers were folded mixed. Three compartments (263, 279 and 299) were randomly selected to form three blocks.

3.3.1 Site Preparation

The site was clear-felled of all teak trees. Teak trees had been planted at spacing of 3 m by 3 m. Harvesting was done in the dry season (January).

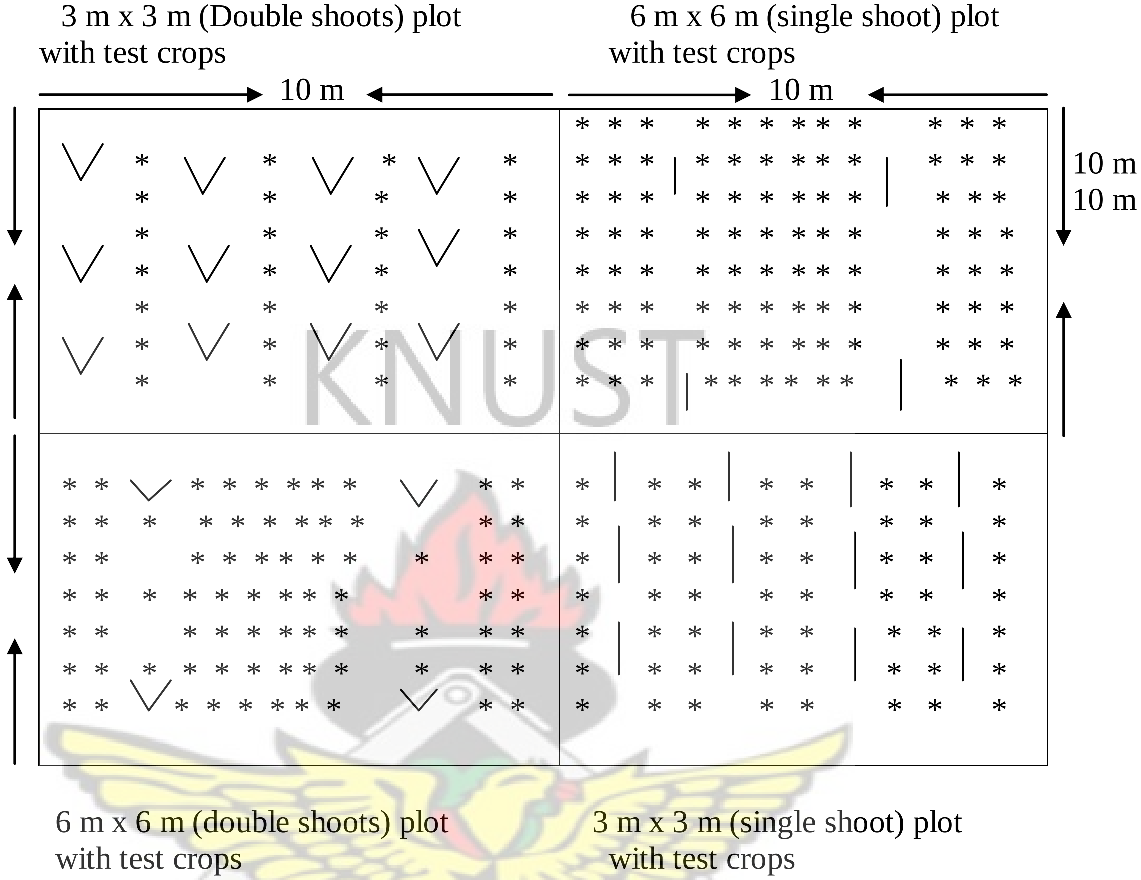
3.4 Design

One hectare plot was demarcated in each of the three compartments.

Twelve 10 m x 10 m plots were demarcated in each block (compartment). Factorial Experiment in Randomized Complete Block Design was used.

There were five treatment combinations and three replications.

Plot Design on the Field



Control Plot (No teak stem, only agricultural crops (cocoyam and maize))

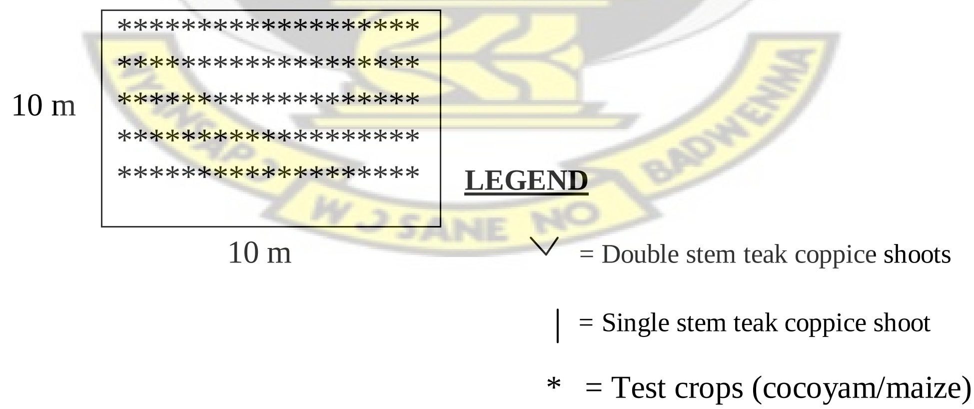


Figure 3.2 Schematic representations of randomized plot treatments in a block.

This was repeated for the two test crops (maize and cocoyam) and the mixture of the two (cocoyam / maize mix) for three experimental blocks; and they were replicated in the three compartments as blocks.

TREATMENT FACTORS

FACTOR A = Coppice density (number of coppice shoots per stump of teak).

FACTOR B = Spacing (planting distance of teak coppice shoots)

TREATMENT COMBINATIONS

T_1= 3 m x 3 m plot with single coppice shoot.

T_2 = 3 m x 3 m plot with double coppice shoots.

T_3 = 6 m x 6 m plot with single coppice shoot.

T_4 = 6 m x 6 m plot with double coppice shoots.

T_5 = Control = No sprouts / coppice shoots.

	FACTOR A	
FACTOR B	Single shoot (A_1)	Double shoots (A_2)
3 m x 3 m (B_1)	A_1B_1	A_2B_1
6 m x 6 m (B_2)	A_1B_2	A_2B_2

3 m x3 m with single coppice shoot (T_1)	3 m x3 m with double coppice shoot (T_2)
6 m x 6 m with single coppice shoot (T_3)	6 m x 6 m with double coppice shoots (T_4)

3.5 Experimental plot layout (randomized)

BLOCK 1

T2 (A2B1)	T3 (A1B1)
T4 (A2B2)	T1 (A1B2)

CONTROL

(No Teak Coppice shoots)

BLOCK 2

T3 (A1B2)	T1 (A1B1)
T2 (A2B2)	T4 (A2B1)

CONTROL

(No Teak Coppice shoots)

BLOCK 3

T4 (A2B2)	T2 (A2B1)
T1 (A1B1)	T3 (A1B2)

CONTROL

(No Teak Coppice shoots)

PLATE 3.1. Teak Coppice shoots suppression at the study site

PLATE 3. 2. 3 m x 3 m teak spacing with single stem maize plot

PLATE 3.3. Maize/cocoyam mix plot

PLATE 3.4. 3 m x 3 m teak spacing with single stem cocoyam plot

3.6 Planting of Agricultural (Test) crops

Maize

The maize ('Obaatanpa' variety) planting stock was obtained from the Brong Ahafo Regional MoFA Directorate. They were air – dried for three days. They were later sieved and cleaned. Four seeds of the planting material were put in each planting hole aligned in between the teak coppice stumps (shoots). Thinning of the maize plants was done after two weeks (14 days) of germination to 3 plants per hole. The planting holes of the maize were arranged zonally as advised by the Brong Ahafo MoFA Directorate to ensure full stocking of the available spaces. The planting distance was 0.45 m in between rows and 0.90 m within rows. The maize plant population was therefore 74,075 plants/ha.

Cocoyam

Cocoyam planting stocks (corms) were obtained from Crops Research Institute (CRI) in Kumasi. In all 200 corms were purchased. Each corm was divided into two setts and air dried for three days.

Each planting hole contained one sett. One cocoyam sett per hole was maintained throughout the whole experiment in all cocoyam trials. The corms were planted 1 m x 1 m in between corms and along rows.

Maize and Cocoyam mix

The maize and the cocoyam were alternated in rows and in zonal arrangement but planting techniques were the same as were done in the single trials.

3.7 Cultural Practices

3.7.1 Coppice shoots removal (coppice suppression)

One plot was established in each of the three Blocks to serve as control. No coppicing treatment was administered to components in these plots.

With the spacing (density), since the plantation was established at 3 m by 3 m, it implies that for 3 m by 3 m spacing treatment the coppice were managed as the stools are; but with 6 m by 6 m spacing, at intervals of 3 m coppice shoots on stumps were completely cut off and stem terminated.

Coppice shoots were removed as they sprout when necessary in each plot. These sprouts removed were used to spread beneath the crops as mulch. Green manuring was not considered.

Pruning

For the teak coppice shoots which were left, the leaves were removed to a standard four leaves per shoot. This was to check excessive shading on the test crops. The prunings were also used as mulching materials.

Weeding

Weeding was done twice within the cropping season as compared to three or four times by the farmers in the District in normal farming practice.

3.8 Data collection

3.8.1 Harvesting of Test Crops

Maize

Dry cobs of the maize in all maize plots and in maize/cocoyam mix plots were all harvested the same day after 4 months with the help of technicians, students and some framers in the 10 m x 10 m plots. Dry grains from each plot were removed from the cobs the following day and air-dried for 14 days. All maize grains from each plot were weighed after 14 days of air-drying with scale balance.

Cocoyam

Fresh cocoyam cormels from each cocoyam plot and cocoyam/maize mix plots were harvested the same after 12months of cultivation.

3.8.2 Weighing of Samples

Maize

Samples of maize were weighed using the CAMRY Weighing Scale (ANASCO SCALES). An empty sack was weighed to determined initial weight. The total weight of the sample and the sack was also taken. The weight of the maize sample was derived by subtracting the initial weight from the total weight.

Y = weight of maize sample
X = initial weight of sack
K = total weight of sack and sample
Y= K–X.

Cocoyam

Samples of cocoyam were weighed using the CAMRY Weighing Scale (ANASCO SCALES). The cocoyam samples were washed and dried in a basin. An empty sack was weighed to determine initial weight. The total weight of the sample and the sack was also taken. The weight of the cocoyam sample was derived by subtracting the initial weight from the total weight. Weights were recorded in kg/100 m^2

Y = weight of cocoyam sample (kg/100m^2)

X = initial weight of sack

K = total weight of sack and sample

$$Y = K - X.$$

3.9 Standardization of Measuring Units

3.9.1 Standard Computation

For the purpose of standardization, all units were converted from kg/100 m^2 to tons/ha. Yields from 100 m^2 plots were converted to yields per hectare (ton/ha) by multiplying by a conversion factor (CF) of 100 as shown below. This was used for both agricultural crops.

X = yield per 1ha

Y = yield in 10 m x 10 m plot (0.01ha)

P = area of plot (10 m x 10 m)

K = area of standard 1ha plot (100 m x 100 m)

$$X = K/P \times Y = KY/P$$

$$X = 10{,}000/100 \times Y \Longrightarrow X = 100Y$$

3.9.2 Method of Soil Sample Collection

Soil sample collection in the control plot adjacent to the plantation area and with the same size as the treatment plots was done and labeled as control. Soil samples in the experimental area just before planting of crops were collected and labeled as ''Initial Soil''. Soil samples in the cropped area were collected at the end of food crop harvesting and labeled as "soil status".

In each sample plot, at three spots (3 m apart), soil samples were collected to 30 m depth (Amanor, 1996) by the use of the soil auger. The samples were bulked together in each plot as composite sample and conveyed into 20 cm poly bags for testing. The soil samples were sent to Soil Research Institute, Kwadaso in Kumasi for analysis.

3.9.3 Soil Analysis

Soil samples collected were tested for minerals nutrients and chemical properties (Nitrogen, Potassium, Phosphorus, pH, and effective Cation Exchange Capacity and Base saturation) present and their relative variations after the study.

Soil pH Determination

Twenty grams of soil were mixed with 50 ml distilled water and stirred at intervals for 30 minutes. The pH of the suspension was then measured with a pH meter.

Soil nitrogen (N)

Percent total N was determined by micro – kjeldahl digestion method. One gram (1g) each of the soil samples was digested in conc. H_2SO_4 using Selenium catalyst. The compound formed was then titrated with 0.02 NHCl.

Cation Exchange Capacity

This was determined by the sum of the exchangeable bases (Ca, Mg, K, Na) and exchangeable Al and H expressed in cmolc/kg (equivalent to meg/100 g).

$$CEC=TEB + EA$$

Exchangeable Acidity

Exchangeable acidity (Al + H) was obtained by treating 10g of soil with 100 ml of 1MKCl. The solution was shaken intermittently for one hour, centrifuged for 10 minutes and the solution filtered. Fifty ml of the filtrate was titrated with 0.05N NaOH using phenolphthalein indicator.

Available Phosphorus and Potassium

The available Phosphorus (P) and Potassium (K) were measured by putting 10g of the soil samples into 50 ml Bray No.1 solution in stopper bottles. The suspension was shaken for 10 minutes and filtered. A colour reagent and ascorbic acid powder were then added and the filtrate allowed to stand for 15 minutes. The level of phosphorus (P) was determined calori-metrically from the absorbance on a spectrophotometer at 660 mu wavelength. The level of potassium (K) was determined by measuring the emissions from a flame photometer. The concentrations of P and K (ppm) were then obtained by extrapolation from standard P and K curves.

3.10 Data Analysis

Data were analyzed using GenSTAT 2008 software. Results are presented in tables and graphs.

CHAPTER FOUR

4.0 RESULTS

4.1 Effect of spacing (planting distance) of teak coppice shoots on the yield of cocoyam in cocoyam crop trial.

Mean yield of cocoyam in the experiment decreased with increasing density of teak coppice shoots. The highest mean yield was recorded in the No sprout (control) treatment plot. The 3 m x 3 m density treatment recorded the lowest mean yield (6.1tons/ha) Fig 4.1.

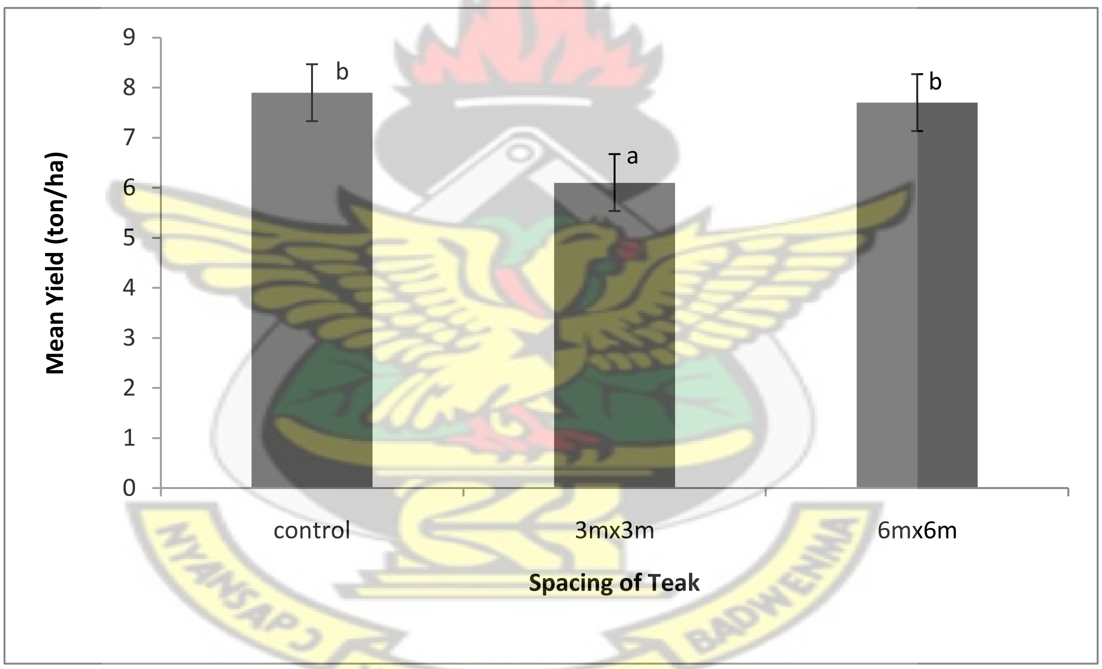


Figure 4.1 Yield of cocoyam (tons/ha) in cocoyam trial planted under different spacings of teak. Means of same letters are not significantly different at 5% level of significance according to DMRT.

Analysis of variance indicated that density of teak coppice shoots had significant effect on the yield of cocoyam in the cocoyam trial. Duncan's multiple range test showed the means of 6 m x 6 m spacing (7.9 tons/ha) and control (no coppice shoots 8.0 tons/ha) of teak were significantly higher than the mean of 3 m x 3 m spacing trial (6.1 tons/ha). The control treatment mean (8.0 tons/ha) was not significantly different from the 6 m x 6 m spacing treatment mean (7.9 tons/ha). This results indicate that cocoyam will do better under 6 m x 6 m planting distances of teak coppice shoots than 3 m x 3 m planting distances of teak in the intercropping of cocoyam in teak coppice management in the Tain II forest plantations.

4.2 Effect of teak coppice density (number of coppice shoots per stump) on the yield of cocoyam.

There was decreasing mean yield of cocoyam with increasing coppice density of teak in this experiment. The highest mean yield (7.8 tons/ha) was recorded at single stem density trial. The double stem recorded the lowest mean yield (6.8 tons/ha). The number of coppice teak had significant effect on the yield of cocoyam in the cocoyam trial (Fig 4. 2).

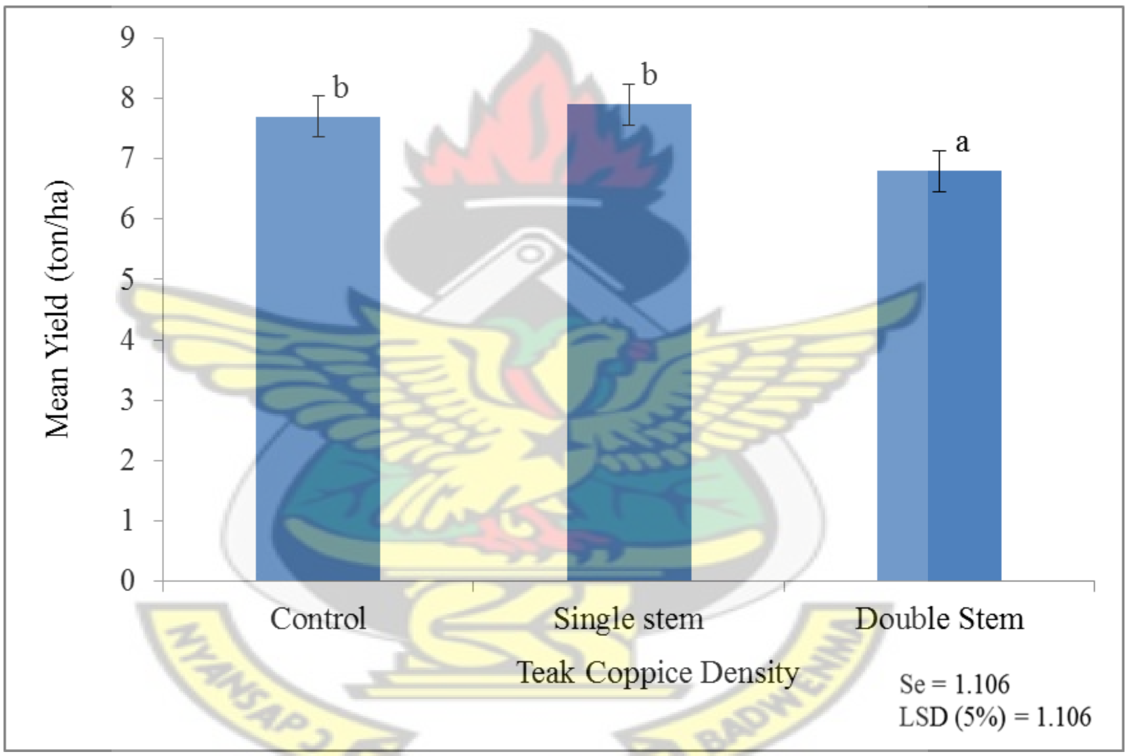


Figure 4.2 Yield of cocoyam (tons/ha) planted under different teak coppice densities.

Means of same letters are not significantly different at 5% level of significance according to DMRT.

Duncan's multiple range test revealed that the double stem treatment mean (6.7 tons/ha) was significantly lower than the single stem treatment mean (8.0 tons/ha) and the control density treatment mean (7.8 tons/ha); but there was no siginificant difference between the single stem treatment and the control density treatment means. Cocoyam yield was better under single stem coppice density than the double stem coppice density treatment. This is an indication that in intercropping cocoyam under teak coppice management require maintaining only one coppice shoot per teak stump probably to avoid shading.

4. 3 Density and spacing of teak coppices on the yield of cocoyam.

An increase in the yield of cocoyam was obtained in low density and spacing of teak as shown in figure 4.3. The highest mean yield (10.1 tons / ha) was recorded in the control and no coppice shoots (control) treatment combination whiles the lowest mean yield (5.7, 5.9 tons/ha) was recorded in the 3 m x 3 m and 6 m x 6 m, respectively with double stem coppice shoots. The highest mean yield (7.8 tons/ha) was recorded in the 6 m x 6 m density with single stem coppice shoot and least for double stem in the 3 m x 3 m.

Duncan's multiple range text indicated no significant difference among double stem coppicing in the 3 m x 3 m spacing and double stem density in the 6 m x 6 density.

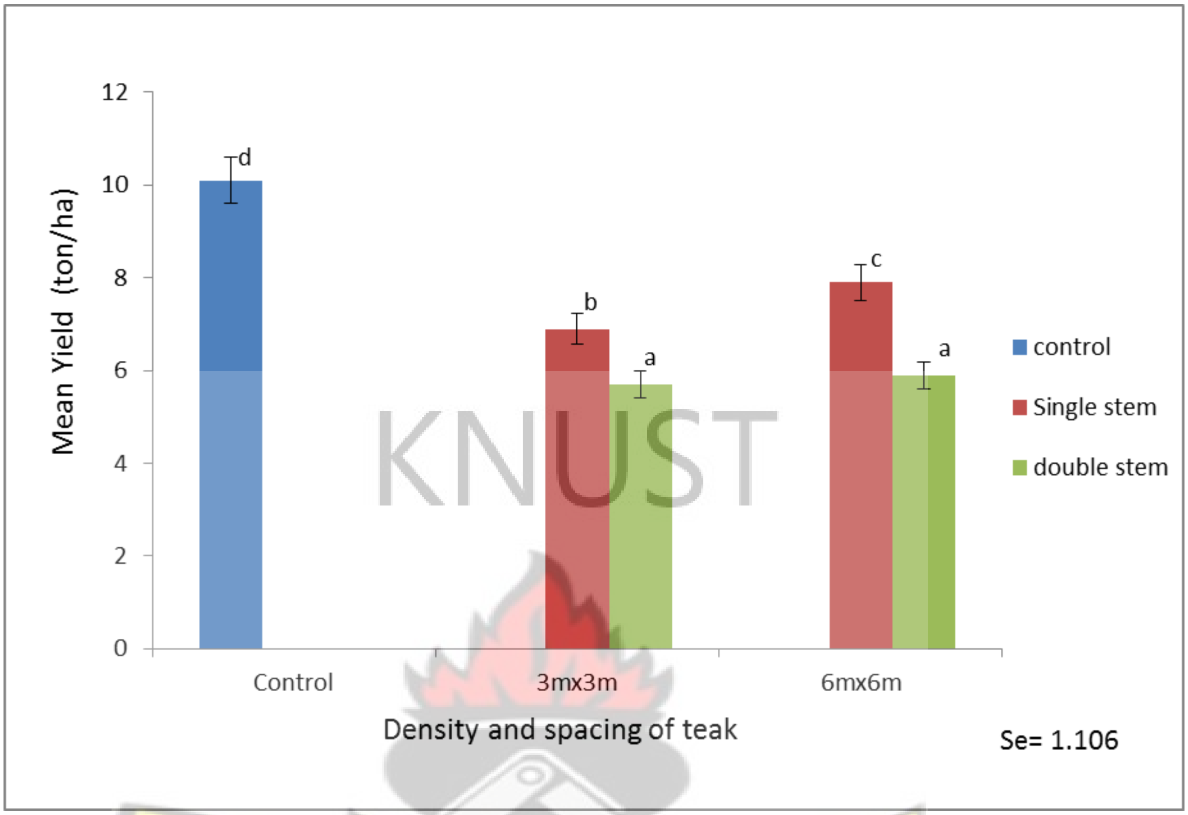


Figure 4.3 Yield of cocoyam (tons/ha) planted under different number of teak coppice shoots and at different planting distances (densities).

Means of same letters showed no significant difference at 5% level of significance according to DMRT.

Since 6 m x 6 m density with single stem coppicing gave the second highest yield of cocoyam after the control (no teak coppice shoots) intercropping of cocoyam under teak coppice shoots should follow the design of 6 m x 6 m planting distance with single stem coppice shoots.

4.4 Effect of teak spacing on the yield of cocoyam in cocoyam and maize mix.

The yield of cocoyam in a mixed cocoyam/maize trial increased with decreasing density of teak coppice shoots. The highest mean yield (4.8 tons/ha) was recorded in the Control treatment and the 3 m x 3 m and 6 m x 6 m density treatments recording 3.9 tons/ha each. However, Control treatment mean (4.80 tons/ha) was significantly higher than 3 m x 3 m (3.9 tons/ha) and 6 m x 6 m (3.9 tons/ha) treatment means. No significant difference was observed between the 3 m x 3 m and 6 m x 6 m treatment means (figure 4.4).

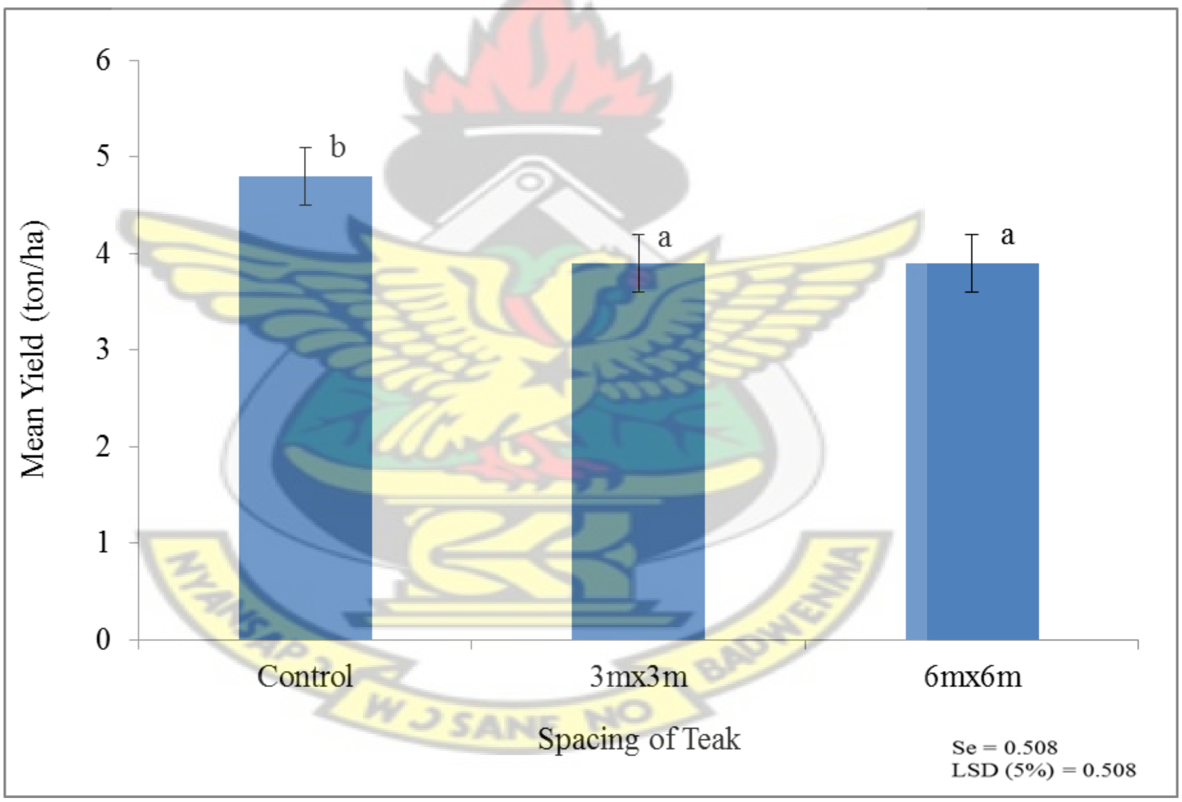


Figure 4.4 Yield of cocoyam (tons/ha) planted under different planting distances (spacing) in a cocoyam/maize mix. Means of same letters showed no significant difference at 5% level of significance according to DMRT.

In the intercropping of mixed cocoyam and maize under teak coppice management, cocoyam yields would be better under planting distance of 6 m x 6 m than 3 m x 3 m of teak coppice shoots. However, comparing figures 4.2 and 4.4, cocoyam yield is far superior if planted alone and not in mixture with maize.

4.5 Effect of number of teak coppice density on the yield of cocoyam in a cocoyam maize mix.

There was decreasing mean yield of cocoyam with increasing coppices of teak in the cocoyam/maize (figure 4.5). The highest mean yield (4.6 tons/ha) was recorded in the control (no stem coppicing) treatment with the double stem coppice shoots treatment recording the lowest mean yield (3.8 tons/ha). Analysis of variance test shows that coppicing of teak had significant effect on the mean yield of cocoyam in the cocoyam/maize mix trial. The double stem coppicing treatment mean (3.8 tons/ha) was significantly lower than single stem (4.3 tons/ha) and the control (4.6 tons/ha) coppicing treatment means. However, no significant difference was observed between single stem coppice shoots and the control treatment. Cocoyam does better in a cocoyam/maize mix under single stem teak coppice shoot than double stem teak coppice shoots.

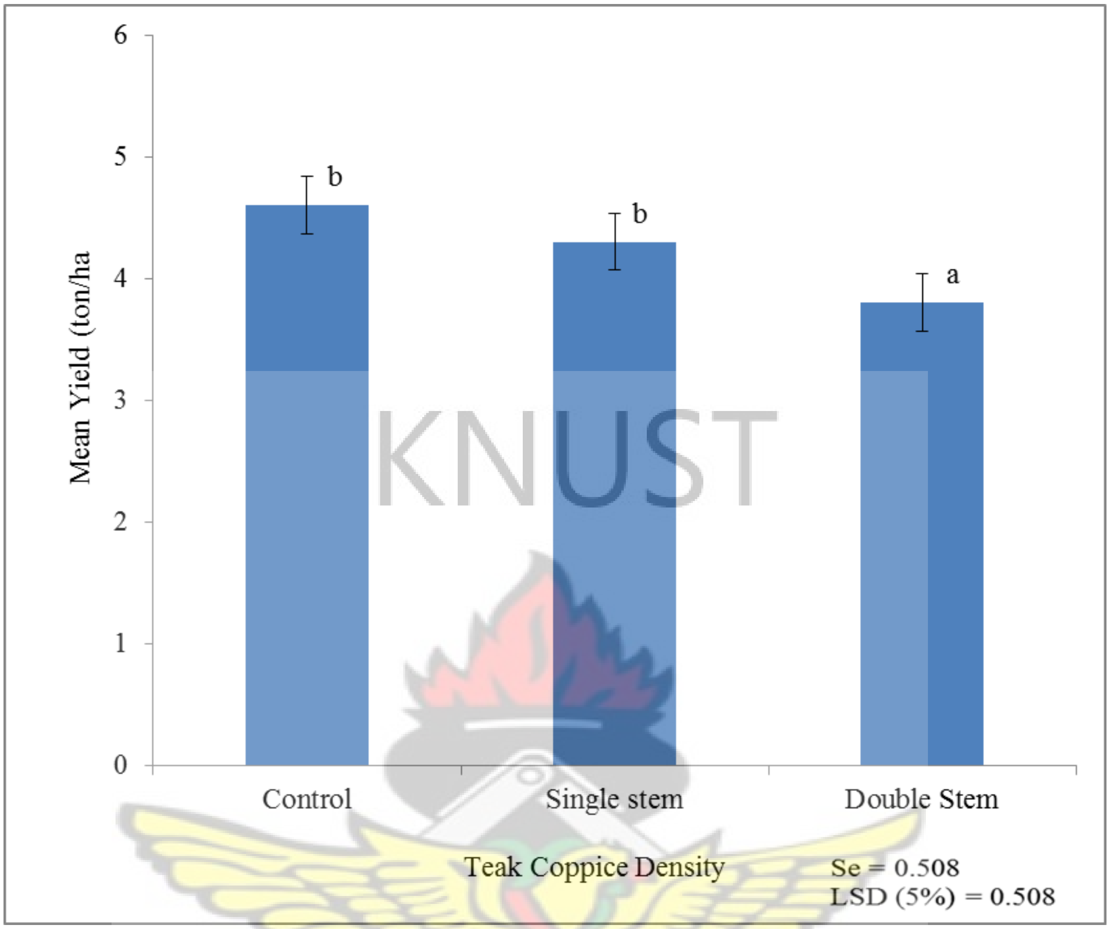


Figure 4.5 Yield of cocoyam (ton/ha) planted under different teak coppice densities in cocoyam/maize mix.

Means of same letters showed no significant difference at 5% level of significance according to DMRT.

4.6 Effect of spacing (planting distance) and coppice density (number of coppice shoots) of teak on the yield of cocoyam in a cocoyam/maize mix.

Increasing coppice density and reducing spacing of teak resulted in decreasing mean yield of cocoyam. It was observed that the Control (no stem treatment) recorded the highest mean yield of cocoyam (5.2 tons/ha) while double stem coppice and 3 m x 3 m spacing recorded the lowest mean yield (3.3 tons/ha). Analysis of variance test showed that spacing and coppice density of teak had significant effect on the yield of cocoyam in the cocoyam/maize mix trial. Duncan's multiple range test revealed that the control (no stem) mean was significantly highest among 3 m x 3 m and single and double stem treatment means; and 6 m x 6 m single and double means. Also 3 m x 3 msingle stem; and 6 m x 6 m single stems were not significantly different. However, 6 m x 6 m spacing and single stem was not significantly different from all the other treatment means except the control.

This result indicates that yield of cocoyam in cocoyam/maize mix will best under 6 m x 6 m spacing with single stem. This is because it recorded the next highest mean yield (4.2 tons/ha) after the control.

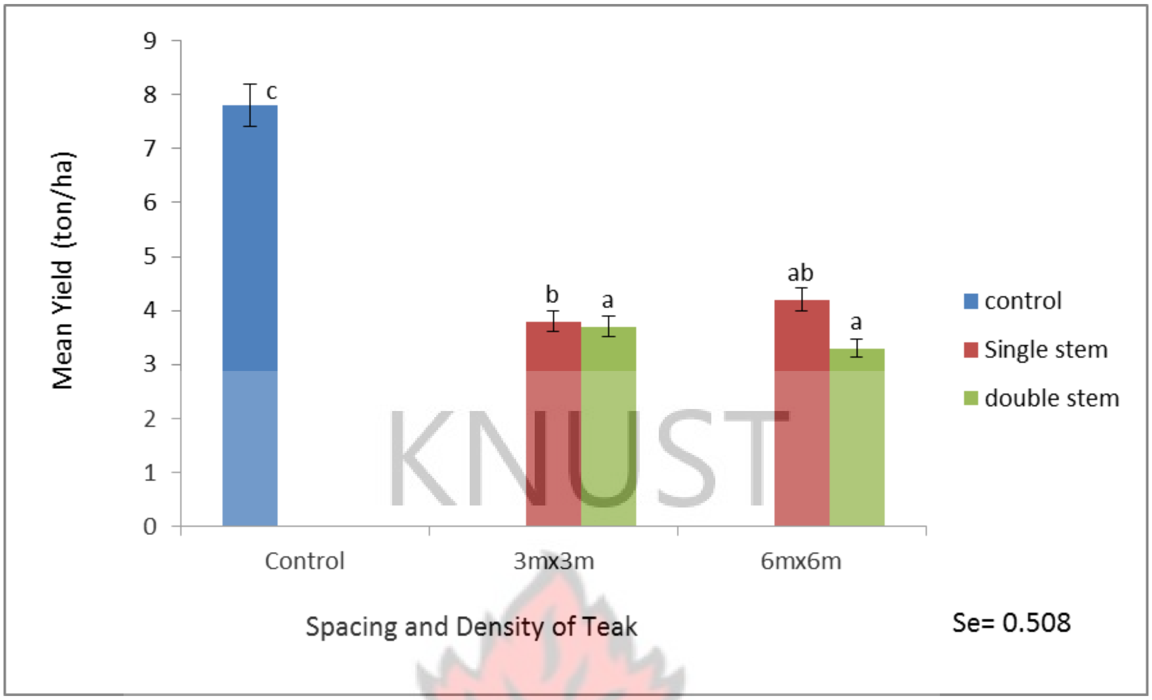


Figure 4.6 Yield of cocoyam (ton/ha) planted under different planting distances and different number of teak coppice shoots.

Means of same letters are not significantly different at 5% level of significance according to DMRT.

4.7 Effect of spacing (planting distance) of teak on the yield of maize.

Decreasing density of teak coppices resulted in decreasing mean yield of maize (Fig. 4.7). The highest mean yield of maize (4.54 tons/ha) was recorded in the control (no sprout) spacing treatment. The 3 m x 3 m spacing treatment recorded the lowest mean yield (2.9 tons/ha). Analysis of variance test indicates that spacing of teak coppices had significant effect on the mean yield of maize in the sole maize trial. Duncan's multiple range test showed that the Control mean (4.54 tons/ha) was significantly higher than 3 m x 3 m (2.89 tons/ha) and 6 m x 6 m (3.34 tons/ha) spacing means. No significant difference was observed between the 3 m x 3 m and 6 m x 6 m spacing means.

The result obtained indicates that yield of maize under 6 m x 6 m and 3 m x 3 m spacing trials performed good against each treatment. However, since the yield under 6m x 6m was higher, maize will do well under such treatment.

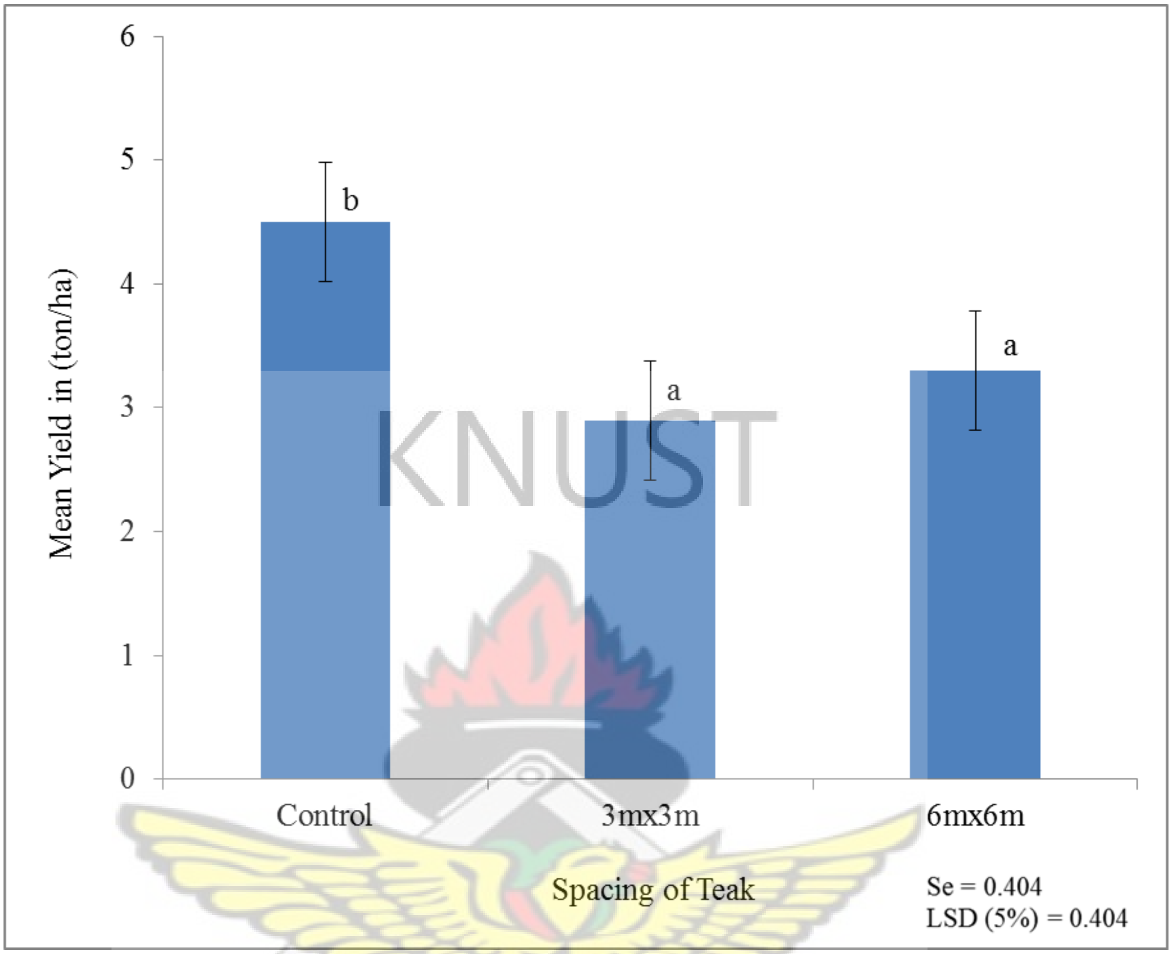


Figure 4.7 Yield of maize (ton/ha) planted among different planting distances (densities) of teak coppices.

Means of same letters are not significantly different at 5% level of significance according to DMRT.

4.8 Effect of coppicing (number of coppice shoots) of teak on the yield of maize

Increasing number of teak coppice shoots resulted in decreasing yield of maize (Fig. 4.8). The highest mean yield (4.60 tons/ha) was recorded in the Control coppicing treatment with the double stem coppicing treatment recording the lowest mean yield (2.80 tons/ha). Analysis of variance test showed that the number of teak coppice shoots (coppicing) had significant effect on the mean yield of maize in the maize trial.Duncan's multiple range testrevealed that Control coppicing treatment mean (4.56 tons/ha) was significantly higherthan Single stem (3.39 tons/ha) and Double stem (2.82 tons/ha) coppicing Treatment means.No significant difference was observed between the Single stem and Double stem coppicing treatment means. Result obtained shows that double stem and single stem teak coppice shoots had fairly similar effect on the yield of maize. However, since the single stem coppice shoot treatment recorded higher yield it implies maize will do better under this design than the double stem coppice shoots treatment.

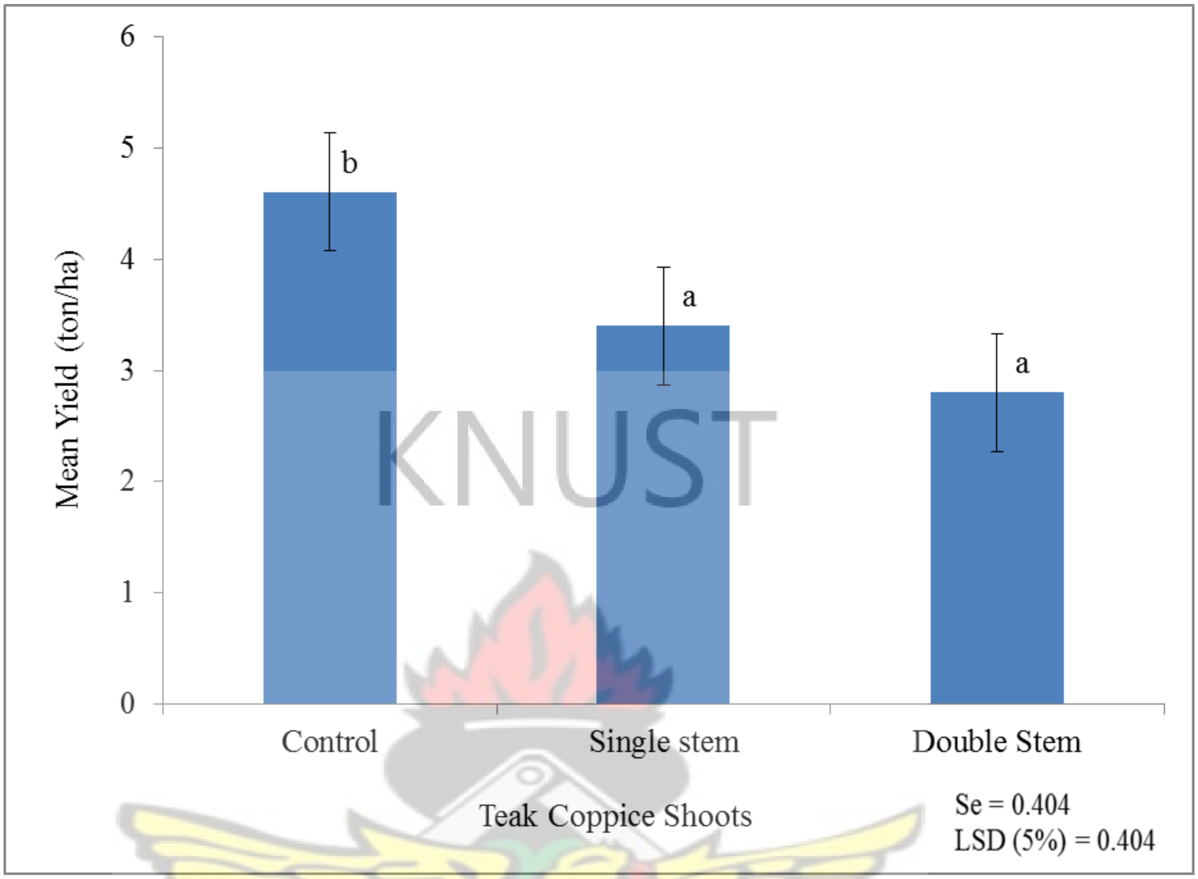


Figure 4.8 Yield of maize (ton/ha) planted among different number of teak coppice shoots.

Means of same letters are not significantly different at 5% level of significance according to DMRT.

4.9 Effect of spacing and density of teak on the yield of maize.

There was a decrease in the mean yield of maize with increasing density of teak coppicing (Fig 4.9). It was observed that the control recorded the highest mean yield of maize (5.30 tons/ha) whiles double stem coppicing with 3 m x 3 m density recorded the lowest mean yield of maize (2.00 tons/ha).

The means of double stem coppicing in the 3m x 3m density (2.00 tons/ha) was significantly lower than single stem coppicing with 6m x 6m density (3.18 tons/ha). Though the mean yield of double stem coppicing in the 3 m x 3 m density (2.03 tons/ha) was not lower than the mean yield of single stem coppices in the 3m x 3m density (2.48 tons/ha) and double stem coppicing in the 6 m x 6 m density (2.62 tons/ha), they were not significantly different. The 6 m x 6 m density with single stem coppice shoots treatment gave optimum yield of maize (3.20 tons/ha). This implies that intercropping maize under teak coppice shoots will do well if teak spacing is wide and only one shoot is left on the stool.

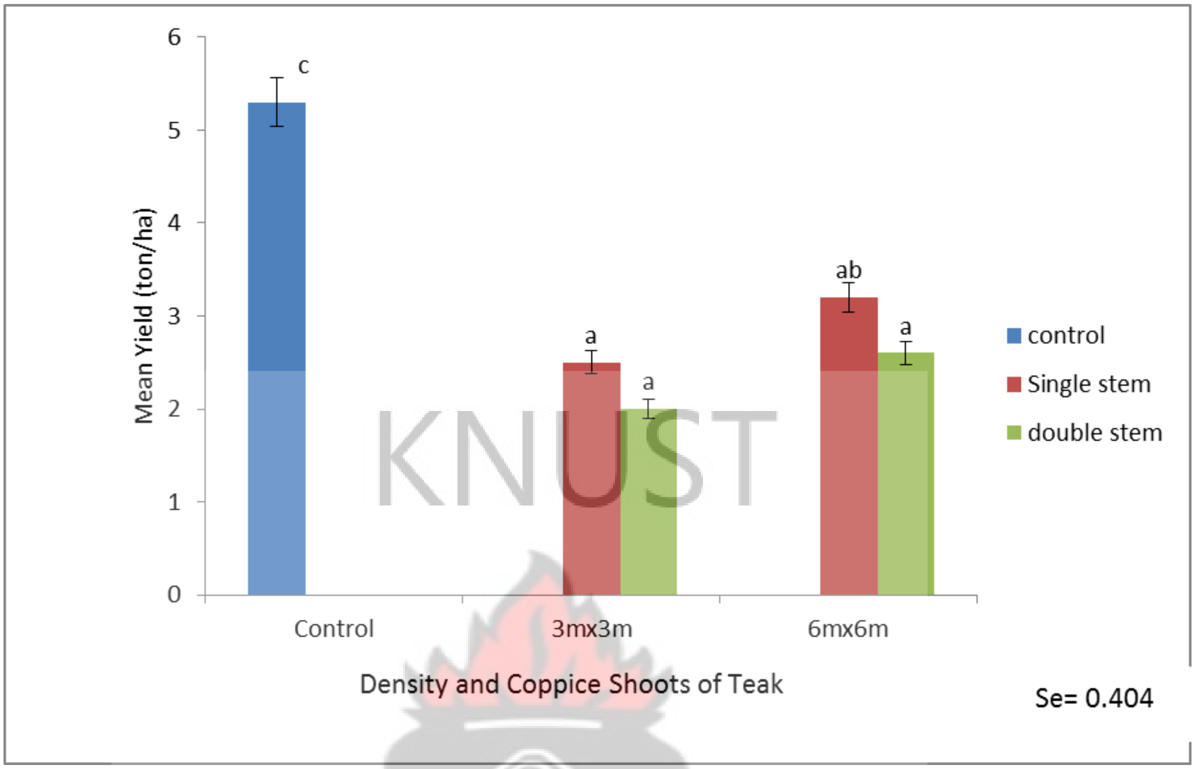


Figure 4.9 Yield of maize (ton/ha) planted under different planting distances (densities) and different number of teak coppice shoots (coppicing).

Means of same letters are not significantly different at 5% level of significance according to DMRT.

4.10 Effect of spacing of teak on the yield of maize in maize/cocoyam combinations.

Decreasing teak spacing (reduction in planting distance) resulted in decreasing maize yield. The highest mean yield (4.30 tons/ha) was recorded in the Control where there were no teak coppice shoots. The 3 m x 3 m spacing treatment recorded the lowest mean yield (2.50 tons/ha). Analysis of variance test indicated that spacing of teak coppices had siginificant effect on the yield of maize in the maize/cocoyam mix trial. Duncan's multiple range test revealed that each density treatment mean was significantly different from each other; 3m x 3m (2.52 tons/ha) was significantly lower than, 6 m x 6 m (3.22 tons/ha) mean. The control treatment mean was significantly higher than the other two treatments.

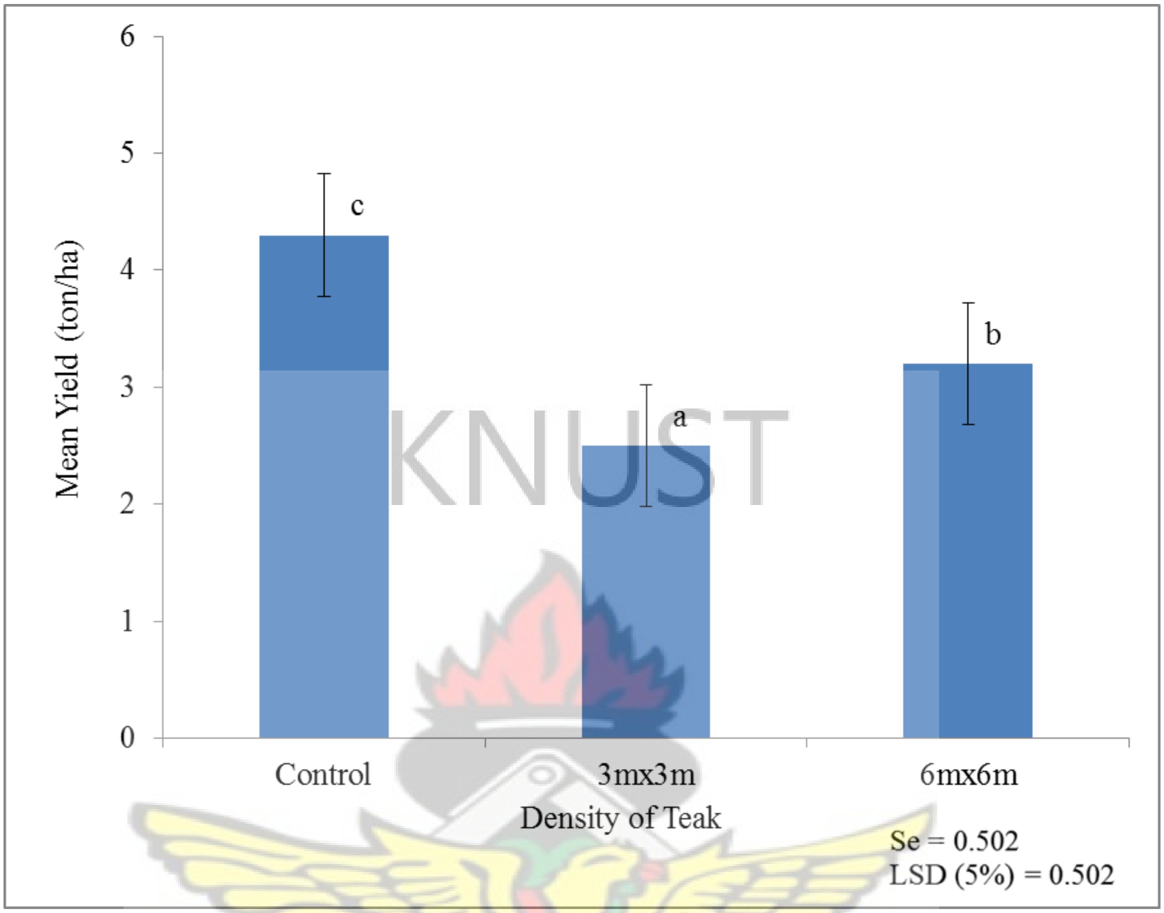


Figure 4.10 Yield of maize (ton/ha) planted among different teak coppice planting distances (densities) in a maize/cocoyam mix.

Means of same letters are not significantly different at 5% level of significance according to DMRT.

4.11 Effect of teak coppice density on the yield of maize in maize/cocoyam mix.

There was increasing yield of maize with decreasing teak coppice density (number of coppice shoots) in this experiment. The single stem coppice density treatment recorded the highest mean yield (3.50 tons/ha). The double stem coppice density treatment recorded the lowest mean yield (3.10 tons/ha), however no significant differences were observed among the treatment neans.

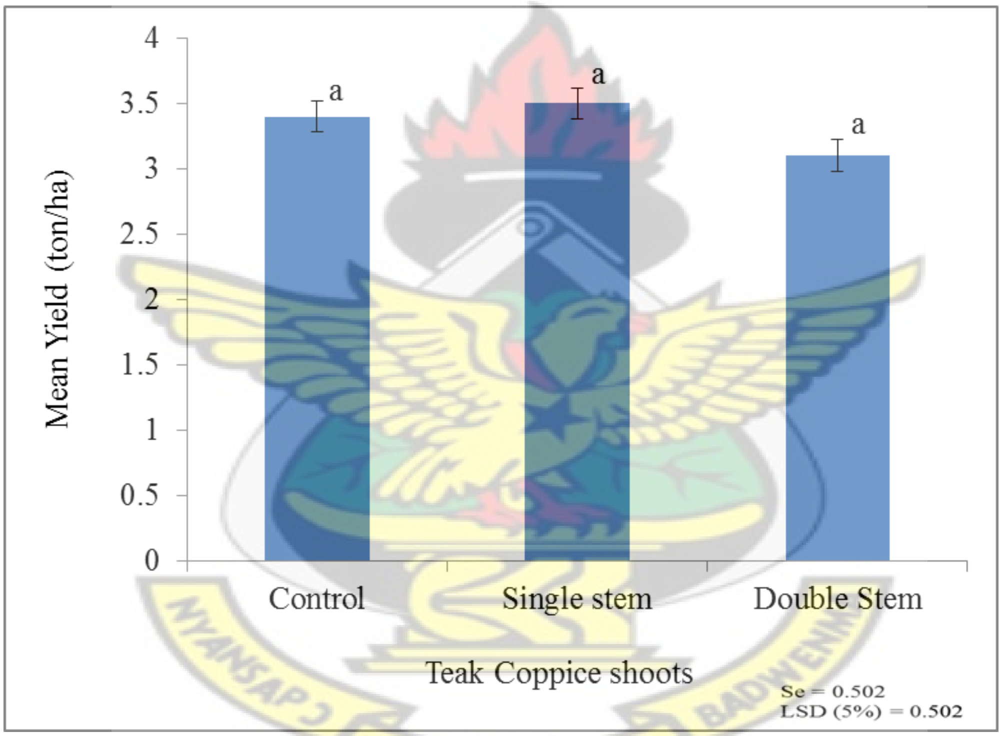


Figure 4.11 Yield of maize (ton/ha) planted among different number of teak coppice shoots (density) in the maize/cocoyam mix.

Means of same letters are not significantly different at 5% level of significance according to DMRT.

4.12 Effect of spacing and coppice density of teak on the yield of maize in maize/cocoyam mix.

Decreasing mean yield of maize observed in the experiment resulted from increasing density and decreasing of teak spacing in the maize/cocoyam mix trial. The highest mean yield (4.00 tons/ha) was recorded in the control (no coppice shoots) plot. The lowest mean yield (2.30 tons/ha) was recorded in the 3 m x 3 m spacing with double stem coppice density treatment plot. The interaction of spacing and density of teak had significant effect on the mean yield of maize in the maize/cocoyam mix trial. The means of single and double stems in the 3 m x 3 m spacing plts were significantly lower than the means of single and double stems in the 6 m x 6 m spacing plots. The mean of the control plot was however, significantly higher than the means of all the other treatments.

This results mean that if maize is intercropped with cocoyam under teak coppice shoots, maize yields per unit area are likely to reduce as number of coppice shoots increases and spacing between the shoot stumps decreases.

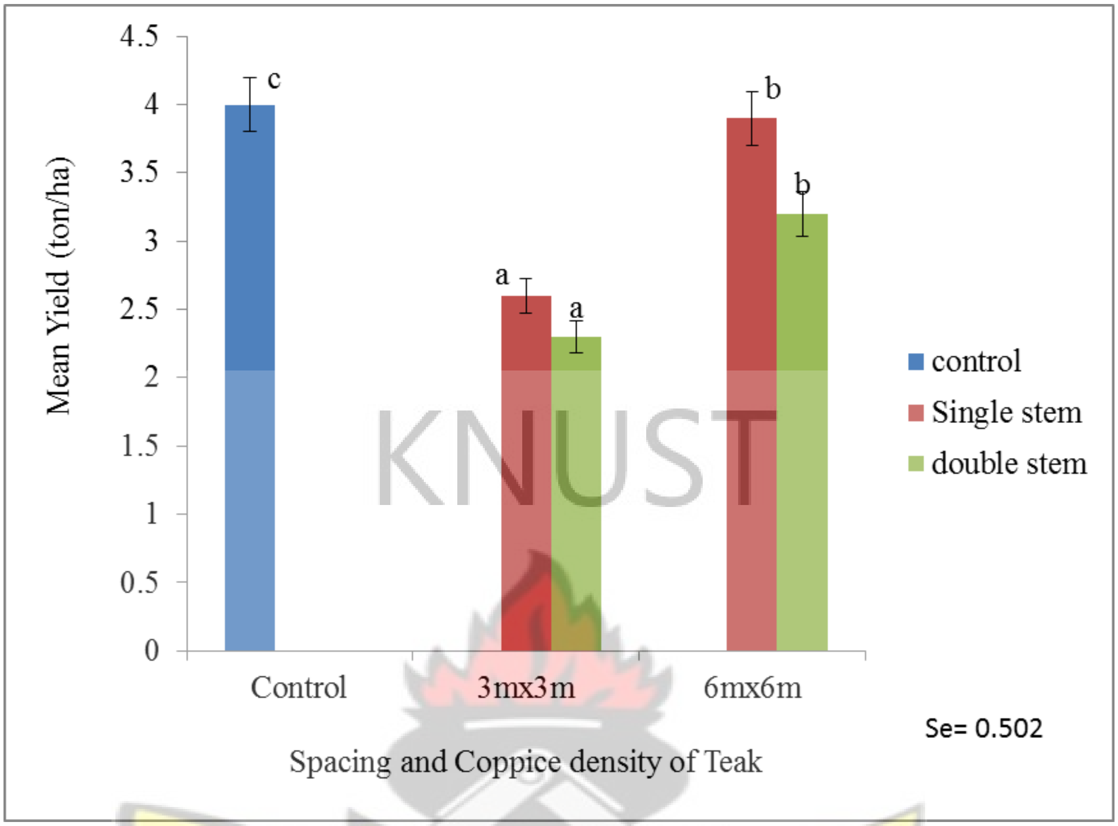


Figure 4.12 Yield of maize (ton/ha) planted under different teak coppice planting distances (spacing) and different number of coppice shoots per stool (density) in the maize/cocoyam mix.

Means of same letters are not significantly different at 5% level of significance according to DMRT.

4.13 Soil pH status under different cropping systems with teak coppicing.

The initial pH of the soil in the study was 7.6, which gradually decreased to 7.0 in the maize/cocoyam block as shown in figure 4.13. This means that the soil became slightly acidic after the experiment from the initial to the maize/cocoyam block.

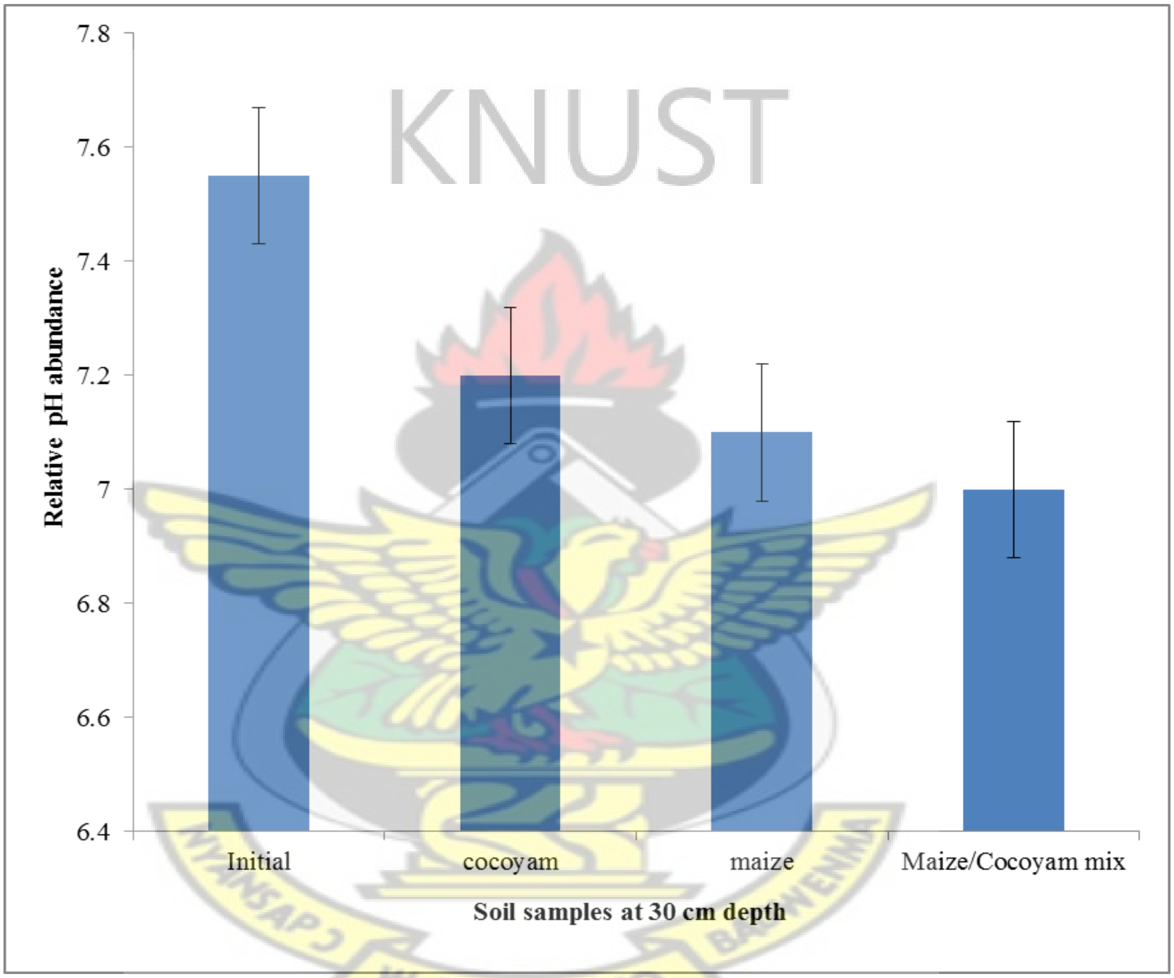


Figure 4.13 Relative abundance of soil pH under different cropping systems and teak coppicing.

4.14 Soil Nitrogen (N) status under different cropping systems with teak coppicing.

The initial soil status for nitrogen was 0.27%, it dropped gradually to 0.21% in the mixed maize/cocoyam combinations (figure 4.14). The results indicate that nitrogen was slightly used by the crops but not enough to cause significant changes in the nitrogen content of the soil before and after the experiment.

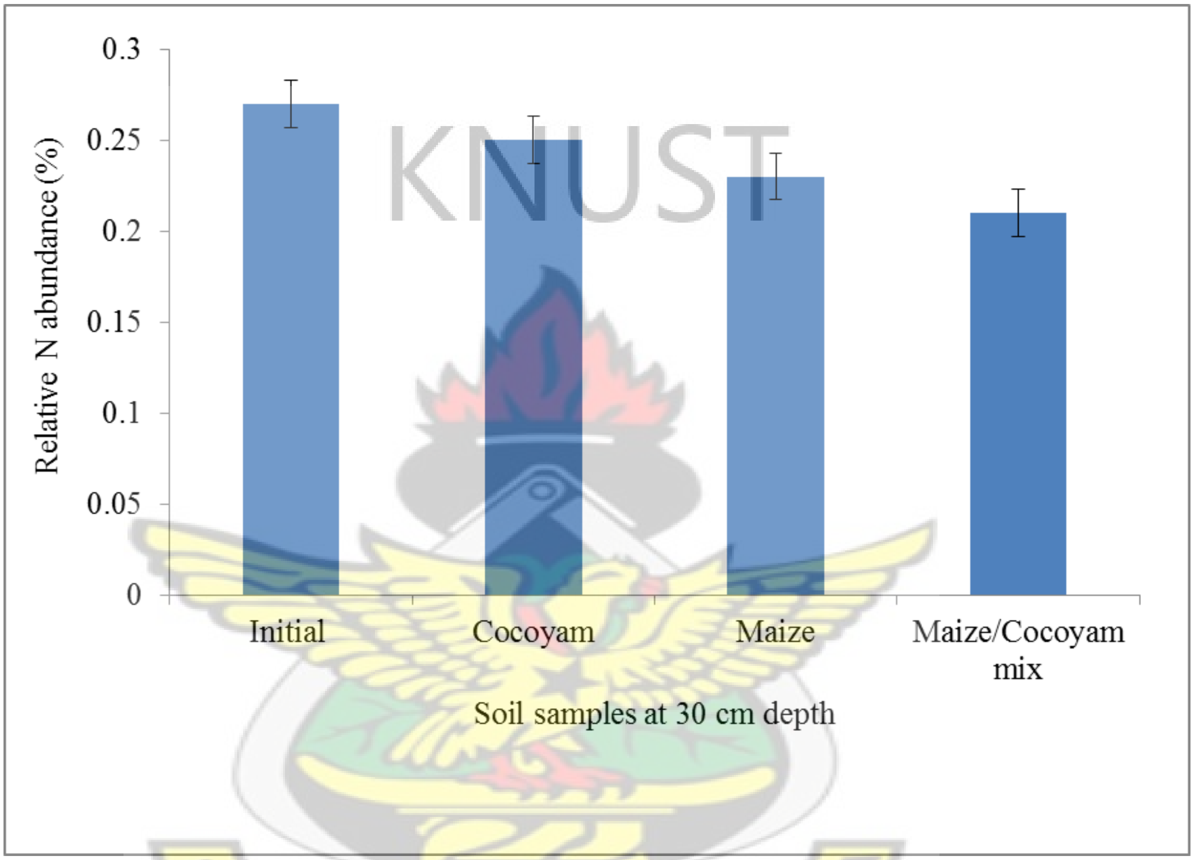


Figure 4.14 Relative abundance of soil Nitrogen (N) under different cropping systems and teak coppicing.

4.15 Soil Potassium (K) status under different cropping systems with teak coppicing.

Initial potassium in the soil was 0.6% but there was slight trend of decrease from this value to 0.5% in the maize/cocoyam block (figure 4.15). However, these decreases did not cause any significant changes in the potassium status of the soil after the experiment.

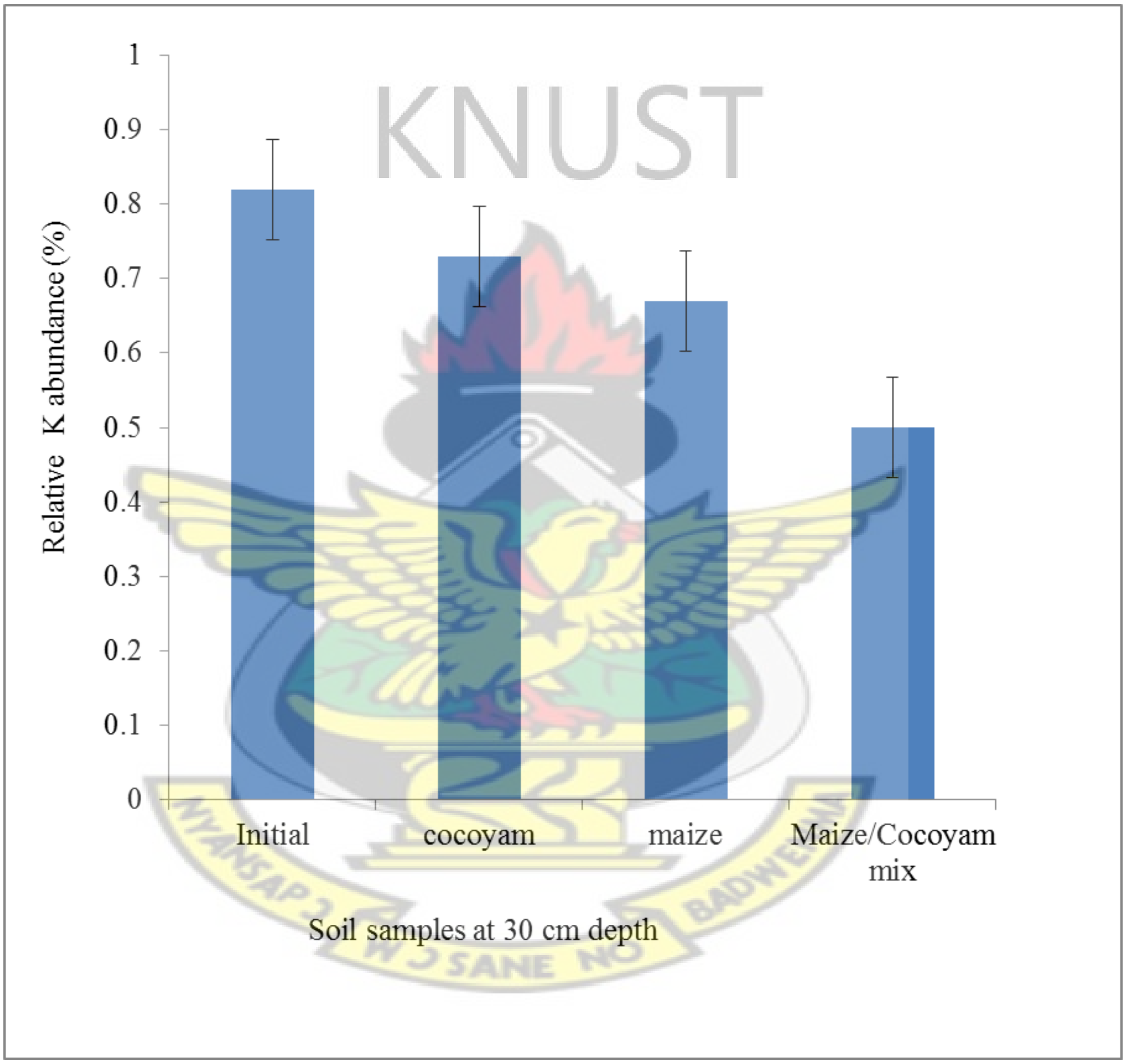


Figure 4.15 Relative abundance of soil Potassium (K) under different cropping systems and teak coppicing.

4.16 Soil Phosphorus (P) status under different cropping systems with teak coppicing.

The phosphorus content recorded in the soil before the study was 8.6%. The cocoyam, maize and mixed maize/cocoyam trial blocks recorded slightly lower quantities (7.2%, 6.8% and 5.8%, respectively (figure 4.16). These slight changes in the levels of phosphorus was enough to cause any significant changed in the status of phosphorus in the soil before and after the experiment

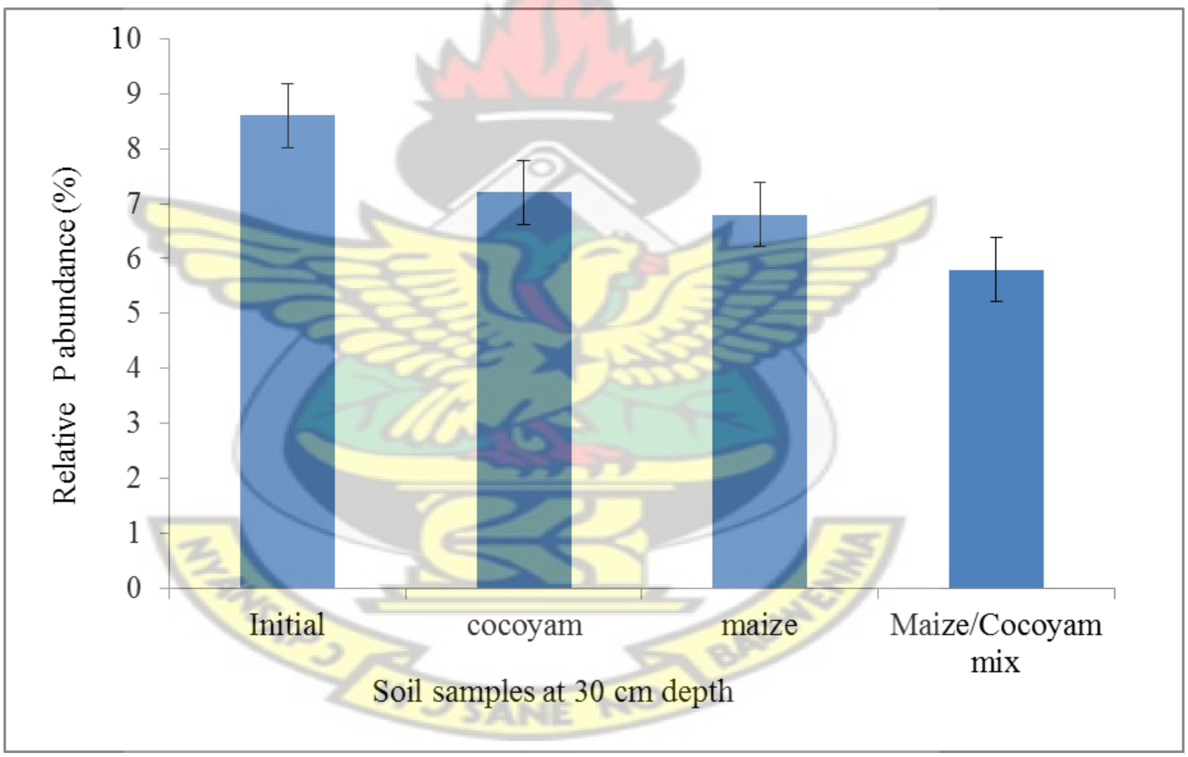


Figure 4.16 Relative abundance of soil Phosphorus (P) under different cropping systems and teak coppicing.

4.17 Soil effective Cation Exchange Capacity (e.C.E.C) under different cropping systems with teak coppicing.

The initial e.C.E.C of the soil before the study was 17.3 me/100g. The cocoyam, maize and maize/cocoyam blocks recorded higher capacities of 21.61, 19.34 and 18.76 me/100g respectively (figure 4.17). The results imply that there were higher absorption of soil nutrients in the plots with the test crops than the initial plot which had only teak trees. This is supported in the slight reduction in the levels of the major soil nutrients (N P K)

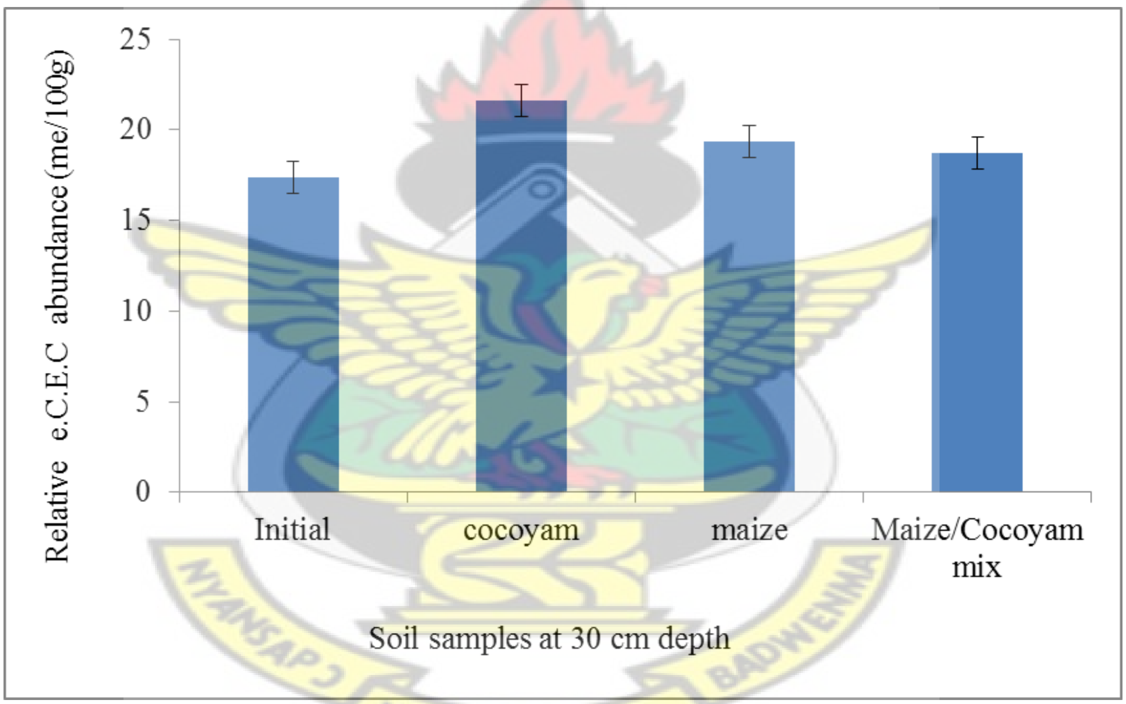


Figure 4.17 Soil effective Cation Exchange Capacity (e. C. E.C) under different cropping systems and teak coppicing.

CHAPTER FIVE

5.0 DISCUSSION

Teak coppice shoots spacing and its effect on maize and cocoyam

According to Nair, (1993), the intercropping of herbaceous and woody perennials can present positive and/ or negative effects on the components within the system. These positive or negative effects can be direct or indirect. For example, with respect to the herbaceous component, direct effects may result from the physical presence of the woody component in the system, which causes microclimate amelioration or nutrient additions via litter fall and root decay (Nair, 1993). Indirect effects may result from management practices connected with or necessitated by the presence of woody perennials, e.g., weeding, pruning, irrigation, singling or fertilization.

Because all members of a plant community utilize the same reserves of growth resources such as light, nutrients, water, and CO_2, some sort of negative interactions, often through competition, are likely to occur in every plant association (Etherington, 1975; Grime, 1979; Neuman, 1983). This competition can be separated into that caused by direct interference (real competition), and that caused by exploitation of shared resources which is mediated by other plants or shared predators (apparent competition).

The major yield decreasing effects at the Tree – Crop Interface (TCI) arise from competition for light, water, and nutrients, as well as from interactions via allelopathy.

It was observed in this study that variation in the yield of test crops were not due to competition between the teak coppices and the test crops for soil nutrients but rather competition for physical space and light were the two major yield decreasing factors.

Teak coppice density and spacing; their effect on cocoyam yields

Generally, it was observed in the study that decreasing spacing (reduced teak planting distance) and increasing number of teak coppice shoots per stool (coppice density) resulted in decreased yields of cocoyam (30%) in teak–cocoyam intercrop and teak – cocoyam/ maize mix (45%) cropping system from the no coppice shoots to the 3m x 3m spacing trials.

Reduction in the yields of cocoyam may be due to number of factors such as:

Teak spacing which influenced available space for planting the cocoyam; for instance the 3 m x 3 m spacing with single stem per stump had a population density of 1,111 shoots per hectare, 3 m x 3 m spacing with double stems per stump had 2,222 shoots per hectare; 6 m x 6 m spacing with single stem per stump had 278 shoots while 6 m x 6 m spacing with double stem per stump had 556 shoots per hectare. The implication is that higher population density of teak coppices will allow small area for cultivating the test crops and therefore, it is possible to obtain relatively lesser yields from the crops.

Another factor may be competition between the teak coppice shoots and the cocoyam for light and water. Etherington, (1975); Grime, (1979); Neuman,(1983), report that all members of a plant community utilize the same reserves of growth resources such as light, nutrients, water, and CO_2. Therefore, negative interactions, often through competition, are likely to occur in every plant association. Singh *et al*, (1989) reported that in any tree - crop interaction there is always competition for below - ground factors (nutrient and water) and above - ground factors (sunlight). However, from the soil status analysis, it was observed that all the required major nutrients (N. P. K.) for crop growth were not in limited supply even after the cropping season. This may be due to the teak which is relatively deep rooted plant and might have recycled soil nutrients from deep soil horizon and made them available for use by the cocoyam. Therefore, the observed variations in the cocoyam yields may have been due to competition for light and water but not necessarily competition for soil nutrients.

Shade from the teak coppice shoots may have been another factor that caused reduction in the cocoyam yields. Work done by Barradas and Fanjul, (1986), compared shaded versus open – grown coffee plantations in Mexico and found out that in a coffee plantation under the shade of *Inga jinicuil* (205 trees/ha; average tree height: 14m), the average maximum temperature was 4.5^0C lower and the minimum temperature 1.5^0 C higher, and that both vapour-pressure deficit (VPD) and Piche evaporation were substantially reduced as compared to open-grown coffee. The smaller temperature fluctuations under shade were attributed to reduced radiation load on the coffee plants during the day and to reduced heat loss during the night. The lower (VPD) was probably caused by a higher water input through the trees' transpiration stream in combination with lower the temperatures. Similar results, indicating a buffering effect of the trees on the microclimate beneath them, were also reported for a combination of coconut and cacao in India (Nair and Balakrishnan, 1977) and for an alley cropping system of millet and *Leaucaena* in India (Corlett *et al*., 1989). Although shade may have accounted for the reduction in the yields in the 3 m x 3 m single and double coppice shoots as well as the 6 m x 6 m double shoots, there was an exception in the 6 m x 6 m single coppice shoots which saw significant increase in the cocoyam yields. Amanor (1996), described cocoyam as a moderate shade tolerant species.

Teak density and coppicing; their effect on maize yields

The trends in the cocoyam yields under the teak spacing and number of coppice shoots per stump/stool were also observed in the teak- maize cropping systems.

Interactive effect of decreasing spacing (reduced planting distance) and increasing coppice density of teak shoots resulted in decrease yields of maize in teak – maize coppice intercrop and teak – maize/cocoyam mix intercropping system from the control to the 3 m x 3 m density with double stem coppicing.

Reduction in the yields of maize was probably due to factors such as: the reduced space for planting the maize; for instance, the 3 m x 3 m spacing with single stem per stump had population density of 1,111 shoots per hectare, 3 m x 3 m spacing with double stems per stump had 2,222 shoots per hectare; 6 m x 6 m spacing with single stem per stump had 278 shoots while 6 m x 6 m spacing with double stem per stump had 556 shoots per hectare.

Agroforestry system components may compete for environmental resources such as light, water, soil nutrients per unit area (Nair, 1993). This can result in negative results such as lower yields of associated components (crops). However, the soil analysis after the experiment showed that there were adequate soil nutrients (NPK) levels for maize growth. Therefore, any observed variations in the maize yields could be due to competition for light and water but not necessarily competition for soil nutrients.

Shade from the teak coppice shoots may have been another factor that caused reduction in the maize yields. Verinumbe and Okali, (1985) grew maize between coppiced teak trees (*Tectona grandis*) and segregated the effects of shading and root competition by the use of barriers and judicious pruning. They found that shading alone depressed maize yield by 40%, root competition alone had no effect but shading and root competition combined depressed yield by more than 60%.They again showed that, competition for light was a more critical factor than root competition for intercropped maize between teak trees (*Tectona grandis)* in Nigeria. Kang *et al*. (1981) attributed low yields from maize rows adjacent to *Leucaena* hedgerows to shade. Neumann and Pietrowicz (1989), who studied competition in agroforestry combination of *Grevillea robusta*, maize, and beans in Rwanda, reported that the shade cast by *Grevillea* appeared more important than other effects of the trees.

Shading was a strong factor in this study and it could be a reason for the low yields of maize recorded.

Although yields of maize in the various treatments were generally low, the 6 m x 6 m spacing with single stem coppice shoot which created moderate shading recorded relatively higher yields of maize after the control.

Soil Nutrient status and physiochemical properties

According to Nair, (1993), nutrients are available for immediate use or may remain stored for the future. Once again, storage is not perfect with possible losses at the soil surface by volatilization and by erosion, and to depth by leaching. Additionally, nutrients may be rendered unavailable by chemical alteration. Nutrients located below the root zone can become available only by extension of the root system. In the absence of serious erosion, surface deposition or fertilization, changes in overall fertility are slow. They are measurable in years, and rely upon continued weathering of the parent material both within and below the root profile. The redistribution of nutrients to the upper soil layers are also by recycling via the litter of deeply rooted species. This resource pool at any site, like light but unlike water is highly predictable. Preferential access depends upon relative profiles, principally root depth, whilst differential access is based upon more efficient absorbing power per unit rooting volume.

The initial soil Nitrogen status was 0.27% and decreased slightly to 0.21% in the mixed teak - cocoyam/maize intercrop. Furthermore, potassium which also had an initial status of 0.6% increased to 0.7% in teak - maize , 0.8% in the teak - cocoyam and decreased to 0.5% in the teak cocoyam/maize mix trial plots.

Phosphorus had an initial status of 5.1%. This increased to 5.8% in the teak cocoyam/maize mix, 7.2% in the teak – cocoyam and 8.5% in the teak – maize but experiments done by Alegre and Sanchez (1991) have shown that maize, like many vegetable crops, benefits from some N and P fertilizer placed close to the seed, even when the bulk of the soil is adequately supplied with nutrients. Maize crops also remove large amounts of potash, typically 4.4 kg K_2O/t fresh yield which amounts to 175 kg/ha for a 40 t/ha crop. Nutrient off take is dependent on yield; a 30 t/ha removes 130 kg K_2O and a 50 t/ha crop removes 220 kg/ha K_2O.

The initial e. C. E. C was 17.4me/100g. The teak – cocoyam trial increased to 21 me/100g, the teak – maize also had 19me/100g.

One of the hopes of agroforestry is that it can capitalize upon the capacity of perennial plants to transfer nutrients from depth into upper soil layers where they are made accessible to companion shallowly rooted herbaceous plants. As the association grows, nutrients are fixed in the vegetation, especially in the perennial components. Nutrients are then removed from the site by harvesting. Whilst the pools available nutrients can be replenished by chemical conversions within the soil profile by accretion to the site, the nutrient content of the upper soil layer, to which the most intense root activity is restricted, will depend largely upon the external recycling system of the perennial component. It can be stated that a successful agroforestry association will have, by nature or management, the following characteristics:

A perennial component has a root system effective in nutrient uptake at depths below the rooting zone of the herbaceous layer.

A highly productive perennial component will have a high nutrient return to the upper soil layer.

A herbaceous component that can either compete with the perennial for nutrient enrichment in the upper soil layer, can be managed to take advantage of this.

Productivity will be restricted to sites in which the uptake of nutrients is less than that required by the vegetation. Growth potential is determined by its access to the other environmental resources, if not, nutrient stress will occur (Huxley, 1985).

Plants require a continuing supply of nutrients to meet the demand of growing tissues. The supply can be aided by efficient transport of nutrients from root system and by remobilization of nutrients already present in senescing tissue; that is by internal recycling. The overall nutrient need can be minimized by genetic, environmental or management restrictions to the rate of growth (Huxley, 1983). Not all nutrients are equally mobile in soils and hence the rate at which they are replenished at the root surface differs. Of the major nutrients NO_3-N is highly mobile because it exists mainly in the solution phase, and the rate of supply is therefore critically affected by the soil water status. Phosphate – P, NH_4 – N, and other cations, which are strongly associated with exchange surfaces, have limited mobility (Huxley, 1983) and rate of uptake is likely to be influenced by the time and extent of fine root extension. During the study, all the soil nutrients (NPK) were slightly taken up but it was also observed that nitrogen was the most used. According to the soil analysis in this study, these nutrients were in adequate supply and available for use by the cocoyam and maize. The nutrients were also not reduced significantly by teak coppicing with cocoyam and maize cultivation. Temporarily removing the trees/bush canopy (by coppicing) may eliminate competitive needs for water between the plant associates where these are sharing the same surface soil levels in some way (Butcher 1977).

Although it is believed that the teak coppice shoots may have not competed with the test crops for soil nutrients, slight decreases in the quantities of pH from 7.6 to 7.0 meant the soil medium was becoming more alkaline which culminates into higher plants absorption capacities of the various soil nutrients (NPK). This is supported by the slightly low levels of the soil nutrients and the slight appreciable increases in the soil effective cation exchange capacities (e.C.E.C.). Since the level of changes in the soil nutrient status was not significant, the observed variation in the yields of the test crops could be attributed in whole to the spatial arrangement and shading of the teak coppice shoots rather than to soil nutrient dynamics.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Coppice density (number of coppice shoots per stump/stool), spacing and the interaction of spacing and density of *Tectona grandis* had significant effect on the yields of cocoyam and maize.

Increasing coppice density (number of coppice shoots) resulted in corresponding yield decreases of cocoyam and maize in the monocropping and mixed cropping trials. Decreasing spacing (reduction in the planting distances) of *Tectona grandis* coppice shoots also resulted in reduction in the yields of cocoyam and maize also in both the monocropping and mixed cropping trials. The interactive effect of teak coppice density and spacing on the yields of cocoyam and maize was significant. Shading and population density of teak reduced the yields of both cocoyam and maize. However, 6 m x 6 m spacing (planting distance) of teak coppices and single stem (coppicing) combination recorded the next highest yields of cocoyam and maize. The following optimum yields were obtained from this combination; cocoyam (7.8 tons/ha), maize (4.18 tons/ha).

It is highly possible to intercrop cocoyam and maize among teak coppice shoots at least for one cropping season. However, the design to obtain optimum yields of cocoyam and maize should be 6 m x 6 m density with single stem coppice shoot. Although the desire is to improve yields of agricultural crops to attract farmers, it is important to maintain perennial crops on farmlands. This will ensure sustained productivity of the cropping system. Although the control treatment (no teak coppice shoot) recorded higher yields of the test crops in all the trials, the other treatments are more sustainable and environmentally acceptable. To harness some of the benefits of agroforestry aforementioned, it is most appropriate to opt for the 6 m x 6 m with single stem teak coppice shoot. This design recorded the next higher mean yields of the test crops after the control treatment.

The intercropping of teak coppice shoots with cocoyam and maize may not significantly modify the soil nutrient status and chemical properties (which are important for soil productivity) after one cropping season. Assessment in just one cropping season may not be enough to conclude and therefore the experiment needs to be continued for more than two years to observe this trend. Soil pH was nearly neutral throughout the study; the other nutrients and effective cation properties also exhibited less variation and were steady for the study.

Intercropping does not significantly change the soil nutrient status and chemical properties. This is useful information for MoFA, Forestry Commission and Researchers in an attempt to integrate farming into teak coppice management in Ghana.

6.2 Recommendations

The following is a summary of the recommendations that have come out of the study which are important for cost effective and sustainable teak coppice management in Ghana.

- In order to attract farmers in the Brong Ahafo Region to assist in teak coppice management while they also plant their agricultural crops on the same piece of land the 6 m x 6 m planting distance with single stem teak coppice shoot should be adopted.
- The study may be repeated in the same experimental environment for at least 3 years.
- Study should be replicated in other ecological zones to confirm trends observed.
- The experiment should be tested on farmer's fields with farmer control systems.
- Cost and benefit analysis of the various treatments (technologies) may be done in subsequent studies to test the economic viability of the various designs.

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APPENDICES

Appendix I

Experimental Plot Layout **T – Treatment** **FACTOR A = Density**

FACTOR B = Spacing

	FACTOR A	
FACTOR B	Single shoot (A_1)	Double shoots (A_2)
3 m x 3 m (B_1)	A_1B_1	A_2B_1
6 m x 6 m (B_2)	A_1B_2	A_2B_2

Block 1

T2 (A2B1)	**T3 (A1B2)**	**(No Teak Coppice shoots)**
T4 (A2B2)	**T1 (A1B1)**	**CONTROL**

Block 2

T3 (A1B2)	**T1 (A1B1)**	**(No Teak Coppice shoots)**
T2 (A2B2)	**T4 (A2B1)**	**CONTROL**

Block 3

T4 (A2B2)	**T2 (A2B1)**	**(No Teak Coppice shoots)**
T1 (A1B1)	**T3 (A1B2)**	**CONTROL**

Appendix II

Analysis of variance

Cocoyam trial (Cocoyam sole crop)
Table 1. ANOVA for sole cocoyam experiments

Source	d.f.	s.s.	m.s.	v.r.	F pr.
blk	2	10.344	5.172	4.22	0.035
Density ignoring Spacing	3	7.003	2.334	1.91	0.172
Density eliminating Spacing	3	6.361	2.120	1.73	0.203
Spacing ignoring Density	2	41.802	20.901	17.07	< 0.001
Spacing eliminating Density	2	41.159	20.580	16.81	< 0.001
Density. Spacing	4	7.652	1.913	1.56	0.235
Residual	15	18.363	1.224		
Total	26	84.522	3.251		

Cocoyam trial (Cocoyam/Maize Mix)
Table 2. ANOVA for cocoyam and maize interaction experiment

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
blk stratum	2	12.6674	6.3337	24.50	
blk.*Units* stratum					
Density	2	3.1280	1.5640	6.05	0.011
Total	26	38.8345			

Maize trial (Maize sole crop)
Table 3. ANOVA for sole maize experiment

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
blk stratum	2	8.2830	4.1415	25.37	
blk.*Units* stratum					
Density	2	14.1650	7.0825	43.39	<.001
Spacing	2	13.0950	6.5475	40.12	<.001
Density. Spacing	4	0.6801	0.1700	1.04	0.416
Residual	16	2.6114	0.1632		
Total	26	38.8345			

Maize trial (Maize/Cocoyam Mix)

Table 4.ANOVA for maize and cocoyam experiment

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
blk stratum	2	0.2312	0.1156	0.46	
blk.*Units* stratum					
Density	2	0.5652	0.2826	1.12	0.350
Spacing	2	14.0725	7.0363	27.89	<.001
Density. Spacing	4	3.1338	0.7834	3.11	0.045
Residual	16	4.0359	0.2522		
Total	26	22.0386			

Appendix III

Duncan's Multiple Range Tests

A. Rank test for Cocoyam trial (Cocoyam sole crop)

Density

Treatment	**Mean**	**Symbols of significance**
Double Stem	3.089	a
Single Stem	3.633	b
Control	4.044	b

Spacing

Treatment	**Mean**	**Symbols of significance**
3m x 3m	3.278	b
6m x 6m	3.311	a
Control	4.178	a

Density and Spacing

Treatment	**Mean**	**Symbols of significance**
Double Stem 3m x 3m	2.030	b
Single Stem 3m x 3m	2.480	a
Double Stem 6m x 6m	2.623	ab
Single Stem 6m x 6m	3.183	a
Control No Sprout	5.307	c

B. Rank test for Cocoyam trial (Cocoyam/Maize Mix)

Density

Treatment	**Mean**	**Symbols of significance**
Double Stem	3.80	a
Single Stem	4.33	b
Control	4.60	b

Spacing

Treatment	**Mean**	**Symbols of significance**
3m x 3m	3.98	a
6m x 6m	3.91	a
Control	4.80	b

Density and Spacing

Treatment	**Mean**	**Symbols of significance**
Double Stem 6m x 6m	3.267	ab
Double Stem 3m x 3m	3.667	b
Single Stem 3m x 3m	3.833	a
Single Stem 6m x 6m	4.167	a
Control No Sprout	5.217	c

C. Rank test for Maize trial (Maize sole crop)

Density

Treatment	Mean	Symbols of significance
Double Stem	2.823	a
Single Stem	3.388	a
Control	4.562	b

Spacing

Treatment	Mean	
3m x 3m	2.891	a
6m x 6m	3.341	a
Control	4.541	b

Density and Spacing

Treatment	Mean	Symbols of significance
Double Stem 3m x 3m	2.030	b
Single Stem 3m x 3m	2.480	a
Double Stem 6m x 6m	2.623	b
Single Stem 6m x 6m	3.183	a
Control No Sprout	5.307	c

D. Rank test for Maize trial (Maize/Cocoyam Mix)

Density

Treatment	Mean	Symbols of significance
Double Stem	3.149	a
Control	3.359	a
Single Stem	3.501	a

Spacing

Treatment	Mean	Symbols of significance
3m x 3m	2.517	a
6m x 6m	3.219	b
Control	4.273	c

Density and Spacing

Treatment	Mean	Symbols of significance
Double Stem 3m x 3m	2.347	a
Single Stem 3m x 3m	2.570	a
Double Stem 6m x 6m	3.150	b
Single Stem 6m x 6m	3.867	b
Control No Sprout	4.803	c

Appendix IV

SOIL ANALYSIS (CHEMICAL PROPERTIES)

Horizon (cm)	PH 1:1 H_2O	Org. C %	Total N %	Org. M %	Exchangeable Cations me/100g Ca	Mg	K	Na	T.E.B	Exch. A (Al + H)	E.C.E.C me/100g	Base Sat. %
INITIAL SOIL STATUS												
B_1 I	7.60	2.24	0.27	3.86	12.82	4.54	0.83	0.13	18.15	0.05	18.20	99.73
B_2 I	7.40	2.20	0.24	3.79	12.02	2.67	0.79	0.21	15.66	0.05	15.71	99.68
B_3 I	7.60	2.51	0.29	4.33	14.69	2.67	0.81	0.15	18.11	0.05	18.16	99.72

SOIL STATUS AFTER EXPERIMENT

SOLE COCOYAM PLOTS												
CB_1	8.50	2.00	0.25	3.45	25.10	3.34	0.86	0.22	29.62	0.05	29.67	99.83
CB_2	6.60	2.55	0.27	4.40	13.88	3.74	0.74	0.16	18.62	0.10	18.72	99.47
CB_3	6.90	2.24	0.25	3.86	11.75	3.87	0.48	0.15	16.33	0.10	16.43	99.39
SOLE MAIZE PLOTS												
MB_1	8.10	1.47	0.18	2.54	20.03	6.41	0.74	0.18	27.44	0.05	27.49	99.82
MB_2	6.60	2.32	0.26	4.00	11.21	3.60	0.66	0.16	15.67	0.10	15.77	99.37
MB_3	6.80	1.93	0.25	3.33	10.41	3.60	0.49	0.13	14.67	0.10	14.77	99.32
MAIZE / COCOYAM MIX PLOTS												
MC B_1	7.30	1.86	0.19	3.21	13.62	2.67	0.60	0.13	17.02	0.05	17.07	99.60
MC B_2	6.70	1.78	0.22	3.07	9.61	2.94	0.49	0.10	13.14	0.10	13.24	99.24
MC B_3	7.10	1.78	0.21	3.07	11.21	2.14	0.48	0.10	13.93	0.05	13.98	99.64

SOIL ANALYSIS (CHEMICAL PROPERTIES)

Horizon (cm)	AVAILABLE BRAYS PP^{m}P	PP^{m}K
	INITIAL SOIL STATUS	
B_1 I	4.07	167.39
B_2 I	5.58	145.63
B_3 I	6.14	103.78
	SOIL STATUS AFTER EXPERIMENT	
	SOLE COCOYAM PLOTS	
CB_1	7.89	154.00
CB_2	5.18	164.04
CB_3	8.69	140.61
	SOLE MAIZE PLOTS	
MB_1	16.02	115.50
MB_2	4.06	133.91
MB_3	4.94	147.30
	MAIZE / COCOYAM MIX PLOTS	
MC B_1	5.10	157.35
MC B_2	3.99	147.30
MC B_3	8.69	137.26

LEGEND

B - Block

C - Cocoyam

M - Maize

I - Initial

MC - Maize/Cocoyam combination

Appendix V

Soil Analysis

TAB. 1 SOIL NUTRIENT CONTENT AND RELATIVE ABUNDANCES DURING STUDY

Plots	Nutrients (%)											
	pH	Org. Carbon	N	Org. Matter	Ca	Mg	Na	K	T.E.B	Exch. A(Al + H)	E.C.E.C me/100g	Base Sat.
B I	7.53	2.32	0.27	3.99	13.18	3.29	0.16	0.61	17.31	0.05	17.36	99.71
C B	7.33	2.26	0.25	3.9	16.81	3.65	0.18	0.79	21.52	0.08	21.61	99.56
M B	7.17	1.91	0.23	3.29	13.88	4.54	0.16	0.68	19.26	0.08	19.34	99.5
MC B	7.36	1.81	0.21	3.12	11.48	2.58	0.11	0.53	14.69	0.07	14.76	99.49

LEGEND

B - Block

C - Cocoyam

M - Maize

I - Initial

MC - Maize/Cocoyam combination

Table.2 Soil Nutrient content and Relative Abundance in Plots adjacent to the Teak Plantation (Tain II Forest)

Plots	Nutrients (%)											
Control	pH	Org. Carbon	N	Org. Matter	Ca	Mg	Na	K	T.E.B	Exch. A(Al + H)	E.C.E.C me/100g	Base Sat.
	6.52	2.20	0.18	3.54	10.35	3.65	0.12	0.41	19.10	0.01	15.35	99.45

Appendix VI

Analysis of Variance for soil analysis

ANOVA for Exchangeable A(Al + H)

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Block	0.004	2	0.002	6	0.0256	4.45897
Treatments	0.002333	4	0.000583	1.75	0.231938	3.837853
Error	0.002667	8	0.000333			
Total	0.009	14				

ANOVA for E.C.E.C me/100g

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Block	369.1154	2	184.5577	6.900308	0.018134	4.45897
Treatments	129.6226	4	32.40564	1.211594	0.377348	3.837853
Error	213.9704	8	26.7463			
Total	712.7083	14				

ANOVA for Base Saturation

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Block	0.316813	2	0.158407	6.591581	0.020342	4.45897
Treatments	0.097307	4	0.024327	1.012275	0.45555	3.837853
Error	0.192253	8	0.024032			
Total	0.606373	14				

ANOVA for pH

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Block	4.288	2	2.144	13.84715	0.002523	4.45897
Treatments	0.257333	4	0.064333	0.415501	0.793375	3.837853
Error	1.238667	8	0.154833			
Total	5.784	14				

ANOVA for Organic Carbon (C)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Block	0.139373	2	0.069687	0.974366	0.418108	4.45897
Treatments	0.59796	4	0.14949	2.090185	0.174023	3.837853
Error	0.57216	8	0.07152			
Total	1.309493	14				

ANOVA for Nitrogen (N)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Block	0.00112	2	0.00056	0.918033	0.437597	4.45897
Treatments	0.0066	4	0.00165	2.704918	0.107741	3.837853
Error	0.00488	8	0.00061			
Total	0.0126	14				

ANOVA for Organic Matter

Source of Variation	SS	df	MS	F	P-value	F crit
Block	0.410093	2	0.205047	0.965054	0.421254	4.45897
Treatments	1.767667	4	0.441917	2.079885	0.175502	3.837853
Error	1.699773	8	0.212472			
Total	3.877533	14				

ANOVA for Calcium (Ca)

Source of Variation	SS	df	MS	F	P-value	F crit
Block	260.9567	2	130.4783	5.849867	0.027197	4.45897
Treatments	90.55877	4	22.63969	1.015028	0.454358	3.837853
Error	178.4359	8	22.30449			
Total	529.9514	14				

ANOVA for Magnesium (Mg)

Source of Variation	SS	df	MS	F	P-value	F crit
Block	6.904693	2	3.452347	4.277798	0.054523	4.45897
Treatments	6.058093	4	1.514523	1.876644	0.20802	3.837853
Error	6.456307	8	0.807038			
Total	19.41909	14				

ANOVA for Sodium (Na)

Source of Variation	SS	df	MS	F	P-value	F crit
Block	0.002893	2	0.001447	1.094578	0.380021	4.45897
Treatments	0.010507	4	0.002627	1.98739	0.189483	3.837853
Error	0.010573	8	0.001322			
Total	0.023973	14				

ANOVA for Potassium (K)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Block	0.26236	2	0.13118	5.160165	0.03636	4.45897
Treatments	0.190707	4	0.047677	1.875434	0.208234	3.837853
Error	0.203373	8	0.025422			
Total	0.65644	14				

ANOVA for T.E.B

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Block	371.2278	2	185.6139	6.924655	0.017973	4.45897
Treatments	129.1866	4	32.29666	1.204884	0.379728	3.837853
Error	214.4383	8	26.80479			
Total	714.8527	14				

Appendix VII

STANDARDS FOR SOIL NUTRIENT (MINERAL) CONTENT

NUTRIENT	RANK/GRADE
Phosphorus, P (ppm)(Blay-1)	
<10	Low
10-20	Moderate
>20	High
Potassium(ppm)	
<50	Low
50-100	Moderate
>100	High
Calcium, Ca (PPM)/Mg=0.25Ca.	
<5.0	Low
5.0-10.0	Moderate
>10.0	High
ECEC (cmol (+)/Kg)	
<10	Low
10-20	Moderate
>20	High
Soil pH(distilled water method)	
<5.0	Very acidic
5.1-5.5	Acidic
5.6-6.0	Moderately Acidic
6.0-6.5	Slightly Acidic
6.5-7.0	Neutral
7.0-7.5	Slightly Alkaline
7.6-8.5	Alkaline
>8.5	Very Alkaline
Organic Matter (%)	
<1.5	Low
1.6-3.0	Moderate
>3.0	High
Nitrogen (%)	
<0.1	Low
0.1-0.2	Moderate
>0.2	High
Exchangeable Potassium (cmol (+)/kg)	
<0.2	Low
0.2-0.4	Moderate
>0.4	High

SOURCE: CSIR- SOIL RESEARCH INSTITUTE, KUMASI

Appendix VIII

PRODUCTION STATISTICS – SUNYANI MUNICIPAL (2005-2008)

CROP	CULTIVATED AREA (HECTARES)				YIELD (T/Ha)			
	2005	**2006**	**2007**	**2008**	**2005**	**2006**	**2007**	**2008**
Maize	33,180	15,000	12,259	10,297	1.25	2.10	2.00	2.60
Cassava	14,700	22,104	17,904	26,997	8.80	11.50	15.00	13.30
Yam	233	4,994	5,004	5,085	12.80	15.70	19.40	20.10
Cocoyam	2,475	4,067	5,445	5,695	4.70	8.30	12.00	11.40
Plantain	5,385	7,462	11,214.2	9,724	7.00	5.40	6.00	6.30

SOURCE: MINISTRY OF FOOD AND AGRICULTURE, SUNYANI