KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

COLLEGE OF SCIENCE

DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

GROWTH PERFORMANCE OF A YOUNG TEAK (*Tectona Grandis* LINN. F) STAND UNDER DIFFERENT SITE PREPARATION METHODS AND PLANTING STOCKS

A THESIS SUBMITTED TO THE DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY IN PARTIAL FULFILMENT OF THE REQUIRMENT FOR THE DEGREE OF MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCE

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DECLARATION

I declare that the results of these studies, except otherwise cited are my own work and have not been submitted for any degree other than that of my Master of Science in the Kwame Nkrumah University of Science and Technology.

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ABSTRACT

Site preparation and the propagative material of plants go a long way to determine the growth performance and biomass production. This study was carried out to determine the effect of propagation material on stem growth and form, the best allometric model to estimate above-ground phytomass of individual Teak trees as well as the impact of site preparation methods on growth of Teak trees. Two planting stocks (bare rooted stump and potted seedling), and four sites preparation methods (burnt, un-burnt, fertilized and un-fertilized) were evaluated using the nested block design in the assessment of the growth performance of a ten year old Teak plantation.The results obtained indicated that the Teak trees propagated from potted seedling had 41% higher survival compared to those of bare rooted stump. In the site preparation method the burnt sites had 11% higher survival relative to those in the un-burnt sites. Fertilization did not have much influence on the survival of the Teak trees demonstrating that there was no significant difference between sites that were fertilized or un-fertilized (p=0.21) The quality of Teak trees reflected in the stem form was not affected by both site preparation methods and the planting stocks.The results showed that the best allometric model for estimating above-ground phytomass of individual Teak trees was $M_T=0.3158\ (Vs)^{1.0806}$ as the model resulted with the highest coefficient of determination ($R^2 = 0.9978$). However, Teak trees in the un-burnt sites had higher growth relative to those in the burnt sites. Also the un-burnt sites accumulated more carbon stock than those in the burnt sites (p = 0.19) as the undergrowth in the un-burnt sites provided additional carbon stock from the litter. The results shows that in the cultivation of a Teak plantation the propagation by potted seedlings planted in an un-burn site with fertilizer application is the best cultivation method for growth performance and high biomass production.

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CHAPTER ONE

1.0 INTRODUCTION

Teak (*Tectona grandis Linn. F.)* belongs to the plant family Verbanaceae. Teak plantations have been established throughout the tropics, within and outside its natural distribution range. Teak tolerates a wide range of climatic conditions, i.e. from the equatorial type to the sub-tropical type with a rainfall range of 500 to 3,500 mm (Kaosa-ard, 1981). Teak has its natural distribution in parts of India, Myanmar, Thailand, Laos and Indonesia (Kaosa-ard, 1983). At the moment it is widely planted in South East Asia, and as exotic species in Africa, South and Central America (Ball *et al*., 1999). Thus it has been successfully established as an exotic tree species in many countries, including Ghana. Also the minimum and maximum temperatures for development of the plant range from 13º to 17ºC and 39º to 43ºC respectively (Pandey and Brown, 2000). Teak plays an important economic role in West Africa and sustainable management is required to ensure its continuous feeding to the local and international markets (Adu-Bredu *et al*., 2008). Teak has very good wood properties such as very high density, fine grain and beautiful gold colour as well as its suitability for multiple uses (Gyimah *et al.*, 2001). The wood of Teak is extensively used as electricity and telephonic transmission poles, and also for housing and industrial construction as well as for furniture manufacture across the West African sub-region (Adu-Bredu *et al*., 2008). The various parts of the tree are used for medicinal purposes. The leaves are also used for wrapping fresh meat and fish and for thatching (Adu-Bredu *et al*., 2008). The mature Teak stands can reach 30 to 40 m height and 60cm diameter at breast height (d_{bh}). Ghana has a program to replant 20,000 hectares of its degraded forestlands each year (Asirifi-Boateng, 2005) and currently several governmental reforestation and afforestation programmes, as well as privately and foreign sponsored reforestation. Among the privately and foreign funded projects are those of Arbocarb Limited, FORM Ghana and German Agency for Technical Co-operation, GTZ-FORUM project (also aimed at the restoration of degraded reserves in the Volta Region of Ghana) apply predominantly Teak. The productivity of a plantation can be largely improved through the selection of a correct site for the establishment. Size, quality, density and the form of Teak trees vary from one location to another. There are several factors which control the distribution and growth pattern of the species. The major factors include the amount and distribution of rainfall and moisture, soil and light (Anyomi, 2008).

1.1 Justification

In view of the fact that site preparation methods play an important role with regards to growth performance of Teak stands, several methods are therefore considered and each of them has its own merits and demerits. A typical example is the slash and burning method. Although it would make planting easier and faster, some of the drawbacks are that some nutrients are lost in the process and also microfauna like ants, worms and snails are destroyed.

Estimation of the above-ground biomass with a sufficient accuracy to assess the variations in carbon stored in the forest is becoming increasingly important (Ketterings *et al*., 2001; Chave *et* al., 2004). Because an accurate estimation of the forest biomass is crucial for commercial uses (e.g., fuel wood and fibre), national development planning, as well as for scientific studies of ecosystem productivity, carbon (C) and nutrient flows and for assessing the contribution of changes in forest lands to the global Carbon cycle (Basuki *et al*., 2009). Therefore the Allometric equations are then used to estimate the tree biomass over large areas. Most allometric equations concerning tropical forests have been developed for the tropical forests of South America and Asia (Brown, 1997; Baker *et* al., 2004; Chave *et al*., 2005). However, there is a lack of such equations for the tropical humid forests of Africa hence equations developed for other regions are as consequence used by default. Moreover, reliability of such equations has never been tested. However, Henry *et al*., (2010) have developed allometric equations for a Wet Tropical forest of Ghana. Some authors concluded that species-specific allometric relationships are not needed to generate reliable estimates for forest carbon stocks (Gibbs *et al*., 2007), while others showed that species-specific allometric equation will improve biomass estimation (Ketterings *et al*., 2001; Pilli *et al*., 2006). Site variables have been shown to improve the performance of equations in both tropical and temperate even-aged forests (Saint-André *et al*., 2005).

1.2 Objective

This study seeks to assess the growth performance of a young Teak stand under different site preparation methods and planting stocks.

1.3 Specific objectives

Specific objectives of the study are:

- To determine the effect of propagation material on growth and stem form.
- To determine the best allometric equation to estimate above-ground dry mass of Teak trees.
- To assess the impact of site preparation methods on growth of Teak trees

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Plantation Development in Ghana

Early plantation development, which dates back from the early 1920s to the 1960s, was undertaken by the British Colonial Forest Service in the Ashanti and Northern Territories (Abu, 1996). Trees were planted by the German administration of Trans-Volta Togoland now the Volta Region and parts of the Yendi District. Productive plantations in forest reserves in Ghana, as far back as 1996, covered 15,000 hectares (Aninakwa, 1996). Over 60% of the total species was Teak, with other exotic species being *Cedrella odorata* (Cedrella), *Gmelina arborea* (Gmelina), *Eucalyptus grandis* (Eucalyptus). Indigenous species include *Triplochiton scleroxylon* (Wawa) and *Terminalia ivorensis* (Emire). Various commercial companies such as the British American Tobacco, Anglogold Ashanti and Bonsuvonberg have established stands of Teak plantation (Bonsuvonberg, 1996). Other small holder stands belonging to individuals and tree plantation associations can also be found all over southern Ghana.

2.1.1 Plantation establishment

Teak plantation establishment vary between and within countries, mainly according to site-specific conditions and prevailing markets. Typically, however, it is recommended that initial stocking rates be in the range of 1000 to 2000 stems per hectare to allow for early mortality rates and to provide an opportunity for selecting the better individuals during thinning operations (Pandey and Brown, 2000). The main objective of Teak plantation establishment is to produce high quality timber in trees with good or acceptable growth rates. Government influence on plantation establishment generally fall into two categories: direct government planting programmes and the payment of incentives for plantation establishment (Pandey and Brown, 2000). A great majority of the world's Teak plantations have been established under government planting programmes. Several countries in Africa also have utilized incentive policies to promote Teak planting. In Africa, much planting is still carried out by government agencies or as part of externally assisted afforestation or reforestation projects. Nonetheless, private sector involvement has been increasing in plantation establishment, often assisted by government incentives. In Ghana over 65% of existing Government plantations, represented by Forest Services Division of the Forestry Commission, consist of Teak (FPDC, 2001).

The government launched the 'National Forest Plantation Development Programme' (NFPDP) in 2001. This programme was implemented under three different strategies to reduce deforestation and to replant the degraded forests in the country via forest plantations in degraded forest reserves. The main goal of the programme is to develop a sustainable forest resource base that will satisfy future demand for industrial timber and enhance environmental quality. Additionally, the programme was expected to generate jobs and significantly increase food production in the country thereby contributing to wealth creation and reduction in rural poverty (FC, 2008). The government focuses on five different ways to achieve the goal of the NFPDP by (1) the establishment of forest plantations, (2) the planting of fruit trees on farming land, (3) the rehabilitation of mangrove forest, (4) urban forestry, and (5) the management of fire (FC, 2008). The species planted in the programme include Teak (*Tectona grandis*), Cedrella (*Cedrella odorata)*, Eucalyptus *(Eucalyptus grandis)*, Edinam (*Entandrophragma utile*), Ofram

(Terminalia superb), Emire *(Terminalia ivorensis)*, Nyankom (*Heritiera utilis*), Wawa *(Triplochiton scleroxylon)*, Mansonia *(Mansonia altissima)* and Mahogany (*Khaya senegalensis*). Past plantation establishments in Ghana have had different funding sources. Funding for reforestation was provided entirely from budgetary sources based on annual estimates under the Taungya system of the 1950s in the establishment of Forest Plantations Programme of the 1970s and the Community Forestry Programme of the 1980s (Nsenkyire, 1996). Mention is also made of a community Forestry Project in the Northern Region sponsored by Official Development Assistance (ODA) of the U.K. Combating Deforestation and Participation by the Rural People sponsored by the European Union, the Collaborative Community Forestry component of the World Bank sponsored Forest Resource Management Project have however benefited from funding from donors.

Plantation programmes have suffered largely due to the reliance on State coffers. The giant reforestation programme of the 1970s had an annual planting target of 10,000 hectares which was achieved by 1975. Planting rates however fell to below 2,000 hectares per annum after 1975 when the economy took a downward turn. Funding from State budgetary sources is therefore not the answer to the development of forest plantation (Nsenkyire, 1996).

2.1.1.1 Planting time

Teak has only one growth flush period throughout the year (Kaosa-ard, 1982). Shoot growth, as expressed in percentage of annual growth, starts soon after the first rain shower (late April), reaches its peak in the beginning of the rainy season (May-June), thereafter declines sharply in the middle of rainy season (July-October) and ceases during the dry season (November-April)

(Kaosa-ard, 1982). Kaosa-ard (1982) also recommended that Teak be planted just prior to, or during the growth flush period, i.e. between late April and early June, depending largely on the arrival of the first monsoon rain.

2.1.1.2 Selection of site

Teak is site-specific (White, 1991; Keogh, 2001), and therefore special consideration is given to site selection in order to maximize plantation returns as far as possible. The site for planting may be either a plain or sloping with excellent drainage. Soils derived from gneisses, schists and trap are good for Teak. Alluvial sites are superior for Teak growth while laterite or lateritic gravel as well as clays, black cotton, sandy and gravely soils derived from sandstone are not suitable for Teak plantations. Soil nutrients, altitude, slope gradient, natural vegetation and environmental assessment are the main parameters considered for site selection and site classification (Bekker *et al*., 2004)

2.1.1.3 Preparation of planting site

The selected sites are usually cleared of vegetation which is then left exposed and burnt when sufficiently dry. A study conducted by the Kerala Forest Research Institute (KFRI) indicates that slash-burning does not help to improve the growth of Teak beyond the first year (Chacko *et al.*, 1991). Depending on slope gradients and more recently on soil assessments, sites which are more erosion prone are treated differently in order to protect against erosion.

2.1.1.4 Planting stock

Teak can be raised either by the use of stumps or potted seedlings. Stump (bare-root seedlings) with a 1-2 cm diameter (at the thickest part, referred to as 'stump thickness') prepared out of one-year old seedlings are planted in holes made with a crowbar. In dry localities, where annual rainfall is less than 900 mm, pre-sprouted stumps raised in polythene containers a few months in advance give satisfactory results (Bekker *et al*., 2004). Direct sowing and transplanting of bare-root seedlings, though practiced in some areas, do not give satisfactory results (Bekker *et.al*., 2004). Stumps have been used for plantation establishment in accordance with the following procedure: The seeds are first pre-treated by soaking in water and dried under full sun alternately several times in order to stimulate germination in nursery germinating beds. However, despite these treatments, the germination process may last from 2 weeks up to 6 months or even more, although in practice, only the seedlings germinated in less than 2 months are used. These seedlings are then cultivated for 10 to 12 months on average until they reach a suitable stage when they can be converted into stumps of 15 to 20 cm in length and at least 12 mm in diameter. Weaker stumps remain in the nursery longer. As an indication, 1000 “seeds” (1.0 kg) ultimately give 170 plantable stumps. Stumps can be stored and transported in much greater quantities and in more cost effective conditions. Stump planting is not time-restricted and can be extended to several weeks. The main disadvantages associated with the use of stumps are as follows; Production of multiple stems resulting from the trimming of the main original stem; Trimming the tip of the original taproot also induces the formation of secondary roots which take over the main root, but incidence on the future of the plant seems very unlikely; and longer periods for stump cultivation and maintenance results in higher cost for production.

In raising potted seedlings the seeds can be sown directly in polythene bags with organic substrate (2 seeds per container), but unpredictable germination rates (35 % on average at present) require further manipulations such as seedling removal or transplanting in order to obtain one seedling per container. Therefore the option of pre-germinating the seeds, in trays for instance or seed beds, in order to do early transplanting into containers of only the germinated seeds has been preferred. The following procedure can thus be used for raising potted seedlings; the seeds are pre-treated by soaking in water and dried under full sun alternately several times in order to stimulate the germination process; the germinated plants are then transplanted into polythene bags of 90 cm^3 filled with organic substrate; seedlings are sorted within the trays according to "size; application of appropriate fertilizers and water supplies to ensure a uniform crop; and control and treatment of pest and disease". Container size and spacing must be large enough to cater for the large leaves. Potted seedlings have some advantages. The taproot remains intact and also less nursery space and time required. There is a greater uniformity in the resulting crop with the possibility of size sorting in the nursery. Also weeding requirements are significantly reduced due to the utilization of sterile medium. However there are some demerits associated with the use of potted seedlings since they are sensitive to hydric stress, require intensive hands-on management, infield planting are not very flexible in terms of timing (require adequate rains before establishment as well as after planting) and they are expensive to store and transport.

2.1.2 Plantation management

Apart from site and seed problems, the success of Teak plantation establishment also depends largely on silvicultural management. The common management practice include, weeding, spacing, singling, pruning and thinning.

2.1.2.1 Weeding

The main reason for carrying out this activity is to reduce competition on the crop trees. Further reasons are for fuel management and the reduction of combustible material for fire prevention.

2.1.2.2 Planting space

Initial spacing of Teak plantation varies (1.8×1.8 to 4×4 m) depending on many factors as site quality, cost of establishment, thinning regime, small wood utilization, planting system, e.g. agro-forestry, intercropping etc. Under dry site conditions, where the initial growth rate of the plantation is poor (e.g. < 1.0 metre per year in height), close spacing of 2×2 m is most suitable. In Thailand a 3×3 m spacing (1,111 trees ha^{-1}) has been recommended and is used as the routine spacing. Similar results of spacing trials are reported from India where close spacing of 1.8×1.8m and wider spacing of 3.6×3.6 m are suitable for dry and good (rainfall <1,500 mm) site conditions respectively (Tewari, 1992). As Teak plants are susceptible to weed infestation, especially the grasses, weed control becomes a very important management activity, particularly during the initial 2 to 3 years of establishment (Tewari 1992).

2.1.2.3 Singling

This activity is the result of the stump preparation process whereby the stem is removed at the root collar. The removal of the stem causes prolific coppicing and the excess stems, numbering from 2 to 6, need to be removed. The strongest growing, straight stem is retained and the rest are removed by hand when the shoots are young and soft. Mortality recorded at this time averages 20 to 25 %. Beating-up is done immediately, and ultimately plantation losses do not exceed 8 % (Bekker *et al*., 2004).

2.1.2.4 Thinning

Thinning is the removal of some trees in the field to provide growing space for the remaining trees. Thinning prescriptions vary from one locality to another. Unfortunately, it is often governed by revenue rather than silvicultural considerations. In a good quality plantation, managed on a 50 year rotation, the thinnings are expected to be carried out at the 4^{th}, 8^{th}, 12^{th}, 18^{th}, 26^{th} and 35^{th} year. Thinning schedule varies with site quality. In better plantations the thinnings are done early as compared to poor plantations

2.1.2.5 Pruning

Pruning is essential when the plant produces prematurely heavy lateral branches. It is not known if this is an inherent genetic problem or a result of site interaction. The heavy branching could be a result of climatic circumstances, especially the markedly long dry season. The management considers that such heavy branching is liable to induce the formation of large nodes which may seriously depreciate log value, especially for rotary veneer production. Intensive pruning is therefore carried out: to remove any multiple stems.

2.2 Nature of Teak

Teak *(Tectona grandis* Linn.F*)* is a large deciduous tree with a rounded crown and, under favourable conditions, a tall clean cylindrical bole of more than 30 m. The base of the tree is often buttressed and sometimes fluted. The leaves of the tree are broadly elliptical and usually 30 to 60 cm long. Over most of its range, Teak occurs in moist and dry deciduous forests below 1000 m elevation and is one of the several species constituting mixed forest stands. Teak wood is dense, rich in oil, almost impervious to splitting, buckling and rot, making it termite proof. Teak has natural resins called technoquinines, thus its ability to naturally repel termites, marine borers and resist rot. Teak has a very attractive straight grain (Pandey and Brown, 2000). It does not corrode iron and steel. Teak is highly resistant to moisture, fire, acid and alkali. The presence of natural oils makes it suitable for use in exposed locations, where it is durable even when not treated with oil or varnish. Teak exhibits a wide range of colours when cut fresh, from pale yellows to orange browns with darker striping, all of which mellows into medium brown tones. The use of Teak trees however has few difficulties. Teak can be difficult to glue together because the oils form a barrier that does not easily absorb the glue into the surface. It can be expensive to buy and because of the gritty nature of the wood grain it can blunt cutting tools very quickly. It is common knowledge among loggers that teak from wetter site conditions, e.g. along river banks or in the lower moist teak forest, is usually darker in wood colour than that from drier site conditions. Teak wood colour seems to be influenced by the site on which it developed.

2.2.1 Germination of Teak trees

It is well known that the germination of Teak seed is one of the most critical problems in a plantation. Experience gained from the Teak growing region, e.g. India, Bangladesh, Myanmar, Thailand, Laos and Indonesia, indicates that the germination of Teak in the nursery is very low and sporadic (Kaosa-ard, 1986). This low and sporadic germination is due to the strong dormancy behaviour of Teak seed, which causes a low plant percentage in nursery production. This low germination percentage and the sporadic germination of the Teak seed can be improved to a certain degree (at least in small-scale nursery practices) through various seed pre-sowing techniques including soaking the seed in water or in a mixture of cow dung and water, alternate soaking and sun drying, heat treatment, etc. (Kaosa-ard, 1986).

2.3 Stem volume estimation

Volume equations or stem profile equations can be used for volume assessment, but the latter brings in more flexibility. With stem profile equation the forest manager has the possibility of estimating volumes at any desired top end. Adu-Bredu *et al*. (2008) therefore developed stem profile equation for Teak in West Africa. They identified three general forms of Teak stem profile namely zero-forked trees, one-fork trees and two-fork trees. Forks in Teak mainly occur when the terminal bud dies either for genetic reasons (flowering) or by accident (wind breaks, insect attacks etc.). Secondary branches therefore relay the dead main axis leading to more or less pronounced forks and sudden decrease in stem diameter.

2.4 Biomass estimation

Estimation of biomass in a given forest consists of carrying out an inventory of the vegetation in sampled plots, application of appropriate allometric equations, and up-scaling to estimate biomass Carbon stocks at the stand level (Chave *et al*., 2004). Key point of this method is the allometric equations (Návar, 2009). Despite their apparent simplicity, they have to be fitted carefully using the latest regression techniques available (Parresol, 1999; Wirth *et al*., 2004). Inappropriate application of allometric equations developed for a particular forest type to a different forest type may lead to considerable bias in Carbon stocks estimations. For example, application of an allometric equation developed for a tropical moist forest (Brown, 1997) when applied to a tropical wet forest (Clark and Clark, 2000) over estimated aboveground biomass by 79% (Clark *et al*., 2001).

2.5 Carbon analysis

Growth of plants is closely linked to the balance of carbon gain and losses. To be able to make full account of the carbon budget and the carbon use efficiency of a stand, it is important to identify all the gains and losses of carbon by the stand (Adu-Bredu, 1997). Through photosynthesis carbon and latent energy is acquired by the plant, whereas through respiration the acquired carbon is broken down into intermediates (carbon skeleton) and the latent energy released in a form that is usable by the plant. Though carbon is lost through respiration, respiration is an essential component of plant metabolism for without it life is impossible (Amthor and McCree, 1990). The other main loss of carbon to the plant is death of plant part. An increase in dead tissue, whether abscised or dead, is loss of functional carbon (Adu-Bredu, 1997).

2.5.1 Biomass carbon stock

Calculations of the quantities of carbon stored by trees require knowledge, not only of their growth rates, but also of the proportions of carbon contributing to their chemical make-up. A 50 % value is assumed for the carbon content of dry wood for most species and purposes (Mathews, 1993). The carbon in a tree is bound in the organic compounds making up the body of the tree, mainly cellulose, hemicelluloses and lignins, and the proportions of these vary with species, position in the tree, the nature of the cells, the geographic location, age, and probably other factors. Since the carbon contents of these substances are considerably different, it would be expected to result in appreciable variation in carbon contents of trees.

2.5.2.9 Soil carbon stock

Soil carbon improves the physical properties of soil by increasing the cation exchange capacity (CEC) and water-holding capacity of sandy soil. It contributes to the structural stability of clay soils by helping to bind particles into aggregates (Leeper and Uren, 1993). Since plant production and decomposition determine carbon inputs into the soil profile the type of vegetation cover may influence the abundance of organic carbon in the soil, which in turn affects plant production (Jobbagy and Jackson, 2000). Although exact quantities cannot be documented, human activities have caused massive losses of soil organic carbon (Ruddiman, 2007). First was the use of fire, which removes soil cover and leads to immediate and continuing losses of soil organic carbon. Tillage and drainage both expose soil organic matter to oxygen and oxidation.

2.5.3 Litter and herb carbon stock

Litter-fall is the shedding of leaves, bark, twigs and other forms of dead organic material and its constituent nutrients from the aerial parts of the biosphere to the top layer of soil, commonly known as the litter layer. It is one of the major pathways of matter and energy flow through a forest ecosystem. However the total dead matter including the attached dead materials should be considered in order to fully understand the production process in trees or stands, because how much dead matter a tree produces is of great significance for its energy budget, especially young trees. Also the quantity of undergrowth herbs present could be use as an indicator for carbon stock.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Site description

The study was conducted at Afram Headwaters Research Center; a research station of the Forestry Research Institute of Ghana (FORIG) at Abofour. The station is located along the Kumasi-Techiman road, in the Offinso District of Ashanti Region (Figure 1). It falls under the Inner zone sub-type of the Dry Semi-deciduous forest ecological zone (DSDF). The other ecological zones in the country are Wet Evergreen forest, Moist Evergreen forest, Moist Semi-deciduous forest (North West and South East sub-types). Mean annual maximum and minimum temperatures as well as mean annual rainfall for the area is 30.61^{o}C, 21.22 ^{o}C and 1,242.7 mm, respectively. The Teak stand was established in the year 2000 by scientist at the Forestry Research Institute of Ghana (FORIG). Elevation of the plot lies between 345 m and 445 m above sea level, with a slope of 10%. The geographical coordinates of the four corners of the plot are: 7.1789 N, 1.7376 W; 7.1797 N, 1.7376 W; 7.1807 N, 1.7393 W; 7.1797 N, 1.7394 W.

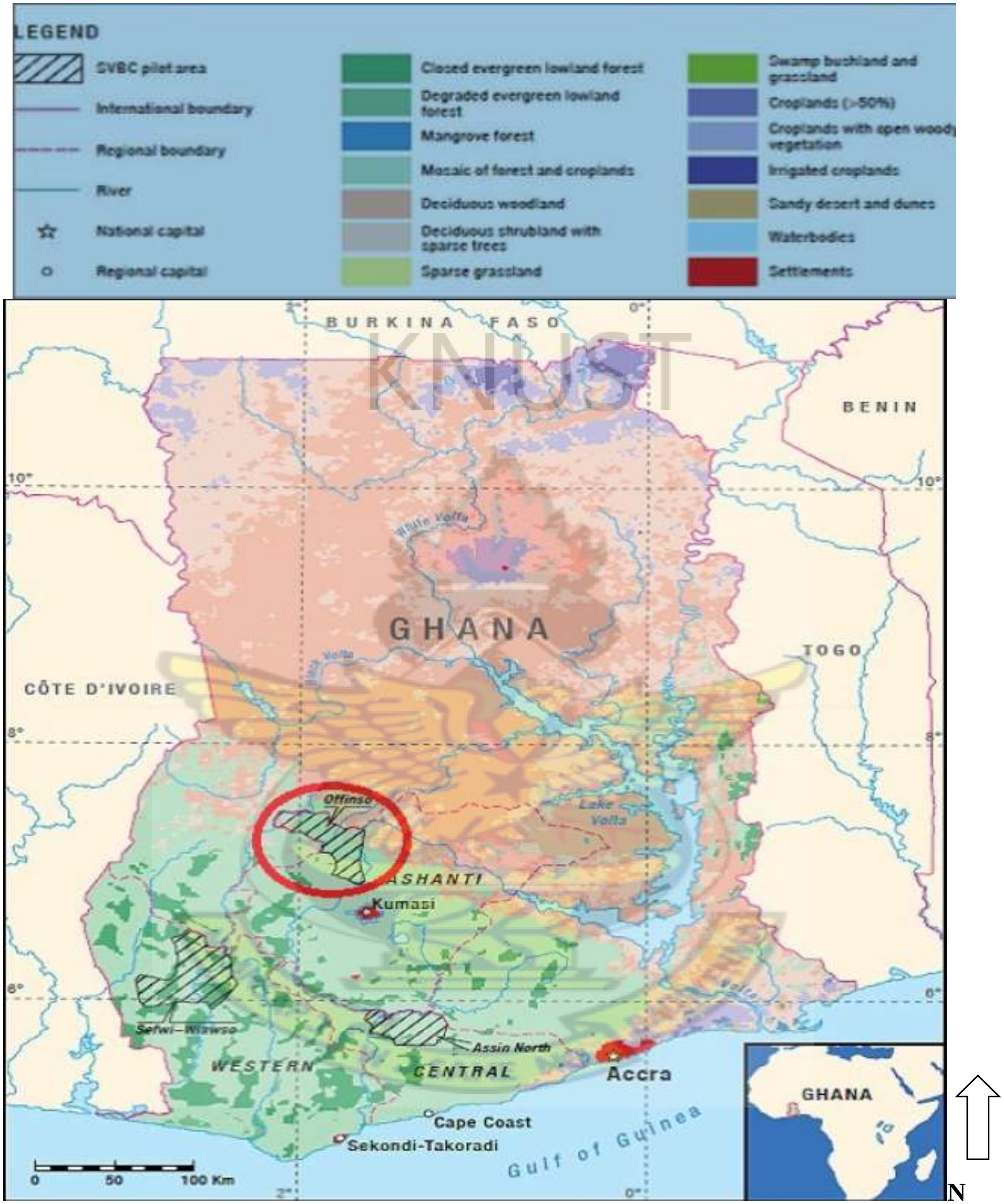

Figure 1: Vegetation map of Ghana showing Offinso District in red circle (Source: IUCN, 2009)

3.2 Experimental design and treatment

Nested Block design (Figure 2) was applied in this experiment to accommodate the Main Treatments, Sub-Treatments and Planting stocks. The dimension of the stand was 200 by 100 m, giving rise to a size of 2.0 ha. The plot was sub-divided into quarter hectare sub-plots of size 50 by 50 m, giving rise to eight sub-plots. The sub-plots were subjected to alternate burnt and un-burnt treatments. In the un-burnt plots the debris was left on the plot. The sub-plots were further divided into sub-sub plots of size 25 by 25 m. Fertilizer was applied to the planting site and was allocated to two sub-sub plots opposite to each other in the sub-plot. Ninety grams of 50: 50: 50 N: P: K inorganic fertilizer was applied to a hole and slightly covered with soil before planting the seedling. This was to prevent direct contact of the seedling with the fertilizer. The planting stock of bare rooted stumps and potted seedlings were then planted in the fertilized and un-fertilized sub-sub plots within each sub-plot. The planting distance was 3.0 by 3.0 m, giving rise to stocking density of 1152 plants per hectare.

Legend

	BURNT SITES
	UN-BURNT SITES
F	FERTILIZED SITES
U/F	UN-FERTILIZED SITES
ST	BARE ROOTED STUMP PLANTING STOCKS
PO	POTTED SEEDLING PLANTING STOCKS
	1X1M QUADRAT

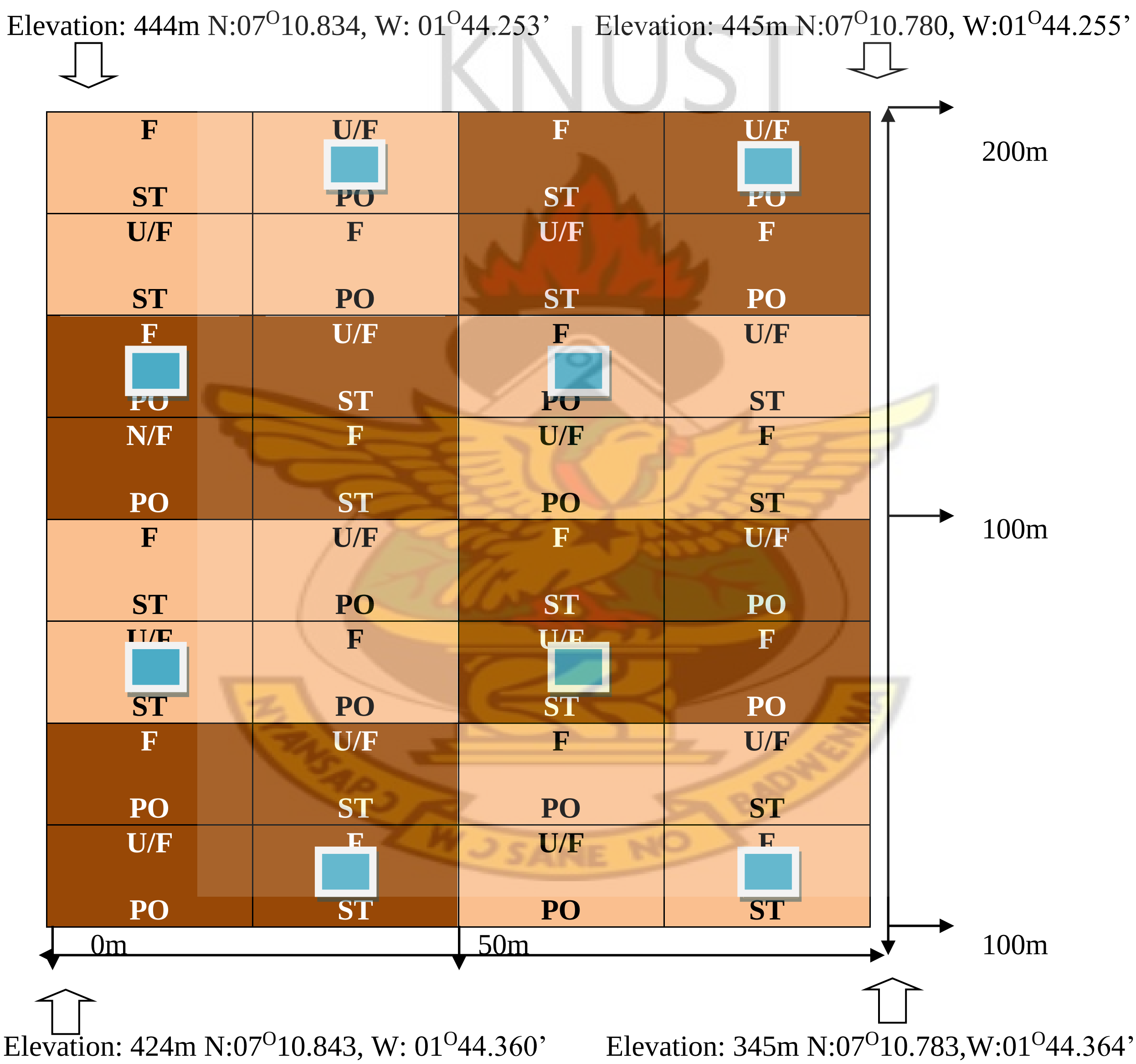

Figure 2. Layout for the nested block design of the treatments, sub-treatments and planting stocks.

3.3 Tree survey

A survey of the trees was carried out in April and May 2010 (Plate 1). During the survey, assessment was conducted on sub-sub plot basis. Each sub-sub plot contains 64 trees (8 by 8 trees), however, only the inner 36 trees (6 by 6 trees) were considered. This is to avoid edge effect. Diameter at breast height (*dbh*) of 1.3 m was measured with callipers (Plate 2), whiles total tree height and forking positions were measured with wide scale relascope (Plate 3). Forks in trees refer to the breaking of axis to give rise to two or more axis of equivalent size (Drénou, 2000). From the measurements, stem volume, individual tree phytomass, as well as stand biomass was calculated by applying the appropriate equation.

Plate 1. Recording of data collected by investigator.

Plate 2. Measurement of diameter at breast height of 1.3 m using callipers.

Plate 3. Measurement of tree height and fork position along bole using wide scale Relascope.

3.4 Undergrowth vegetation and litter sampling

Undergrowth vegetation (herbs) and litter were assessed through the laying of 1.0 m by 1.0 m quadrat (Appendix, 1A) in eight selected sub-sub plots. The plots were selected to reflect the site treatment and planting stock. Within each quadrat the undergrowth vegetation was uprooted. The litter within the quadrat was also gathered and sorted into leaf and wood litter. The total fresh mass of undergrowth vegetation and litter were then weighed with electronic balance in the field (Appendix, 1B). Sub samples were collected for dry mass determination at the laboratory. The sub samples were oven-dried at 65 ^{o}C to constant mass in the laboratory.

3.5 Soil sampling

After the underground vegetation and litter have been removed from the quadrats, soil samples were collected (Appendix, 1C). The soil samples were collected from the soil depth of 0-10 cm, 10-20 cm, 20-30 cm and 30-40 cm using soil augur for nutrient analysis. Corresponding soil samples were collected from the same soil depth for bulk density determination using soil core samplers. The soil samples for nutrient analysis were air dried (Appendix, 1D) and then sieved through 2.0 mm wire mesh to separate fine soil from the rocks. The fine soil was then used for the nutrient analysis. With regards to the soil sample for bulk density determination, the fresh weight of the soil samples were measured (Appendix, 1E) and then oven dried at 105 °C to constant mass at the laboratory. The oven dried samples were then sieved through 2.0 mm sieve to separate the fine soil from the gravels or coarse soil.

3.6 Nutrient analysis of soil

The organic matter and organic carbon content of the soil were analyzed in the laboratory at Soil Research Institute (SRI), Kumasi. The fine soil samples were weighed in duplicate and transferred to 250 ml Erlenmeyer flask. Ten millilitre (10 ml) of 1N of $K_2Cr_2O_7$ solution was pipetted accurately into each flask and swirled gently to disperse the soil, and then 20 ml concentrated H_2SO_4 was added rapidly using an automatic pipette, directing the stream into suspension. The flask with soil and reagents was gently swirled immediately until the content was mixed and then swirled more vigorously for one minute. The beaker was rotated again and the flask was allowed to stand on a sheet of asbestos for about 30 minutes. Afterwards 100 ml of distilled water was added to the flask. About 3 to 4 drops of the indicator, O-phenanthroline-ferrous complex (0.025M) (Ferroin) was added and titrated with 0.5 N ferrous sulphate skyolution. As the end point approached, the solution turned to a greenish cast and then changed to dark green. At that point, the ferrous sulphate was added drop by drop until the colour changed sharply from blue to red (maroon colour) in reflected light against a white background. The result was then calculated according to the following formula:

$$OC\ (\%) = \frac{(meK_2Cr_2O_7 - meFeSO_4)\times 0.003\ \times 100\times f}{Air\ Dry\ Soil\ (g)}$$ .... equation 1

Where;

- OC = Organic carbon
- f = 1.33 (Correction factor)
- me = Normality of solution x ml of solution used.:
- Organic matter in soil (%) = Organic Carbon (%) x 1.729.

The soil carbon per hectare was estimated using the underlining equation:

Soil C (Mg ha-1) = C content (kg/kg) x Bulk density (kg/l) x depth (cm) x 100............equation 2

3.7 Destructive sampling of trees

Asomaning (2006) developed allometric equations for the estimation of above ground phytomass of Teak trees on the basis of fourteen (14) destructively sampled trees all under the Dry Semi-deciduous Forest ecological zones. Diameter at breast height and total tree height were used as the independent variables in the development of the equation. The data was re-analysed and stem volume was included as independent variable as well as wood density. The sample trees were selected from four different aged stands at Braboagya, Akrobi, Nchiraa, and Ofuman plantation areas. Five trees were sampled from 6-year-old stand, whereas three trees each were sampled from 12-, 19- and 31-year-old stands, giving a total of fourteen trees. The sampled trees were felled close to the ground, but before felling the breast height position of 1.3 m were marked. Diameter measurement was carried out on the stem of the felled trees at 0.5, 1.3, 2.0, and thereafter at one-metre intervals along the bole of the stem up to the tree top (Figure 3). Diameter measurements were also carried out on the main branches and their corresponding sub-branches at one-meter intervals starting from the base (Figure 4). Diameter tape was used to measure the larger sized diameters whereas digital calliper was applied for the smaller sized diameters. Disks were taken from the stem at 0.5, 1.3, 2.0, 3.0 m and thereafter at 2.0 m intervals for the big trees (Appendix, 1F) and 1.0 m intervals for smaller trees. The measured characteristic of the sample trees affected by destructive sampling is shown in Appendix 2. Disks were also taken from the branches. They were taken in such a way that all sizes of branches were represented. The Fresh mass of the stem and branch disks were taken on-site, with digital scale. The samples were taken to the laboratory for dry mass determination. The disk samples were oven-dried at 105 °C to constant mass. This was to ensure a true indication of the dry matter, unaffected by the soil moisture or relative humidity at the experimental site. This therefore allowed valid comparisons of oven dry mass of samples across sites.

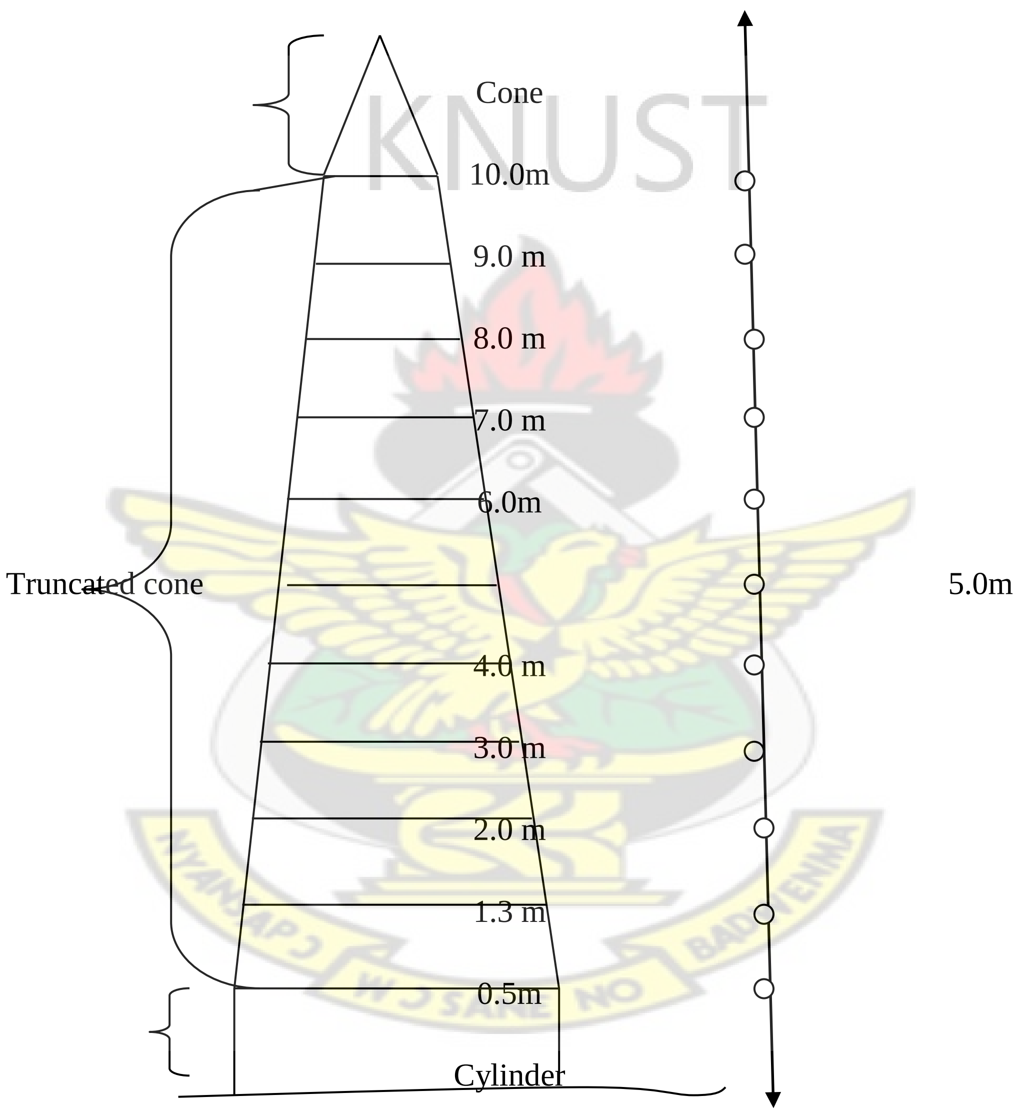

Figure 3. Sections of the stem for destructive measurement and stem disc retrieval.

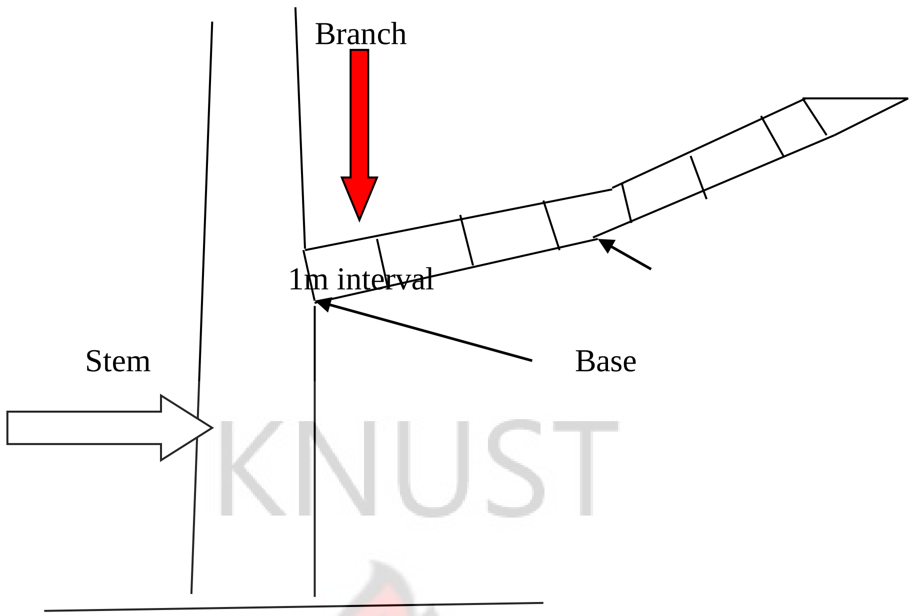

Figure 4. Sections of branch for destructive measurement and branch disc retrieval

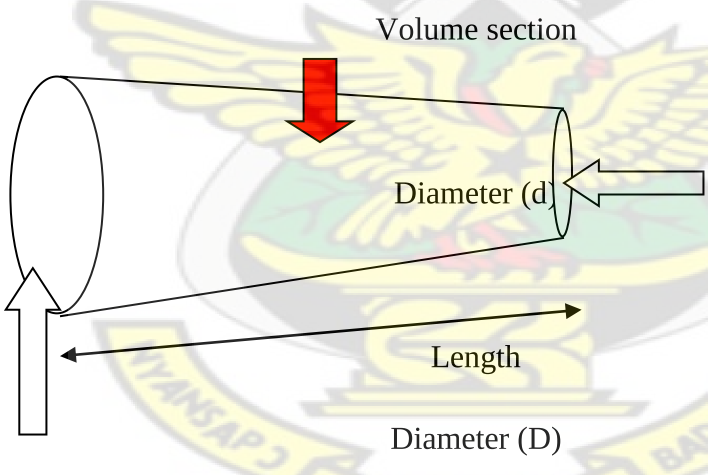

Figure 5. Volume of the stem section

3.8 Data Analyses

3.8.1 Allometric equations

3.8.1.1 Tree phytomass calculation

The stem diameter measurements at 0.5, 1.3, 2.0 m, and thereafter at 1.0 m intervals up to the tree top and total tree height were used in the stem volume, $V_{S,}$ calculation, whereas the branch diameters at the 1.0 m intervals starting from the branch base, were used for that of branch volume, $\mathbf{V}_B$. Volume was calculated from each stratum. The stem was divided into cylinder (base), truncated cone (main) and the conical (top) parts. However, for the branches all the strata, with the exception of the top, were regarded as truncated cone. Volume for the base was calculated as,

$$V_{(base)} = \pi \frac{D^2}{4} L \text{...equation 3}$$

L is the length and *D* is Diameter of the first segment.

Volume of the stem section (Figure 5) was calculated as;

$$V_{(main)} = \frac{\pi}{12} L\,(D^2 + Dd + D^2) \text{..equation 4}$$

Where *D* is diameter of large end and *d* is diameter of small end.

For the top part, which was regarded as cone, the volume was calculated as

$$V_{(top)} = \frac{L}{12}\,(\pi D^2) \text{...equation 5}$$

Summation of the volume at the various strata gives the volume of the stem or branch.

The wood density of the disks collected from each stratum was calculated as the ratio of disk dry mass to disk volume. For the stem, the wood density was multiplied by the corresponding stratum volume to determine dry mass of the stratum. For the branch, the dry mass of all the disk samples was proportionally related to the disk volume to determine the branch wood density for the sample tree, and this was multiplied by the total branch volume of the tree to determine the branch dry mass. The stem and branch mass was summed up to obtain mass of the tree.

3.8.1.2 Regression Model

One, two and three variable models were developed for the estimation of above ground tree phytomass.

For the one-variable model, tree phytomass was modelled as a function of diameter at breast height (*dbh)*, and this is given as:

Tree phytomass = f (*dbh*)

Also tree phytomass was modelled as a function of tree volume (*V*s), and this is given as:

Tree phytomass = f (*Vs*)

for the two-variable model, *dbh* and tree height (*h*) were the independent variables and this is given as;

Tree phytomass = f (*dbh, h*)

whereas for three-variable model wood density (ρ) was added as the third independent variable, and given as;

Tree phytomass = f (*dbh, h, ρ*)

The above-ground phytomass (kg) of tree was used as the dependent variable and independent variables used were d_{bh} (cm), combination of d_{bh} (cm) and height (m), combination of wood density (kg dm^{-3}) and d_{bh} (cm), combination of wood density (kg dm^{-3}), d_{bh} (cm) and height (m), and stem volume (dm^3). Four types of regression functions namely exponential, linear, and polynomial and power function were assessed to select the best fit. Coefficient of determination (R^2) was used as the criterion for the selection of the best fit.

3.8.2 Stem volume estimation

For zero-forked trees, that is trees without forks, the model was given as,

$$dr = a[(1-bhr)(1+c\exp^{-dhr}) - (1-b)\,hr^{e}] \quad \text{.......equation 6}$$

where a and b are coefficients that describe the general tapering of the tree, (a is also the intercept on the dr axis while b is also a measure of the slope of the bole), d is a measure of the curve of buttressing, c is a measure of the magnitude of buttressing and e describes form of the tree top. In addition exp is the exponential function. The parameters a, b, c, d and e are estimated by fitting procedure. Multiplying both side of equation 3 by d_{bh}, results in the estimation of diameter, D.

The stem profile of trees with one fork was modelled as:

when hr ≤ z1 then,

$$dr = a[(1-bhr)(1+c\exp^{-dhr}) \quad \text{.......equation 7}$$

And when hr > z1

$$dr = a\,(1-bz_1)(1+c\exp^{-dz1}) \times drop1 \times \frac{(1-bbhr) - (1-bb)\,hr^{e}}{(1-bbz1) - (1-bb)\,z_1^{e}} \quad \text{.......equation 8}$$

Where z_1 is the position of the first fork relative to the total tree height, *bb* is the slope after the first fork and *drop 1* is the extent of diameter reduction due to the first fork.

The model for two-forked tree was given as:

when hr ≤ z_1 then

$$dr = a[(1-bhr)(1+c\exp^{-dhr}) \quad \text{.......equation 9}$$

when $z_1 < hr \leq z_2$ then

$dr = a(1-bz_1)(1+c\exp^{-dz_1}) \times drop1 - bb(hr - z_1)$..equation 10

and when $hr > z_2$ then,

$dr = a(1-bz_1)(1+c\exp^{-dz_1}) \times drop1 - bb(z_2 - z_1) \times drop\ 2 \times \frac{(1-hr)}{(1-z_2)}$.........................equation 11

Where z_2 is the position of the second fork relative to the total tree height, *drop 2* the extent of diameter reduction due to the second fork and *bb* the stem taper between the first and second forks. Data collected from the census on tree height, d_{bh} and fork positions were considered, whereas *a, b, bb, c, d, e, drop 1* and *drop 2* are estimated by the fitting procedures. The formulated model does not allow an analytical integration. The stem volume was therefore numerically calculated. The total tree height (*h*) was divided into 20 sections, and the diameter at each of the 20 relative heights was estimated using the taper equation and each log volume (*v*) was obtained from the truncated cone formula. The total volume was calculated as the sum of the 20 sections as

$v = \sum_{n=1}^{20}\left(\frac{\pi}{12}\frac{h}{20}(d_i^2 + d_i d_j + d_j^2)\right)$..equation 12

where d_i and d_j are the predicted diameter at the smaller and larger end of the sections, respectively.

3.8.3 Stand level estimation

The appropriate equations were applied for the calculation of stem level parameters like stem volume, biomass and system carbon stocks under the various site preparation methods and planting stocks. The differences were then analysed with two-way Analysis of Variance (ANOVA).

CHAPTER FOUR

4.0 RESULTS

4.1 Survival of Teak trees

4.1.1 Burnt and un-burnt sites

The mean percentage survival of Teak trees in the sub plots of the burnt and un-burnt sites is shown in Table 1. In the sub plots of the burnt and un-burnt sites the Teak trees in the burnt sites had a mean percentage survival of 57% whiles those in the un-burnt sites had 46%. The mean percentage survival of Teak trees in the burnt sites was greater but not significantly different (p = 0.19) from those in the un-burnt sites.

The Teak trees in the un-burnt-un-fertilized-potted seedling sites had the highest mean percentage survival followed in a decreasing order by the burnt-fertilized-potted seedling, burnt-un-fertilized-potted seedling, un-burnt-fertilized-potted seedling, burnt-un-fertilized-stump, burnt-fertilized-stump, un-burnt-fertilized-stump and un-burnt-un-fertilized-stump sites with the values being 84,74,73,60, 41, 40, 22, and 22% respectively. However un-burnt-fertilized-stump and un-burnt-un-fertilized-stump sites had the same mean percentage survival. There was no significant difference (p = 0.53) between the mean percentage survival of Teak trees in the sub-sub plots.

Table 1. Mean percentage survival of Teak trees in the burnt and un-burnt sites.

TREATMENTS	MEAN ± SD (%): $\bar{x}$ ± S.D
1	74 ± 7
2	40 ± 10
3	73 ± 18
4	41 ± 27
BURNT SITES	**57 ± 11**
5	60 ± 16
6	22 ± 10
7	82 ± 20
8	22 ± 8
UN-BURNT SITES	**46 ± 5**

Key

1: Burnt-fertilized-potted seedling sites
2: Burnt-fertilized-bare rooted stump sites
3: Burnt-un-fertilized-potted seedling sites
4: Burnt-un-fertilized-bare rooted stump sites
5: Un-burnt-fertilized-potted seedling sites
6: Un-burnt-fertilized-bare rooted stump sites
7: Un-burnt-un-fertilized-potted seedling sites
8: Un-burnt-un-fertilized- bare rooted stump sites

4.1.2 Fertilized and un-fertilized sites

The mean percentage survival of Teak trees in the fertilized and un-fertilized sites is shown in Table 2. In the sup plots of the burnt and un-burnt sites the mean percentage survival of Teak trees in the fertilized sites was 49 % whiles those in the un-fertilized sites had 54 %. The mean percentage survival of Teak trees in the fertilized sites was lower than those in the un-fertilized sites but not significantly different (p = 0.21).

The Teak trees in the un-fertilized-un-burnt-potted seedling sites had the highest mean percentage survival followed in a decreasing order by the fertilized-burnt-potted seedling , un-fertilized-burnt-potted seedling, fertilized-un-burnt-potted seedling, un-fertilized-burnt-stump, fertilized-burnt-stump, fertilized-un-burnt-stump and un-fertilized -un-burnt -stump sites with the values being 84,74,73,60 41, 40, 22, and 22 % , respectively. However fertilized-un-burnt-stump and un-fertilized-un-burnt-stump sites had the same mean percentage survival. There was no significant difference (p = 0.20) between the mean percentage survival of Teak trees in the sub-sub plots.

Table 2. Mean percentage survival of Teak trees in the fertilized and unfertilized sites.

TREATMENTS	MEAN ± SD (%): $\bar{X}$ ± S.D
1	74 ± 7
2	40 ± 10
3	60 ± 16
4	22 ± 10
FERTILIZED SITES	**49 ± 7**
5	73 ± 18
6	41 ± 27
7	82 ± 20
8	22 ± 8
UN-FERTILIZED SITES	**54 ± 7**

Key

1: Fertilized-burnt-potted seedling sites
2: Fertilized-burnt-bare rooted stump sites
3: Fertilized-un-burnt-potted seedling sites
4: Fertilized-un-burnt-bare rooted stump sites
5: Un-fertilized-burnt-potted seedling sites
6: Un-fertilized-burnt-bare rooted stump sites
7: Un-fertilized-un-burnt-potted seedling sites
8: Un-fertilized-un-burnt-bare rooted stump sites

4.1.3 Planting stocks

The mean percentage survival of the planting stocks of potted seedling and bare rooted stump Teak trees is shown in Table 3. In the sub plots of the burnt and un-burnt sites the mean percentage survival of the planting stocks of potted seedling trees was 72 % and those of the stump planting stocks had 31%. The mean percentage survival of Teak trees of the potted seedling planting stocks was significantly greater (p = 0.001) than those of the stump planting stocks.

The Teak trees of the potted seedling-un-fertilized-un-burnt planting stocks had the highest mean percentage survival followed in a decreasing order by the potted seedling-fertilized-burnt, potted seedling-un-fertilized-burnt, potted seedling-fertilized-un-burnt, bare rooted stump-un-fertilized-burnt, bare rooted stump-fertilized-burnt, bare rooted stump-fertilized-un-burnt and bare rooted stump-un-fertilized-un-burnt planting stocks with the values being 84,74,73,60 41, 40, 22, and 22 % respectively. However the trees of the bare rooted stump-fertilized-un-burnt and bare rooted stump-un-fertilized-un-burnt planting stocks had the same mean percentage survival. There was no significant difference (p = 0.57) between the mean percentage survival of Teak trees in the sub-sub plots.

Table 3. Mean percentage survival of the planting stock of potted seedling and bare rooted stump Teak trees.

TREATMENTS	MEAN ± SD (%): $\bar{x}$ ± S.D
1	74 ± 7
2	60 ± 16
3	73 ± 18
4	82 ± 20
POTTED SEEDLINGS	**72 ± 9**
5	40 ± 10
6	22 ± 10
7	41 ± 27
8	22 ± 8
BARE ROOTED STUMPS	**31 ± 8**

Key

1: Potted seedling-fertilized-burnt planting stocks
2: Potted seedling-fertilized-un-burnt planting stocks
3: Potted seedling-un-fertilized-burnt planting stocks
4: Potted seedling-un-fertilized-un-burnt planting stocks
5: Bare rooted stump-fertilized-burnt planting stocks
6: Bare rooted stump-fertilized-un-burnt planting stocks
7: Bare rooted stump-un-fertilized-burnt planting stocks
8: Bare rooted stump-un-fertilized-un-burnt planting stocks

4.2 Allometric relationship for tree phytomass

4.2.1 Tree phytomass estimations

The comparisons of model fit for the above-ground phytomass determination is represented in Table 4. For the one variable model with diameter at breast height, d_{bh}, as the independent variable the highest R^2 value was the power functional model followed in a decreasing order by the polynomial, linear and exponential functional models with the values being 0.9890, 0.9579, 0.9572 and 0.7326, respectively. With stem volume (*Vs*) as the independent variable the highest R^2 value was power functional model followed in a decreasing order by the polynomial, linear and exponential functional models with the values being 0.9978, 0.9960, 0.9928 and 0.7388, respectively. It was observed that the stem volume (*Vs*) as independent variable had the highest the R^2 value at 0.9978 (Table 4).

In the two-variable model using the combination of d_{bh} and h as the independent variable the highest R^2 value was the power functional model followed in a decreasing order by the polynomial, linear and exponential functional model with the values being 0.9951, 0.9865, 0.9865 and 0.7004, respectively. However the polynomial and the linear functional model had the same R^2 value. It was observed that by combining h to d_{bh} as the independent variable the R^2 value increased from 0.9890 to 0.9951 in Figure 6 and 7 respectively. Further with the combination of d_{bh} and wood density, ρ as the independent variable the highest R^2 value was the power functional model followed in a decreasing order by the polynomial, linear and exponential functional models with the values being 0.9929, 0.9673, 0.9669 and 0.7208, respectively.

Table 4. Comparison of model fit for above-ground phytomass determination

MODEL	EQUATION	INPUT	PARAMETERS			R^2
			A	*B*	*C*	
ONE VARIABLE MODEL						
LINEAR	$M_T = A\,D + B$	D_{BH}	0.3144	-12.773		0.9572
POLYNOMIAL	$M_T = AD^2 + BD + C$	D_{BH}	0.000003	0.2869	-9.1012	0.9579
POWER	$M_T = AD^B$	D_{BH}	0.0604	1.2462		**0.9890**
EXPONENTIAL	$M_T = A\,Exp^{BD}$	D_{BH}	12.488	0.0041		0.7326
LINEAR	$M_T = A\,D + B$	V_S	0.5454	-7.8405		0.9928
POLYNOMIAL	$M_T = AD^2 + BD + C$	V_S	0.0002	0.4431	-0.8768	0.9960
POWER	$M_T = AD^B$	V_S	0.3158	1.0806		**0.9978**
EXPONENTIAL	$M_T = A\,Exp^{BD}$	V_S	13.542	0.007		0.7388
TWO VARIABLE MODEL						
LINEAR	$M_T = A\,D + B$	D_{BH} H	0.0179	-1.0074		0.9865
POLYNOMIAL	$M_T = AD^2 + BD + C$	D_{BH} H	$-1x10^{-8}$	0.0182	-1.4539	0.9865
POWER	$M_T = AD^B$	D_{BH} H	0.0171	1.0025		**0.9951**
EXPONENTIAL	$M_T = A\,Exp^{BD}$	D_{BH} H	15.173	0.0002		0.7004
LINEAR	$M_T = A\,D + B$	D_{BH} P	0.6206	-7.7691		0.9669
POLYNOMIAL	$M_T = AD^2 + BD + C$	D_{BH} P	$8x10^{-5}$	0.5806	-5.2925	0.9673
POWER	$M_T = AD^B$	D_{BH} P	0.2480	1.1529		**0.9929**
EXPONENTIAL	$M_T = A\,Exp^{BD}$	D_{BH} P	13.541	0.0079		0.7208
THREE-VARIABLE MODEL						
LINEAR	$M_T = A\,D + B$	D_{BH} P H	0.0357	2.23		0.9965
POLYNOMIAL	$M_T = AD^2 + BD + C$	D_{BH} P H	$-1x10^{-7}$	0.0365	1.4413	0.9966
POWER	$M_T = AD^B$	D_{BH} P H	0.0588	0.9409		**0.9975**
EXPONENTIAL	$M_T = A\,Exp^{BD}$	D_{BH} P H	16.008	0.0004		0.6902

Similarly it was observed that by adding ρ to d_{bh} as the independent variable the R^2 value increased from 0.9890 to 0.9929 in Figure 6 and 8, respectively.

In the three-variable model with the combination of d_{bh}, wood density ρ and h as the independent variable the highest R^2 value was the power functional model followed in a decreasing order by the polynomial, linear and exponential functional models with the values being 0.9975, 0.9966, 0.9965 and 0.6902, respectively. Combining the d_{bh} and wood density (ρ) to height, h the R^2 value was found to increase from 0.9929 to 0.9975 as shown in figure 8 and 9, respectively.

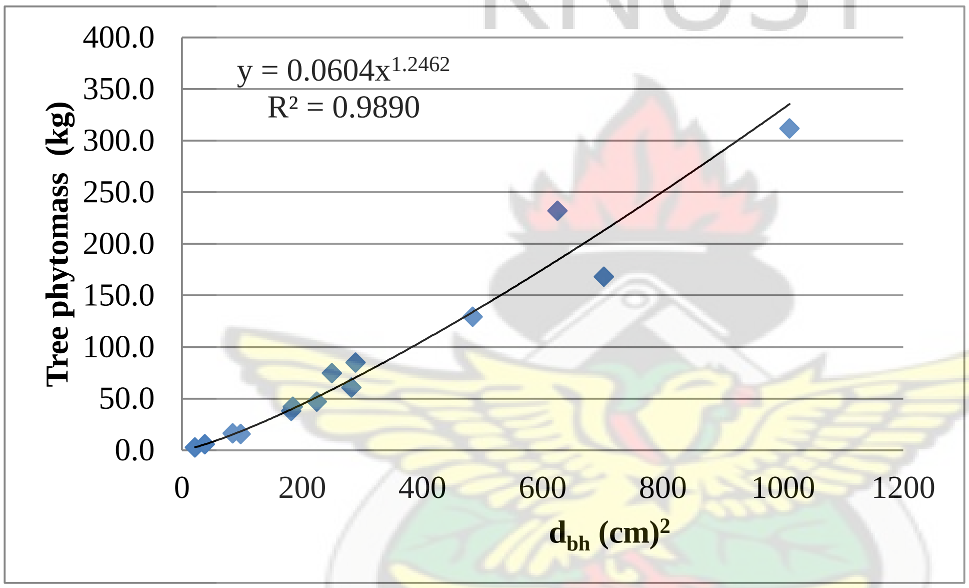

Figure 6. Regression model for estimating tree phytomass (kg) from d_{bh} (cm) of Teak trees.

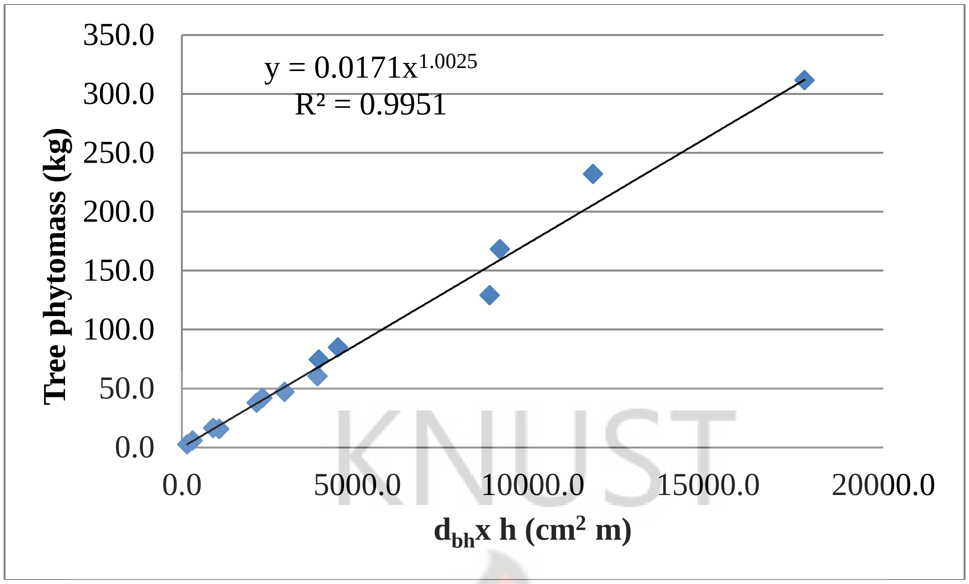

Figure 7. Regression model for estimating tree phytomass (kg) from d_{bh}(cm) and h (m) of Teak trees.

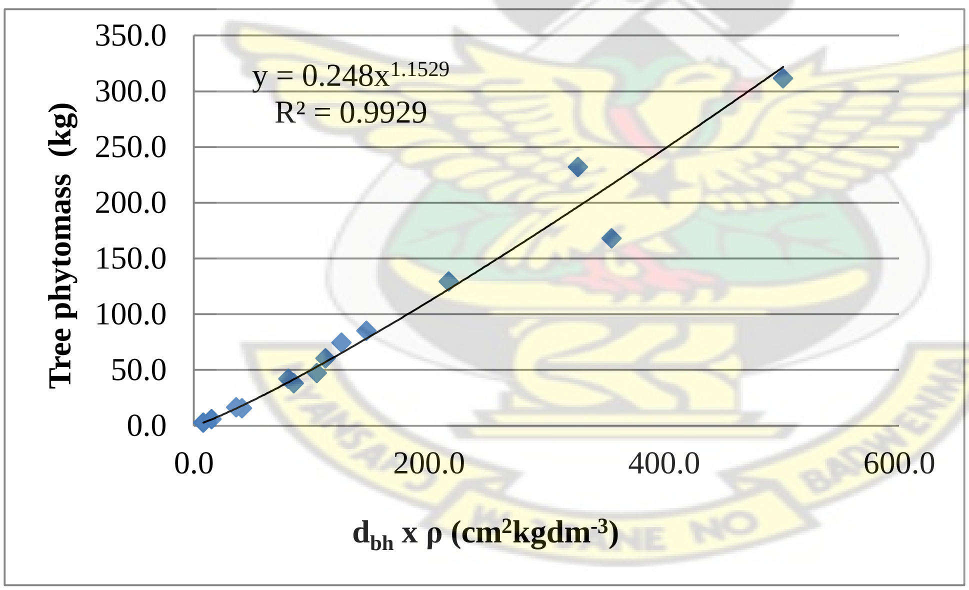

Figure 8. Regression models for estimating tree phytomass (kg) from d_{bh} (cm) and wood density (kg dm^{-3}) of Teak trees.

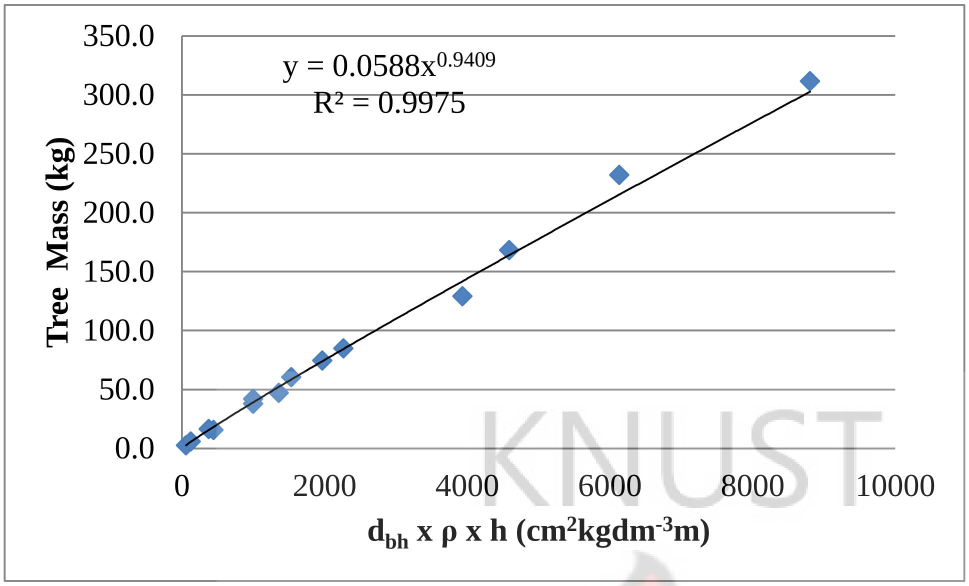

Figure 9. Regression model for estimating tree phytomass (kg) from d_{bh} (cm) and wood density (ρ) (kg dm^{-3}) and h (m) of Teak trees.

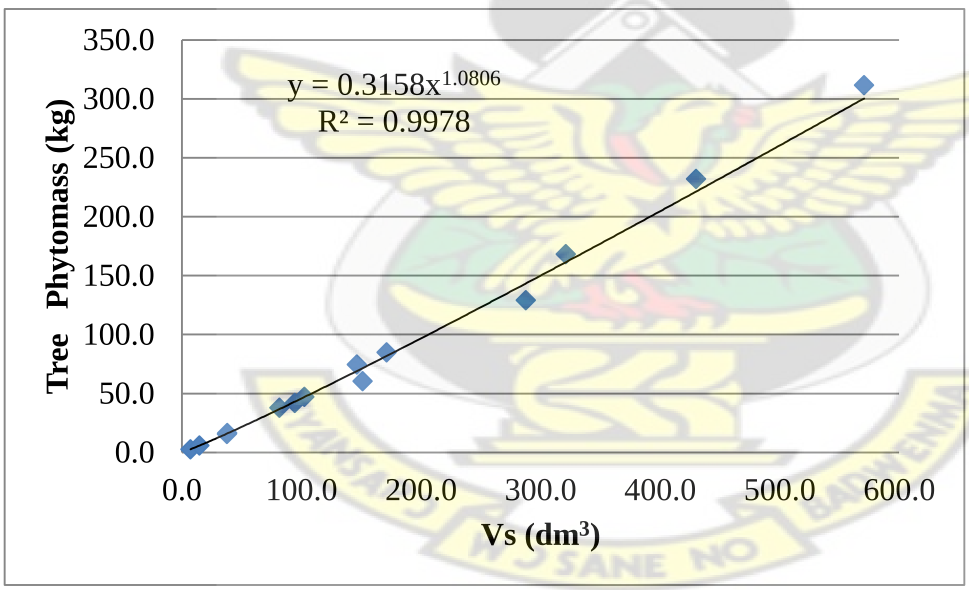

Figure 10. Regression model for estimating tree phytomass (kg) from stem volume (dm^3) of Teak trees.

The R^2 values from the independent variables were ranked into tiers, and the higher the tier the better the regression model for phytomass estimation. The relationship of the tiers with the coefficient of determination was that *Vs* had the highest tier (Figure 10) and followed in a decreasing order of $\rho\, d_{bh}\, h$, $d_{bh}\, h$, $\rho\, d_{bh}$ and d_{bh} with tier 1, tier 2, tier 3, tier 4 and tier 5 respectively.

Therefore the model for above-ground phytomass was given as;

$M_t = 0.3158(Vs)^{1.0806}$ $R^2 = 0.9978$..equation 13

Below-ground phytomass, M_R, was estimated from the knowledge of the above ground biomass based on the revised equation of Cairns *et al.* (1997) for tropical forest (Pearson *et al.* 2005) as;

$M_R = \text{Exp}(-1.0587 + 0.8836 \times \text{Ln}(W))$, $R^2 = 0.83$......................................equation 1

4.3 Effect of site preparation methods and planting stocks on growth

4.3.1 Tree height and diameter

4.3.1.1 Burnt and un-burnt sites

The mean height (m) and diameter (cm) of Teak trees in the burnt and un-burnt sites is shown in Table 5. In the sub plots of the burnt and un-burnt sites the Teak trees in the burnt sites had a mean height (m) of 10.39 m and a mean diameter (cm) of 10.55 cm whereas the those in the un-burnt sites had 11.56 m and 11.60cm, respectively. The mean tree height (m) in the un-burnt sites was significantly greater ($p = 0.02$) than those in the burnt sites. Similarly the mean tree diameter (cm) in the un-burnt sites was greater than those in the burnt sites but not significant ($p = 0.21$).

The Teak trees in the un-burnt-fertilized-potted seedling sites had the highest mean height (m) followed in a decreasing order by the un-burnt-un-fertilized-bare rooted stump, un-burnt-un-fertilized-potted seedling, burnt-fertilized-potted seedling, burnt-un-fertilized-potted seedling, burnt-un-fertilized-bare rooted stump, burnt-fertilized-bare rooted stump and un-burnt-fertilized-bare rooted stump sites with the values being 12.51, 11.89, 11.49, 10.95, 10.67, 10.47, 10.07 and 9.42 m, respectively. There was significant difference ($p = 0.005$) between mean height of (m) Teak trees in the sub-sub plots.

Table 5. Mean height (m) and diameter (cm) of Teak trees in the burnt and un-burnt sites.

TREATMENTS	HEIGHT (M) MEAN ± SD (M): $\bar{X}$ ± S.D	DIAMETER AT BREAST HEIGHT (CM) MEAN ± SD (CM): $\bar{X}$ ± S.D
1	10.95 ± 3.42	11.46 ± 4.25
2	10.07 ± 1.60	10.53 ± 1.71
3	10.67 ± 1.11	10.40 ± 1.52
4	10.47 ± 2.04	10.65 ± 2.51
BURNT SITES	**10.39± 1.85**	**10.55 ± 2.43**
5	12.51 ± 2.29	13.02 ± 3.17
6	9.42 ± 0.58	9.58 ± 1.31
7	11.49 ± 1.46	11.13 ± 2.26
8	11.89 ± 2.46	12.45 ± 3.46
UN-BURNT SITES	**11.56 ± 1.55**	**11.60 ± 1.94**

Key

1: Burnt-fertilized-potted seedling sites
2: Burnt-fertilized-bare rooted stump sites
3: Burnt-un-fertilized-potted seedling sites
4: Burnt-un-fertilized-bare rooted stump sites
5: Un-burnt-fertilized-potted seedling sites
6: Un-burnt-fertilized-bare rooted stump sites
7: Un-burnt-un-fertilized-potted seedling sites
8: Un-burnt-un-fertilized-bare rooted stump sites

Similarly the highest mean diameter (cm) was the Teak trees in the un-burnt-fertilized-potted seedling sites followed in a decreasing order by the un-burnt-un-fertilized-bare rooted stump, burnt-fertilized-potted seedling, un-burnt-un-fertilized-potted seedling, burnt-un-fertilized-bare rooted stump, burnt-fertilized-bare rooted stump, burnt-un-fertilized-potted seedling and un-burnt-fertilized- bare rooted stump sites with the values being 13.02, 12.45, 11.46, 11.13, 10.65, 10.53, 10.40 and 9.58 cm, respectively. There was significant difference ($p = 0.04$) between mean diameter (cm) of Teak trees in the sub-sub plots.

4.3.1.2 Fertilized and un-fertilized sites

The mean height (m) and diameter (cm) of Teak trees in the fertilized and un-fertilized sites is shown in Table 6. In the sub plots of the burnt and un-burnt sites the Teak trees in the fertilized sites had a mean height (m) of 11.06 m and a mean diameter of 11.52 cm whereas those in the un-fertilized sites had 10.82 m and 10.59 cm, respectively. The mean tree height (m) in the fertilized sites was greater than those in the un-fertilized sites but not significant (p = 0.69). Similarly the mean tree diameter (cm) in the fertilized sites was greater than the Teak trees in the un-fertilized sites but there was no significant (p = 0.14).

The Teak trees in the fertilized-un-burnt-potted seedling sites had the highest mean height (m) followed in a decreasing order by the un-fertilized-un-burnt- bare rooted stump, un-fertilized-un-burnt-potted seedling, fertilized-burnt-potted seedling, un-fertilized-burnt-potted seedling, un-fertilized-burnt- bare rooted stump, fertilized-burnt-bare rooted stump and fertilized-un-burnt-bare rooted stump sites with the values being 12.51, 11.89, 11.49, 10.95, 10.67, 10.47, 10.07 and 9.42 m, respectively. There was no significant difference (p = 0.05) between mean heights of Teak trees in the sub-sub plots. Similarly the highest mean diameter (cm) was the Teak trees in the fertilized-un-burnt-potted seedling sites followed in a decreasing order by the un-fertilized-un-burnt- bare rooted stump, fertilized-burnt-potted seedling, un-fertilized-un-burnt-potted seedling, un-fertilized-burnt-bare rooted stump, fertilized-burnt-bare rooted stump, un-fertilized-burnt-potted seedling and fertilized-un-burnt-bare rooted stump sites with the values being 13.02, 12.45, 11.46, 11.13, 10.65, 10.53, 10.40 and 9.58 cm, respectively. There was significant difference (p = 0.02) between mean diameter (cm) of Teak trees in the sub-sub plots.

Table 6. Mean height (m) and diameter (cm) of Teak trees in the fertilized and un-fertilized sites.

TREATMENTS	HEIGHT (M) MEAN ± SD (M): X̄ ± S .D	DIAMETER AT BREAST HEIGHT (CM) MEAN ± SD (CM): X̄ ± S .D
1	10.95 ± 3.42	11.46 ± 4.25
2	10.07 ± 1.60	10.53 ± 1.71
3	12.51 ± 2.29	13.02 ± 3.17
4	9.42 ± 0.58	9.58 ± 1.31
FERTILIZED SITES	**11.06 ± 2.21**	**11.52 ± 2.56**
5	10.67 ± 1.11	10.40 ± 1.52
6	10.47 ± 2.04	10.65 ± 2.51
7	11.49 ± 1.46	11.13 ± 2.26
8	11.89 ± 2.46	12.45 ± 3.46
UN-FERTILIZED SITES	**10.82 ± 1.17**	**10.59 ± 1.69**

Key

1: Fertilized-burnt-potted seedling sites
2: Fertilized-burnt-bare rooted stump sites
3: Fertilized-un-burnt-potted seedling sites
4: Fertilized-un-burnt-bare rooted stump sites
5: Un-fertilized-burnt-potted seedling sites
6: Un-fertilized-burnt-bare rooted stump sites
7: Un-fertilized-un-burnt-potted seedling sites
8: Un-fertilized-un-burnt-bare rooted stump sites

4.3.1.3 Planting stocks

The mean height (m) and diameter (cm) of the planting stocks of potted seedling and bare rooted stump Teak trees is shown in Table 7. In the sub plots of the bunt and un-burnt sites the Teak trees of the potted seedling planting stocks had a mean height (m) of 11.22 m and a mean diameter (cm) of 11.22 cm whereas those of the bare rooted stump planting stocks had 10.28 m and 10.64 cm, respectively. The mean tree height (m) of planting stock of the potted seedlings was greater than those of the planting stock of bare rooted stumps but not significant (p = 0.17).

Similarly the mean tree diameter (cm) of the potted seedling planting stocks was greater than those of the bare rooted stump planting stocks but not significant (p = 0.54).

The Teak trees of the potted seedling-fertilized-un-burnt planting stocks had the highest mean height (m) followed in a decreasing order by the bare rooted stump-un-fertilized-un-burnt planting stocks, potted seedling-un-fertilized-un-burnt planting stocks, potted seedling-fertilized-burnt planting stocks, potted seedling-un-fertilized-burnt planting stocks, bare rooted stump-un-fertilized-burnt planting stocks, bare rooted stump-fertilized-burnt planting stocks and bare rooted stump-fertilized-un-burnt planting stocks with the values being 12.51, 11.89, 11.49, 10.95, 10.67, 10.47, 10.07 and 9.42 m, respectively. There was no significant difference (p = 0.05) between mean tree height (m) of the potted seedling and bare rooted stump planting stocks in the sub-sub plots.

Similarly the highest mean diameter (cm) was the Teak trees of the potted seedling-fertilized-un-burnt planting stocks followed in a decreasing order by the bare rooted stump-un-fertilized-un-burnt planting stocks, potted seedling-fertilized-burnt planting stocks, potted seedling-un-fertilized-un-burnt planting stocks, bare rooted stump-un-fertilized-burnt planting stocks, bare rooted stump-fertilized-burnt planting stocks, potted seedling-un-fertilized-burnt planting stocks and bare rooted stump-fertilized-un-burnt planting stocks with the values being 13.02, 12.45, 11.46, 11.13, 10.65, 10.53, 10.40 and 9.58 cm, respectively. There was no significant difference (p = 0.10) between mean tree diameter (cm) of the potted seedling and bare rooted stump planting stock in the sub-sub plots.

Table 7. Mean height (m) and diameter (cm) of the planting stock of potted seedling and bare rooted stump Teak trees.

TREATMENTS	HEIGHT (M)	DIAMETER AT BREAST HEIGHT (CM)
	MEAN ± SD (M): $\bar{X} \pm$ S.D	MEAN ± SD (CM): $\bar{X} \pm$ S.D
1	10.95 ± 3.42	11.46 ± 4.25
2	12.51 ± 2.29	13.02 ± 3.17
3	10.67 ± 1.11	10.40 ± 1.52
4	11.49 ± 1.46	11.13 ± 2.26
POTTED SEEDLING	**11.22 ± 1.85**	**11.22 ± 2.46**
5	10.07 ± 1.60	10.53 ± 1.71
6	9.42 ± 0.58	9.58 ± 1.31
7	10.47 ± 2.04	10.65 ± 2.51
8	11.89 ± 2.46	12.45 ± 3.46
BARE ROOTED STUMP	**10.28 ± 1.47**	**10.64 ± 1.65**

Key

1: Potted seedling-fertilized-burnt planting stocks
2: Potted seedling-fertilized-un-burnt planting stocks
3: Potted seedling-un-fertilized-burnt planting stocks
4: Potted seedling-un-fertilized-un-burnt planting stocks
5: Bare rooted stump-fertilized-burnt planting stocks
6: Bare rooted stump-fertilized-un-burnt planting stocks
7: Bare rooted stump-un-fertilized-burnt planting stocks
8: Bare rooted stump-un-fertilized-un-burnt planting stocks

4.3.2 Stem volume

4.3.2.1 Burnt and un-burnt sites

The mean volume ($dm^3\ ha^{-1}$) of Teak trees in the burnt and un-burnt Teak sites is shown in Table 8. In the sub plots of the burnt and un-burnt sites the mean volume ($dm^3\ ha^{-1}$) of Teak trees in the burnt sites was 4772 $dm^3\ ha^{-1}$ and those in the un-burnt sites had 5768 $dm^3\ ha^{-1}$. The mean tree volume (dm^3ha^{-1}) in the un-burnt sites was greater than those in the burnt sites but not significant ($p = 0.14$).

The Teak trees in the un-burnt-fertilized-potted seedling sites had the highest mean volume (dm^3 ha^{-1}) followed in a decreasing order by the un-burnt-un-fertilized-bare rooted stump, burnt-fertilized-potted seedling, un-burnt-un-fertilized-potted seedling, burnt-fertilized-bare rooted stump, burnt-un-fertilized-potted seedling, burnt-un-fertilized- bare rooted stump, and un-burnt-fertilized-bare rooted stump sites with the values being 7630, 6528, 6489, 5418, 4414, 4300, 4234 and 2677 dm^3 ha^{-1}, respectively. The least mean tree volume (dm^3 ha^{-1}) was in the un-burnt-fertilized-bare rooted stump sites. There was no significant difference ($P = 0.53$) between mean tree volume (dm^3 ha^{-1}) in the sub-sub plots.

Table 8. Mean of volume (dm^3 ha^{-1}) of Teak trees in the burnt and un-burnt sites.

TREATMENTS	MEAN VOLUME (DM^3 HA^{-1})
1	6489
2	4414
3	4300
4	4234
BURNT SITES	**4772**
5	7630
6	2677
7	5418
8	6528
UN-BURNT SITES	**5768**

Key

1: Burnt-fertilized-potted seedling sites
2: Burnt-fertilized-bare rooted stump sites
3: Burnt-un-fertilized-potted seedling sites

4: Burnt-un-fertilized-bare rooted stump sites
5: Un-burnt-fertilized-potted seedling sites
6: Un-burnt-fertilized-bare rooted stump sites
7: Un-burnt-un-fertilized-potted seedling sites
8: Un-burnt-un-fertilized-bare rooted stump sites

4.3.2.2 Fertilized and un-fertilized sites

The mean volume ($dm^3\ ha^{-1}$) of Teak trees in the fertilized and un-fertilized sites is shown in Table 9. In the sub plots of the burnt and un-burnt sites the mean volume ($dm^3\ ha^{-1}$) of Teak trees in the fertilized sites was 5981 $dm^3\ ha^{-1}$ and those in the un-fertilized sites had 4565 $dm^3\ ha^{-1}$. The mean tree volume ($dm^3\ ha^{-1}$) in the fertilized sites was greater than those in the un-fertilized sites but not significant ($p = 0.20$).

The Teak trees in the fertilized-un-burnt-potted seedling sites had the highest mean volume ($dm^3\ ha^{-1}$) followed in a decreasing order by the un-fertilized-un-burnt-bare rooted stump, fertilized-burnt-potted seedling, un-fertilized-un-burnt-potted seedling, fertilized-burnt-bare rooted stump, un-fertilized-burnt-potted seedling, un-fertilized-burnt- bare rooted stump, and fertilized-un-burnt-bare rooted stump sites with the values being 7630, 6528, 6489, 5418, 4414, 4300, 4234 and 2677 $dm^3\ ha^{-1}$, respectively. The least mean tree volume ($dm^3\ ha^{-1}$) was in the fertilized-un-burnt-bare rooted stump sites. There was no significant difference ($P = 0.05$) between mean tree volume ($dm^3\ ha^{-1}$) in the sub-sub plots.

Table 9. Mean volume (dm^3 ha^{-1}) of Teak trees in the fertilized and un-fertilized sites.

TREATMENTS	MEAN VOLUME (DM^3 HA^{-1})
1	6489
2	4414
3	7630
4	2677
FERTILIZED SITES	**5981**
5	4300
6	4234
7	5418
8	6528
UN-FERTILIZED SITES	**4565**

Key

1: Fertilized-burnt-potted seedling sites
2: Fertilized-burnt-bare rooted stump sites
3: Fertilized-un-burnt-potted seedling sites
4: Fertilized-un-burnt-bare rooted stump sites
5: Un-fertilized-burnt-potted seedling sites
6: Un-fertilized-burnt-bare rooted stump sites
7: Un-fertilized-un-burnt-potted seedling sites
8: Un-fertilized-un-burnt-bare rooted stump sites

4.3.2.3 Planting stocks

The mean volume (dm^3 ha^{-1}) of the planting stocks of the potted seedling and bare rooted stump Teak trees is shown in Table 10. In the sub plots of the burnt and un-burnt sites the mean tree volume (dm^3 ha^{-1}) of the potted seedling planting stocks was 5646 dm^3 ha^{-1} and those of the bare rooted stump planting stocks had 4296 dm^3 ha^{-1}. The mean volume (dm^3 ha^{-1}) of Teak trees of the potted seedling planting stocks was greater than those of the bare rooted stump planting stocks but not significant ($p = 0.28$).

The Teak trees of the potted seedling-fertilized-un-burnt planting stocks had the highest mean volume ($dm^3\ ha^{-1}$) followed in a decreasing order by the bare rooted stump-un-fertilized-un-burnt, potted seedling-fertilized-burnt, potted seedling-un-fertilized-un-burnt, bare rooted stump-fertilized-burnt, potted seedling-un-fertilized-burnt, bare rooted stump-un-fertilized-burnt, and bare rooted stump-fertilized-un-burnt planting stocks with the values being 7630, 6528,6489, 5418, 4414, 4300, 4234 and 2677 $dm^3\ ha^{-1}$, respectively. The least mean volume ($dm^3\ ha^{-1}$) was Teak trees of the bare rooted stump-fertilized-un-burnt planting stocks. There was no significant difference ($p = 0.10$) between mean tree volume ($dm^3\ ha^{-1}$) of the potted seedling and bare rooted stump planting stock in the sub-sub plots.

Table 10. Mean volume ($dm^3\ ha^{-1}$) of the planting stocks of potted seedling and bare rooted stump Teak trees.

TREATMENTS	MEAN VOLUME ($DM^3\ HA^{-1}$)
1	6489
2	7630
3	4300
4	5418
POTTED SEEDLINGS	**5646**
5	4414
6	2677
7	4234
8	6528
BARE ROOTED STUMPS	**4296**

Key

1: Potted seedling-fertilized-burnt planting stocks
2: Potted seedling-fertilized-un-burnt planting stocks
3: Potted seedling-un-fertilized-burnt planting stocks
4: Potted seedling-un-fertilized-un-burnt planting stocks

5: Bare rooted stump-fertilized-burnt planting stocks
6: Bare rooted stump-fertilized-un-burnt planting stocks
7: Bare rooted stump-un-fertilized-burnt planting stocks
8: Bare rooted stump-un-fertilized-un-burnt planting stocks

4.3.3 Above-ground biomass

4.3.3.1 Burnt and un-burnt sites

The mean biomass (kg ha^{-1}) of Teak trees in the burnt and un-burnt sites is shown in Table 11. In the sub plots of the burnt and un-burnt sites the mean biomass (kg ha^{-1}) of Teak trees in the burnt sites was 2388 kg ha^{-1} and those in the un-burnt sites had 2898 kg ha^{-1}. The mean biomass (kg ha^{-1}) of Teak trees in the un-burnt sites was greater than those in the burnt sites but not significant (p = 0.15).

The Teak trees in the un-burnt-fertilized-potted seedling sites had the highest mean biomass (kg ha^{-1}) followed in a decreasing order by the burnt-fertilized-potted seedling, un-burnt-un-fertilized-bare rooted stump, un-burnt-un-fertilized-potted seedling, burnt-fertilized-bare rooted stump, burnt-un-fertilized-potted seedling, burnt-un-fertilized-bare rooted stump, and un-burnt-fertilized-bare rooted stump sites with the values being 3903, 3324, 3276, 2709, 2205, 2110, 2080 and 1248 kg ha^{-1}, respectively. The least mean biomass (kg ha^{-1}) was Teak trees in the un-burnt-fertilized sites-bare rooted stump sites. There was significant difference (p = 0.01) between mean biomass (kg ha^{-1}) of Teak trees in the sub-sub plots.

Table 11. Mean biomass (kg ha^{-1}) of Teak trees in the burnt and un-burnt sites.

TREATMENTS	MEAN BIOMASS (KG HA^{-1})
1	3324
2	2205
3	2110
4	2080
BURNT SITES	**2388**
5	3903
6	1248
7	2709
8	3276
UN-BURNT SITES	**2898**

Key

1: Burnt-fertilized-potted seedling sites
2: Burnt-fertilized-bare rooted stump sites
3: Burnt-un-fertilized-potted seedling sites
4: Burnt-un-fertilized-bare rooted stump sites
5: Un-burnt-fertilized-potted seedling sites
6: Un-burnt-fertilized-bare rooted stump sites
7: Un-burnt-un-fertilized-potted seedling sites
8: Un-burnt-un-fertilized-bare rooted stump sites

4.3.3.2 Fertilized and un-fertilized sites

The mean biomass (kg ha^{-1}) of Teak trees in the fertilized and un-fertilized sites is shown in Table 12. In the sub plots of the burnt and un-burnt the mean biomass of Teak trees in the fertilized sites was 3037 kg ha^{-1} and those in the un-fertilized sites had 2244 kg ha^{-1}. The mean biomass of Teak trees in the fertilized sites was greater than those in the un-fertilized sites but not significant ($p = 0.20$).

The Teak trees in the fertilized-un-burnt-potted seedling sites had the highest mean biomass (kg ha^{-1}) followed in a decreasing order by the fertilized-burnt-potted seedling, un-fertilized-un-burnt-bare rooted stump, un-fertilized-un-burnt-potted seedling, fertilized-burnt- bare rooted stump, un-fertilized-burnt-potted seedling, un-fertilized-burnt-bare rooted stump, and fertilized-un-burnt-bare rooted stump sites with the values being 3903, 3324, 3276, 2709, 2205, 2110, 2080 and 1248 kg ha^{-1}, respectively. The least mean biomass (kg ha^{-1}) was Teak trees in the fertilized-un-burnt- bare rooted stump sites. There was no significant difference ($p = 0.05$) between mean biomass (kg ha^{-1}) of Teak trees in the sub-sub plots.

Table 12. Mean biomass (kg ha^{-1}) of Teak trees in the fertilized and un-fertilized sites.

TREATMENTS	MEAN BIOMASS (KG HA^{-1})
1	3324
2	2205
3	3903
4	1248
FERTILIZED SITES	**3037**
5	2110
6	2080
7	2709
8	3276
UN-FERTILIZED SITES	**2255**

Key

1: Fertilized-burnt-potted seedling sites
2: Fertilized-burnt-bare rooted stump sites
3: Fertilized-un-burnt-potted seedling sites
4: Fertilized-un-burnt-bare rooted stump sites
5: Un-fertilized-burnt-potted seedling sites
6: Un-fertilized-burnt-bare rooted stump sites

7: Un-fertilized-un-burnt-potted seedling sites
8: Un-fertilized-un-burnt-bare rooted stump sites

4.3.3.3 Planting stocks

The mean biomass (kg ha^{-1}) of planting stocks of the potted seedling and bare rooted stump Teak trees is shown in Table 13. In the sub plots of the burnt and un-burnt sites the mean biomass of Teak trees of the potted seedling planting stocks was 2846 kg ha^{-1} and those of the stump planting stocks had 2118 kg ha^{-1}. The mean biomass (kg ha^{-1}) of Teak trees of the potted seedling planting stocks was greater than those of the stump planting stocks but not significant ($p = 0.27$).

The Teak trees of the potted seedling-fertilized-un-burnt planting stocks had the highest mean biomass (kg ha^{-1}) followed in a decreasing order by the potted seedling-fertilized-burnt, bare rooted stump-un-fertilized-un-burnt, potted seedling-un-fertilized-un-burnt, bare rooted stump-fertilized-burnt, potted seedling-un-fertilized-burnt, bare rooted stump-un-fertilized-burnt, and bare rooted stump-fertilized-un-burnt planting stocks with the values being 3903, 3324, 3276, 2709, 2205, 2110, 2080 and 1248 kg ha^{-1}, respectively. The least mean biomass (kg) was Teak trees of the bare rooted stump-fertilized-un-burnt planting stocks. There was no significant difference ($p = 0.10$) between mean biomass (kg ha^{-1}) of Teak trees of the potted seedling and stump planting stock in the sub-sub plots.

Table 13. Mean biomass (kg ha^{-1}) planting stock of the potted seedling and bare rooted stump Teak trees.

TREATMENTS	MEAN BIOMASS (KG HA^{-1})
1	3324
2	3903
3	2110
4	2709
POTTED SEEDLINGS	**2846**
5	2205
6	1248
7	2080
8	3276
BARE ROOTED STUMPS	**2118**

Key

1: Potted seedling-fertilized-burnt planting stocks
2: Potted seedling-fertilized-un-burnt planting stocks
3: Potted seedling-un-fertilized-burnt planting stocks
4: Potted seedling-un-fertilized-un-burnt planting stocks
5: Bare rooted stump-fertilized-burnt planting stocks
6: Bare rooted stump-fertilized-un-burnt planting stocks
7: Bare rooted stump-un-fertilized-burnt planting stocks
8: Bare rooted stump-un-fertilized-un-burnt planting stocks

4.4 Effect of site preparation methods and planting stocks on stem form

4.4.1 Relative position of first fork

A total of 399 Teak trees were used in the determination of relative position of first fork. The relative position of first fork is the ratio given by the fork length over the height of tree. The fork length is also referred to as the clean stem bole (that is the length from the ground level to the axis on the tree where the forking occurs). Thus the higher the relative position of first fork the better the stem form.

4.4.1.1 Burnt and un-burnt sites

The mean percentage relative positions of first fork of Teak Trees in the burnt and un-burnt sites is shown in Table 14. In the sub plots of the burnt and un-burnt sites the mean percentage relative position of first fork of Teak trees in the burnt sites was 50 % and those in the un-burnt sites had 52 %. The mean percentage relative position of first fork of Teak trees in the un-burnt sites was slightly greater than those in the burnt sites but not significant (p = 0.40). The Teak trees in the burnt sites had a mean minimum percentage relative position of first fork of 48 % and a mean maximum percentage relative position of first fork of 53 % whereas those in the un-burnt sites had 52 % and 55 %, respectively.

The Teak trees in the burnt-fertilized-potted seedling sites had a mean percentage relative position of first fork (50 %) slightly greater than those in the un-burnt-fertilized-potted seedling sites (49 %). The Teak trees in the burnt-un-fertilized-potted seedling sites had a mean percentage relative position of first fork (51 %) lower than the trees in the un-burnt-un-fertilized-potted seedling sites (54 %). In addition Teak trees in the burnt-fertilized-bare rooted stump sites had a mean percentage relative position of first fork (48 %) lower than those in the un-burnt-fertilized-bare rooted stump sites (60 %). The Teak trees in the burnt-un-fertilized-bare rooted stump sites had a mean percentage relative position of first fork (49 %) slightly higher than trees in the un-burnt-un-fertilized- bare rooted stump sites (47 %). There was no significant difference (p = 0.62) between mean percentage relative position of first fork of Teak trees in the sub-sub plots.

Table 14. Mean percentage relative position of first fork of Teak Trees in the burnt and un-burnt sites.

TREATMENTS	MEAN ± SD %	MINIMUM %	MAXIMUM %
1	50 ± 4	44	53
2	49 ± 4	46	55
3	51 ± 4	49	57
4	54 ± 3	50	56
BURNT SITES	**50 ± 3**	48	53
5	48 ± 5	46	55
6	60 ± 6	51	63
7	49 ± 5	43	54
8	47 ± 4	43	52
UN-BURNT SITES	**52 ± 3**	52	55

Key

1: Burnt-fertilized-potted seedling sites
2: Burnt-fertilized-bare rooted stump sites
3: Burnt-un-fertilized-potted seedling sites
4: Burnt-un-fertilized-bare rooted stump sites
5: Un-burnt-fertilized-potted seedling sites
6: Un-burnt-fertilized-bare rooted stump sites
7: Un-burnt-un-fertilized-potted seedling sites
8: Un-burnt-un-fertilized-bare rooted stump sites

4.4.1.2 Fertilized and un-fertilized sites

The mean percentage relative positions of first fork of Teak trees in the fertilized and un-fertilized sites are represented in Table 15. In the sub plots of the burnt and un-burnt sites the Teak trees in the fertilized and the un-fertilized sites both had a mean percentage relative position of first fork of 51 %. There was no significant difference (p = 0.90) between mean percentage relative position of first fork of Teak trees in the fertilized and un-fertilized sites. The Teak trees in the fertilized sites had a mean minimum relative position of first fork of 49 % and a mean maximum percentage relative position of first fork of 55 % whereas those in the un-fertilized sites had 51 and 53 %, respectively. In the sub-sub plots the Teak trees in the fertilized-burnt-potted seedling sites had a mean percentage relative position of first fork (50 %) slightly lower than those in the un-fertilized-burnt-potted seedling sites (51 %). The Teak trees in the fertilized-un-burnt-potted seedling sites had a mean percentage relative position of first fork (49 %) lower than trees in the un-fertilized-un-burnt-potted seedling sites (54 %). The Teak trees in the fertilized-burnt-bare rooted stump sites had a mean percentage relative position of first fork (48 %) slightly lower than those in the un-fertilized-burnt-bare rooted stump sites (49 %). In addition Teak trees in the fertilized-un-burnt-bare rooted stump sites had a mean percentage relative position of first fork (60 %) higher than trees in the un-fertilized-un-burnt-bare rooted stump sites (47 %). There was no significant difference (p = 0.51) between mean percentage relative position of first fork of Teak trees in the sub-sub plots.

Table 15. Mean relative position of first fork of Teak trees in the fertilized and un-fertilized sites.

TREATMENTS	MEAN ± SD %	MINIMUM %	MAXIMUM %
1	50 ± 4	44	53
2	48 ± 5	46	55
3	49 ± 4	46	55
4	60 ± 6	51	63
FERTILIZED SITES	**51 ± 3**	**49**	**55**
5	51 ± 4	47	57
6	49 ± 5	43	54
7	54 ± 3	50	56
8	47 ± 4	43	52
UN-FERTILIZED SITES	**51 ± 2**	**51**	**53**

Key

1: Fertilized-burnt-potted seedling sites
2: Fertilized-burnt-bare rooted stump sites
3: Fertilized-un-burnt-potted seedling sites
4: Fertilized-un-burnt-bare rooted stump sites
5: Un-fertilized-burnt-potted seedling sites
6: Un-fertilized-burnt-bare rooted stump sites
7: Un-fertilized-un-burnt-potted seedling sites
8: Un-fertilized-un-burnt-bare rooted stump sites

4.4.2.3 Planting stocks

The mean percentage relative position of first fork of the planting stocks of potted seedling and bare rooted stump Teak trees are represented in Table 16. In the sub plots of burnt and un-burnt sites the mean percentage relative position of first fork of Teak trees of the potted seedling planting stocks was 51% and those of the bare rooted stump planting stocks had 50 %. There was no significant difference (p = 0.80) between mean percentage relative position of first fork of Teak trees of the potted seedling and stump planting stocks. The Teak trees of the potted seedling planting stocks had a mean minimum percentage relative position of first fork of 51 % and a mean maximum percentage relative position of first fork of 53 % whereas those of the stump planting stocks had 46 and 55%, respectively. In the sub-sub plots the Teak trees of potted seedling-fertilized-burnt planting stocks had a mean percentage relative position of first fork (50 %) slightly greater than those using the bare rooted stump-fertilized-burnt planting stocks (48 %). The Teak trees of the potted seedling-un-fertilized-burnt planting stocks had a mean percentage relative position of first fork (51%) slightly higher than those of the bare rooted stump-un-fertilized-burnt planting stocks (49%). Teak trees of the potted seedling- fertilized-un-burnt planting stocks had a mean percentage relative position of first fork (49 %) lower than those of the bare rooted stump-fertilized-un-burnt planting stocks (60 %). In addition Teak trees of potted seedling-un-fertilized-un-burnt planting stocks had a mean percentage relative position of first fork (54 %) higher than those of the bare rooted stump-un-fertilized-un-burnt planting stocks (47 %). There was no significant difference (p = 0.51) between mean percentage relative position of first fork of Teak trees of the potted seedling and bare rooted stump planting stocks.

Table 16. Mean percentage relative position of first fork of the planting stocks of potted seedling and bare rooted stump Teak trees.

TREATMENTS	MEAN ± SD %	MINIMUM %	MAXIMUM %
1	50 ± 4	44	53
2	49 ± 4	46	55
3	51 ± 4	49	57
4	54 ± 3	50	56
POTTED SEEDLING PLANTING STOCKS	**51 ± 2**	**51**	**53**
5	48 ± 5	46	55
6	60 ± 6	51	63
7	49 ± 5	43	54
8	47 ± 4	43	52
BARE ROOTED STUMP PLANTING STOCKS	**50 ± 4**	**46**	**55**

Key

1: Potted seedling-fertilized-burnt planting stocks
2: Potted seedling-fertilized-un-burnt planting stocks
3: Potted seedling-un-fertilized-burnt planting stocks
4: Potted seedling-un-fertilized-un-burnt planting stocks
5: Bare rooted stump-fertilized-burnt planting stocks
6: Bare rooted stump-fertilized-un-burnt planting stocks
7: Bare rooted stump-un-fertilized-burnt planting stocks
8: Bare rooted stump-un-fertilized-un-burnt planting stocks

4.5 Effect of site preparation methods and planting stocks on carbon stock

4.5.1 Biomass carbon stock

4.5.1.1 Burnt and un-burnt sites

The mean biomass carbon (Mg C ha^{-1}) stock of Teak trees in the burnt and un-burnt sites is represented in Table 17. In the sub plots of the burnt and un-burnt sites the mean biomass carbon (Mg C ha^{-1}) stock of Teak trees in the burnt sites was 98.03 Mg C ha^{-1} and those in the un-burnt sites had 122.81 Mg C ha^{-1}. The mean biomass carbon (Mg C ha^{-1}) stock of Teak trees in the un-burnt sites was greater than those in the burnt sites but not significant ($p = 0.12$). The Teak trees in the un-burnt-fertilized-potted seedling sites had the highest mean biomass carbon (Mg C ha^{-1}) stock followed in a decreasing order by the un-burnt-un-fertilized-bare rooted stump, burnt-fertilized-potted seedling, un-burnt-un-fertilized-potted seedling, burnt-fertilized-bare rooted stump, burnt-un-fertilized-bare rooted stump, burnt-un-fertilized-potted seedling, and un-burnt-fertilized- bare rooted stump sites with the values being 166.59, 130.11, 130.09, 115.43, 98.16, 90.68, 84.86 and 51.60 Mg C ha^{-1}, respectively. The least mean biomass carbon (Mg C ha^{-1}) stock was Teak trees in the un-burnt-fertilized-bare rooted stump sites. There was significant difference ($p = 0.01$) between mean biomass carbon (Mg C ha^{-1}) stock of Teak trees in the sub-sub plots.

Table 17. Mean biomass carbon stock (Mg C ha^{-1}) of Teak trees in the burnt and un-burnt sites.

TREATMENTS	MEAN BIOMASS CARBON (MG C HA^{-1})
1	130.09
2	98.16
3	84.86
4	90.68
BURNT SITES	**98.03**
5	166.59
6	51.60
7	115.43
8	130.11
UN-BURNT SITES	**122.81**

Key

1: Burnt-fertilized-potted seedling sites
2: Burnt-fertilized-bare rooted stump sites
3: Burnt-un-fertilized-potted seedling sites
4: Burnt-un-fertilized-bare rooted stump sites
5: Un-burnt-fertilized-potted seedling sites
6: Un-burnt-fertilized-bare rooted stump sites
7: Un-burnt-un-fertilized-potted seedling sites
8: Un-burnt-un-fertilized-bare rooted stump sites

4.5.1.2 Fertilized and un-fertilized sites

The mean biomass carbon (Mg C ha^{-1}) stock of Teak trees in the fertilized and un-fertilized sites is represented in Table 18. In the sub plots of the burnt and un-burnt sites the mean biomass carbon (Mg C ha^{-1}) stock of Teak trees in the fertilized sites was 126.33 Mg C ha^{-1} and those in the un-fertilized sites had 93.96 Mg C ha^{-1}. The mean biomass carbon (Mg C ha^{-1}) stock of Teak trees in the fertilized sites was greater than trees in the un-fertilized sites but not significant ($p = 0.19$).

The Teak trees in the fertilized-un-burnt-potted seedling sites had the highest mean biomass carbon (Mg C ha^{-1}) stock followed in a decreasing order by the un-fertilized-un-burnt- bare rooted stump, fertilized-burnt-potted seedling, un-fertilized-un-burnt-potted seedling, fertilized-burnt-bare rooted stump, un-fertilized-burnt-bare rooted stump, un-fertilized-burnt-potted seedling, and fertilized-un-burnt-bare rooted stump sites with the values being 166.59, 130.11, 130.09, 115.43, 98.16, 90.68, 84.86 and 51.60 Mg C ha^{-1}, respectively. The least mean biomass carbon (Mg C ha^{-1}) stock was Teak trees in the fertilized-un-burnt- bare rooted stump sites.

There was no significant difference (p = 0.05) between mean biomass carbon (Mg C ha^{-1}) stock of Teak trees in the sub-sub plots.

Table 18. Mean biomass carbon (Mg C ha^{-1}) stock of Teak trees in the fertilized and un-fertilized sites.

TREATMENT	MEAN BIOMASS CARBON (MG C HA^{-1})
1	130.09
2	98.16
3	166.59
4	51.60
FERTILIZED SITES	**126.33**
5	84.86
6	90.68
7	115.43
8	130.11
UN-FERTILIZED SITES	**93.96**

Key

1: Fertilized-burnt-potted seedling sites
2: Fertilized-burnt-bare rooted stump sites
3: Fertilized-un-burnt-potted seedling sites
4: Fertilized-un-burnt-bare rooted stump sites
5: Un-fertilized-burnt-potted seedling sites
6: Un-fertilized-burnt-bare rooted stump sites
7: Un-fertilized-un-burnt-potted seedling sites
8: Un-fertilized-un-burnt-bare rooted stump sites

4.5.1.3 Planting stocks

The mean biomass carbon (Mg C ha^{-1}) stock of the planting stocks of potted seedling and bare rooted stump Teak trees is shown in Table 19. In the sub plots of the burnt and un-burnt sites the mean biomass carbon (Mg C ha^{-1}) stock of Teak trees of the potted seedling planting stocks was 117.27 Mg C $ha^{-1}$and those of the bare rooted stump planting stocks had 91.06 Mg C ha^{-1}. The mean biomass carbon (Mg C ha^{-1}) stock of Teak trees of the potted seedling planting stocks was greater than trees of the bare rooted stump planting stocks but not significant ($p = 0.30$).

The Teak trees of the potted seedling-fertilized-un-burnt planting stocks had the highest mean biomass carbon (Mg C ha^{-1}) stock followed in a decreasing order by the bare rooted stump-un-fertilized-un-burnt, potted seedling-fertilized-burnt, potted seedling-un-fertilized-un-burnt, bare rooted stump-fertilized-burnt, bare rooted stump-un-fertilized-burnt, potted seedling-un-fertilized-burnt, and bare rooted stump-fertilized-un-burnt planting stocks with the values being 166.59, 130.11, 130.09, 115.43, 98.16, 90.68, 84.86 and 51.60 Mg C ha^{-1}, respectively. The least mean biomass (Mg C ha^{-1}) carbon stock was Teak trees using the bare rooted stump-fertilized-un-burnt planting stocks. There was no significant difference ($p = 0.08$) between mean biomass carbon (Mg C ha^{-1}) stock of Teak trees of the potted seedling planting stocks and bare rooted stump planting socks in the sub-sub plots.

Table 19. Mean biomass carbon (Mg C ha^{-1}) stock of the planting stock of potted seedling and bare rooted stump Teak trees.

TREATMENTS	MEAN BIOMASS CARBON (MG C HA^{-1})
1	130.09
2	166.59
3	84.86
4	115.43
POTTED SEEDLINGS	**117.27**
5	98.16
6	51.60
7	90.68
8	130.11
BARE ROOTED STUMPS	**91.06**

Key

1: Potted seedling-fertilized-burnt planting stocks
2: Potted seedling-fertilized-un-burnt planting stocks
3: Potted seedling-un-fertilized-burnt planting stocks
4: Potted seedling-un-fertilized-un-burnt planting stocks
5: Bare rooted stump-fertilized-burnt planting stocks
6: Bare rooted stump-fertilized-un-burnt planting stocks
7: Bare rooted stump-un-fertilized-burnt planting stocks
8: Bare rooted stump-un-fertilized-un-burnt planting stocks

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4.5.2 Soil carbon stocks

4.5.2.1 Bulk density in the burnt and un-burnt sites

The mean bulk density (g/cm^3) of Teak trees in the burnt and un-burnt sites is shown in Table 20. In the sub plots of the burnt and un-burnt sites Teak trees in the burnt sites had mean bulk density (g/cm^3) of 3.59 g/cm^3whiles those in the un-burnt sites had 4.14 g/cm^3. The Teak trees in un-burnt sites had mean bulk density (g/cm^3) higher than Teak trees in the un-burnt sites but were not significant ($p = 0.42$). Teak trees in the burnt sites had a mean minimum bulk density (g/cm^3) of 1.81 g/cm^3 and a mean maximum bulk density (g/cm^3) of 4.76 g/cm^3 at depths of 0-10 cm and 20-30 cm, respectively whiles those in the un-burnt sites had a mean minimum bulk density of 1.74 g/cm^3 and a mean maximum bulk density (g/cm^3) of 5.73 g/cm^3 at depths of 0-10 cm and 20-30 cm, respectively. There was no significant difference ($p = 0.08$) between the mean bulk density (g/cm^3) of Teak trees in the burnt and un-burnt sites at the various depths.

Table 20. Mean bulk density (g/cm^3) of Teak trees in the burnt and un-burnt sites.

Treatments	Mean (g/cm^3)				Mean (g/cm^3)	Min (g/cm^3)	Max (g/cm^3)
Depth	**0-10 (cm)**	**10-20 (cm)**	**20-30 (cm)**	**30-40 (cm)**			
Burnt sites	1.81	4.37	4.76	3.41	3.59	1.81	4.76
Un-burnt sites	1.74	3.69	5.73	5.40	4.14	1.74	5.73

4.5.2.2 Soil carbon stocks in the burnt and un-burnt sites

The mean soil carbon (Mg C ha^{-1}) stock of Teak trees in the burnt and un-burnt sites is shown in Table 21. In the sub plots of the burnt and un-burnt sites the Teak trees in the burnt sites had a mean soil carbon (Mg C ha^{-1}) stock of 55.24 Mg C ha^{-1} whiles those in the un-burnt sites had 67.16 Mg C ha^{-1}. The mean soil carbon (Mg C ha^{-1}) stock of Teak trees in the un-burnt site was greater than those in the burnt site but not significant ($p = 0.07$). The Teak trees in the burnt sites had a mean minimum soil carbon (Mg C ha^{-1}) stock of 33.25 Mg C ha^{-1} and a mean maximum of 78.23 Mg C ha^{-1} at depths of 30-40 cm and 20-30 cm, respectively whiles those in the un-burnt sites had a mean minimum soil carbon (Mg C ha^{-1}) stock of 43.48 Mg C ha^{-1} and a mean maximum carbon stock of 103.07 Mg C ha^{-} at depths of 30-40 cm and 20-30 cm, respectively. There was significant difference ($p = 0.01$) between mean soil carbon (Mg C ha^{-1}) stock in the burnt and un-burnt sites at the various depths. Generally the soil carbon (Mg C ha^{-1}) stock decrease as the depth increased in both the burnt and un-burnt sites. Thus considering the depth ranges from 0-30 cm and 30-40 cm.

Table 21. Mean soil carbon (Mg C ha^{-1}) stock in the burnt and un-burnt sites.

Treatments	Mean (Mg C ha^{-1})				Mean (Mg C ha^{-1})	Min (Mg C ha^{-1})	Max (Mg C ha^{-1})
Depth (cm)	0-10 (cm)	10-20 (cm)	20-30 (cm)	30-40 (cm)			
Burnt sites	46.71	62.76	78.23	33.25	55.24	33.25	78.23
Un-burnt sites	53.66	68.43	103.07	43.48	67.16	43.48	103.07

4.5.3 Litter carbon stocks

4.5.3.1 Burnt and un-burnt sites

The mean litter carbon (Mg C ha^{-1}) stock of Teak trees in the burnt and un-burnt sites is shown in Table 22. In the sub plots of the burnt and un-burnt sites the Teak trees in the burnt sites had mean litter carbon (Mg C ha^{-1}) stock of 0.86 Mg C ha^{-1} whiles those in the un-burnt sites had 1.06 Mg C ha^{-1}. The mean litter carbon (Mg C ha^{-1}) stock of Teak trees in the un-burnt sites was slightly higher than mean litter carbon (Mg C ha^{-1}) stock of Teak trees in the burnt sites but not significant (P = 0.22).

Table 22. Mean Litter carbon stock of Teak trees in the burnt and un-burnt sites.

Treatments	Mean (Mg C ha^{-1})
Burnt sites	0.86
Un-burnt sites	1.06

4.5.4 Herbaceous carbon stocks

4.5.4.1 Burnt and un-burnt sites

The mean herbaceous carbon (Mg C ha^{-1}) stock of Teak trees in the burnt and un-burnt sites is shown in Table 23 shows. In the sub plots of the burnt and un-burnt sites the Teak trees in the burnt sites had a mean herbaceous carbon (Mg C ha^{-1}) stock of 0.38 Mg C ha^{-1} whiles those in un-burnt sites had 0.28 Mg C ha^{-1}. The mean herbaceous carbon (Mg C ha^{-1}) stock of Teak trees in the burnt sites were slightly higher than those in the un-burnt sites but not significant (P = 0.51).

Table 23. Mean herbaceous carbon stock of Teak trees in the burnt and un-burnt sites.

Treatments	**Mean (Mg C ha^{-1})**
Burnt sites	0.38

Un-burnt sites	0.28

CHAPTER FIVE

9.0 DISCUSION

5.1 Survival of Teak trees

The survival of Teak trees in the burnt sites was greater (57 %) than the survival of Teak trees in the un-burnt sites (46 %) (Table1). This suggests that the Teak trees in the un-burnt sites required frequent weeding compared with the Teak trees in the burnt sites due to fast growing weeds in the former. This might have contributed to the relatively lower survival of Teak trees in the un-burnt sites. Further the Teak trees in the fertilized and un-fertilized sites also exhibited differences in their survival but the difference was not significant. The Teak trees in the fertilized sites had survival (49 %) slightly lower than the Teak trees in the un-fertilized sites (54 %)

(Table 2). This suggests that application of fertilizer did not affect the survival of Teak trees. The Teak trees of the potted seedling planting stocks had significantly higher survival (72 %) than the Teak trees of the stump planting stocks (31%) (Table 3). This trend may be due to the fact that the Teak trees of the potted seedling planting stocks were sturdier whereas the viability of the stumps could not be fully certified. The relatively high standard deviation for the mean percentage survival of Teak trees could be attributed to natural variations or the small sample size. Probably a larger sample size could minimize these variations.

5.2 Allometric relationships

The relationship for the above-ground phytomass estimation became stronger as different more parameters were introduced to the already existing ones as independent variables (Table 4). Specifically the addition of height, *h* to diameter at breast height d_{bh} resulted in an increase in the R^2 value for the above-ground phytomass estimation as shown in figure 6. Also by the introduction of wood density, ρ to d_{bh} and d_{bh} *h,* the R^2 value increased when compared with their preceding values as shown in figure 7 and 8, respectively. But the introduction of stem volume, *Vs* as independent variable resulted with the highest R^2 value for above-ground phytomass estimation as shown in figure 9. It was realized that the strength of the relationship was based on the significance of the independent variable present. Therefore in instances where only diameter values are available, the equation obtained from the use of the diameter alone could be used. A lot of studies in the tropical areas Araujo *et al.* (1999); Brown (1997); Laurance *et al.* (1997); Overman *et al.* (1994), has confirmed that a strong correlation was found between the above-ground phytomass of a tree (organic matter content) and its diameter at breast height (d_{bh}). Inclusion of height in the regression equation can improve the R^2 value and increase the precision, but measuring height of all trees across a large number of plots in an inventory can be very time consuming and often extremely difficult as the top of tall emergent trees can be almost impossible to see. Thus for practical purposes, regression equations based on diameter alone, and stratified by species groups or by climate type, are more useful (Brown, 2002). But strongest tiers are recommended at the international level because of their accuracy. Therefore it will be appropriate to use *Vs*, the highest tier, since the best estimate of above-ground phytomass would be obtained.

5.3 Growth of Teak trees

The heights and diameters of Teak trees in the un-burnt sites were both thicker and taller than those in the burnt sites (Table 5). Teak trees in the fertilized sites had higher heights and diameters than Teak trees in the unfertilized sites (Table 6). The heights and diameters of Teak trees using the potted seedling planting stocks were both thicker and taller than Teak trees using the stump stands planting stocks (Table 7). This suggest that the site preparation methods and planting stocks of the Teak trees in un-burnt and fertilized sites as well as the potted seedling plantings stocks were effective in improving the growth relative to Teak trees in the burnt and un-fertilized sites and using the stump planting stocks. Other factors including site differences such as soil, topography, natural variations and competitive interactions might have also contributed to differences since the reduce growth were not significant. The relatively high standard deviation from the mean heights and diameters of Teak trees could be attributed to natural variations or the small sample size. Probably a larger sample size could minimize these variations.

The stem volume of Teak trees in the un-burnt sites had a mean volume relatively higher than the Teak trees in the burnt sites. Also the stem volume of Teak trees in the fertilized sites had a mean volume relatively higher than Teak trees in the un-fertilized sites but the difference was not significant. The stem volume of Teak trees using the potted seedling planting stocks had a mean volume relatively higher than Teak trees using the stump planting stocks but the difference was not significant. This suggest that the site preparation method and planting stock of Teak trees in the un-burnt sites, fertilized sites and potted seedling planting stock was effective in improving the growth relative to the Teak trees in the burnt sites, un-fertilized sites and using stump planting stocks (Table 8-10). This can be attributed to site differences such as soil, topography, natural variations and competitive interactions might have also contributed to differences.

The mean biomass of Teak trees in the un-burnt sites was higher than those in the burnt sites. Teak trees in the fertilized sites had a higher mean biomass than those un-fertilized sites. The biomass of Teak trees of the potted seedling planting stock was relatively higher than Teak trees using stump planting stocks. This suggest that the site preparation method and planting stock of Teak trees in the un-burnt sites, fertilized sites and the potted seed planting stocks was effective in improving the growth relative to Teak trees in the burnt sites, un-fertilized sites and using stump planting stocks (Table 11-13). Site differences such as soil, topography, natural variations and competitive interactions might have also contributed to differences.

5.4 Stem form

Teak trees in the un-burnt sites had a higher mean percentage relative position of first fork of 52 % whiles the burnt sites had 50 % respectively (Table 14). The Trees in the fertilized sites and the un-fertilized sites both had a mean percentage relative position of first fork of 51 % (Table 15). The Teak trees of potted seedling and bare rooted stump planting stocks had mean percentage relative position of first fork of 51 and 50%, respectively (Table 16). The mean percentage relative position of first fork on stem form was not significant in Teak trees in the burnt and un-burnt sites. Also fertilization and the planting stocks used did not affect stem form. Hence the effect of site preparation methods and planting stocks on stem form was not variable and therefore did not affect the stem volume which can influence the form the Teak tree. Adu-Bredu *et al*., 2008 reported that Teak trees with percentage relative position of first fork ranging from 16% to 84 % can lead to relative loss of stem volume of 6.5% under Dry semi-deciduous forest ecological zone (DSDF). Environmental factors might have contributed to the reason why the site preparation methods and planting stocks had no influence on stem form. For the Teak trees, it can therefore be surmised that the seeds for the potted seedling and bare rooted stump were from the same source. The relatively low standard deviation from the mean percentage relative position of first fork of Teak trees in the burnt and un-burnt sites, fertilized and un-fertilized sites and of the potted seedling and stump planting stocks suggests that the results would not differ significantly even when the sample size were increased.

5.5 Carbon stocks

The mean biomass carbon stock of Teaks trees in the burnt sites was 98.03 Mg C ha^{-1} whereas the Teak trees in the un-burnt sites had 122.81 Mg C ha^{-1} (Table 17). Although the difference was not statistically significant the biomass carbon stocks of Teak trees in the un-burnt sites were relatively higher than those in the burnt sites by as much as 24.78 Mg C ha^{-1}. As expected the organic carbon was highest in Teak trees in the un-burnt sites. This can be attributed to increase level of organic matter that were utilized by the Teak trees as they were not burnt away and thereby their decomposition made it available for the tree root and stem. The values of the biomass carbon stocks for the Teak trees in this study are comparable with the range of 60.0 to 200.0 Mg C ha-1 given for the tropical humid forests by Brown (1997). The Teak trees in fertilized sites had mean biomass carbon stock of 126.33 Mg C ha^{-1} whiles those in the un-fertilized site had 93.96 Mg C ha^{-1} (Table 18) a difference of 32.37 Mg C ha^{-}. This suggests that application of fertilizer improves growth of trees into preferable sizes as the amount of biomass carbon stock present can be related to the mass of a tree. The Teak trees using the potted planting stocks had mean biomass carbon stock at 117.27 Mg C ha^{-1} whereas Teak trees using stump planting stocks had 91.06 Mg C ha^{-1} (Table 19) a difference of 26.21 Mg C ha^{-1}. The differences in biomass carbon stock can be explained with regards to the higher survival of the potted stands and thereby having increase mass and invariably leading to higher carbon stock.

Bulk density indicates whether how difficult or easy the soil will be for roots to penetrate. Generally soil with low bulk density are more suitable for agriculture, since the high pore space has a greater potential to store water and roots are able to grow more readily. An increase in bulk density means resistance to root increases and the amount of water available to crop decreases.

Tangsinmankong (2004) reported that bulk density in mixed deciduous forest and Teak plantations tend to increased with increasing depth because of higher litter and organic matter in the surface soil thus organic matter tends to reduce the degree of compaction. Similar results were observed in this study as the bulk density was increasing with depth. However the sub soil depth (30-40 cm) of both the burnt and un-burnt sites exhibited some slight variations (Table 20). Furthermore it was observed that un-burnt sites had a higher mean bulk density than the burnt sites but was not significant. The relatively high mean bulk density in the un-burnt sites to the burnt sites could be attributed to natural variations, or the small sample size. Bulk density determination is an important factor in soil carbon determination. Soil rich in organic matter generally have low bulk density. However the trend was prominent in this work but probably a larger sample size could minimize these variations.

Although, forest management through weed burning or prescribe burning is essential it can lead to intensification of carbon as well as exit of carbon from the soil. Carbon stored in soil organic matter is important in improving soil properties such as nutrient supply, moisture retention and consequently, increase land productivity and crop yields (Lal *et al.*, 1999; FAO, 2001). The results showed some variations from the normal trend as generally soil carbon tend to decrease with increasing depth but that pattern was not observed systematically but some variations were displayed along the soil profile in both the burnt and un-burnt sites (Table 21). The seepage of soil nutrients along the soil profile can also contribute to these variations. Also another interesting development was observed from the burnt and un-burnt sites as soil carbon of the later were higher than the former across the soil depth thus from 0-40 cm in all cases. This reflected in the mean soil carbon which was 55.24 Mg C ha^{-1} and 67.16 Mg C ha^{-1} for burnt and un-burnt sites, respectively.

The litter carbon stocks of the un-burnt sites were higher than the burnt sites. The mean litter carbon stock was 1.06 Mg C ha^{-1} and 0.86 Mg C ha^{-1}, for the un-burnt and burnt sites respectively (Table 22). The high litter carbon exhibited in the un-burnt sites can be the result of high leaf turnover due to the favourable environmental conditions.

In the herbaceous carbon stocks the burnt sites were higher than the un-burnt sites but the difference was not significant. As the mean herbaceous carbon stock was 0.38 Mg C ha^{-1} and 0.28 Mg C ha^{-1}, for burnt and un-burnt sites respectively (Table 23). Research has shown that fire also encourages the growth of herbs and retards the growth of the woody plants (Adu-Bredu *et al*., 2010).

The biomass carbon stock had the highest contribution because of the increase in weight of the Teak stands and thereby increased carbon. The herbs carbon stock contribution to the total carbon stock was the least and was followed in an increasing order of litter carbon stock, soil carbon stock and the biomass carbon stock. The un-burnt sites recorded higher values in carbon stocks when compared with the burnt sites except with the herbaceous carbon stock. Since fire support herbs thereby increased quantity of the herbaceous carbon stock in the burnt sites could have invariable yielded higher carbon stock. The values of the total carbon stock in the un-burnt sites were as follow; biomass carbon stock (122.81 Mg C ha^{-1}), soil carbon stock (67.16 Mg C ha^{-1}), litter carbon stock (1.06 Mg C ha^{-1}) and herb carbon stock (0.28 Mg C ha^{-1}). The burnt sites resulted as follows; carbon stock (98.03 Mg C ha^{-1}), soil carbon stock (55.24 Mg C ha^{-1}), biomass, litter carbon stock (0.86 Mg C ha^{-1}) and herb carbon stock (0.38 Mg C ha^{-1}).

CHAPTER SIX

6.0 CONCLUSION

It has been shown from the results of this study that the potted seedlings of Teak trees are better suited when selecting planting stocks. The potted seedlings of Teak trees had significantly higher survival ($p = 0.001$) compared to the stumps of Teak trees. Also the Teak trees in the burnt sites had higher survival relative to Teak trees in the un-burnt sites. Fertilization did not have much influence on the survival of the Teak trees.

The results showed that the stem form of Teak trees were not affected by the site preparation methods and planting stocks. Hence the Teak trees in the burnt and un-burnt sites did not affect stem form. Also fertilization and the planting stocks of Teak trees had no influence on stem form significantly.

Teak trees in the un-burnt sites had higher growth relative to those burnt sites. Therefore it is important to establish Teak plantation in un-burnt sites since it prevents the burning of debris which can lead to accumulation of carbon dioxide in the atmosphere which may contribute to climatic change in the near future. Also Teak trees in the fertilized sites were higher in growth relative to those in the un-fertilized sites. The Teak trees of potted seedling planting stocks had higher growth relative to those of the bare rooted stump planting stocks. The growth variables of the tree height, diameter, volume and biomass in the un-burnt sites, fertilized sites and of the potted seedling planting stocks were higher relative to those in the burnt sites, unfertilized sites and of bare rooted stump planting stocks.

It was shown that the best allometric model for estimating above-ground phytomass of individual Teak trees was M_t=0.3158 (Vs) $^{1.0806}$ as the model resulted with the highest coefficient of determination (R^2 = 0.9978).

Furthermore the results showed that the un-burnt sites accumulated more soil carbon stock compared to the burnt sites. The soil carbon stock is important since the stored in soil organic matter helps in improving soil properties such as nutrient supply, moisture retention and thus increase land productivity and crop yields. It was shown that higher proportion of soil carbon stock was allocated to the top 30 cm soil depth and declines afterwards. And also the un-burnt sites had higher proportion of soil carbon stock at the various depths relative to the burnt sites. The results further revealed the biomass carbon stock in the un-burnt sites were higher relative to the burnt sites. Also the litter accumulation reflected a higher proportion in the un-burnt sites than the burnt sites. However the herbaceous carbon stock resulted with higher amount of carbon stock in the burnt sites relative to the un-burnt sites.

6.1 RECOMMENDATIONS

It is therefore recommended that for better growth performance the following should be considered in the establishment of Teak Plantation:

- If possible site should not burnt
- Fertilizer application should be considered
- Potted seedling should be preferred to bared rooted stumps as planting stocks

The various allometric equations developed can be used in the estimation of aboveground phytomass, depending on the sort of inventory data available, for Teak in Dry Semi-deciduous forest zone. The inventory data are diameter at breast height (Dbh), height, wood density and stem volume. However the best equation is the use of volume as independent variable and is given as: $M_t=0.3158\ (Vs)^{1.0806}\ (R^2 = 0.9978)$.

Further studies can be conducted to determine the effect of the various site preparation methods on nutrient status of the soil and their effect on the growth of the stem.

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APPENDIX 1

Appendix 1A. Setting of 1m x 1m quadrat for undergrowth sampling.

Appendix 1B. Measuring fresh mass of wood litter.

Appendix IC. 1mx1m quadrat for soil samples collectio.

Appendix 1D. Drying of soil samples.

Appendix 1E. Weighing of sub-sample soil bulk density at lab.

Appendix 1F. Cutting of stem into disc and sections.

APPENDIX 2

Measured characteristic of Teak trees for destructive sampling

PA	SA	Tnb	Dbh (cm)	Ht (m)	Vs dm^3	ρ kg/dm^3	Mt (kg)
Braboayga	6	1	4.70	7.07	7.252	0.886	2.734
Braboayga	6	2	6.20	8.19	14.9	0.823	5.799
Braboayga	6	3	9.90	10.85	38.179	0.914	15.733
Braboayga	6	4	13.50	11.74	82.722	0.967	38.043
Braboayga	6	5	15.00	13.00	104.123	0.981	47.183
Akrobi	12	1	9.20	10.55	38.479	0.925	16.445
Akrobi	12	2	13.60	12.45	96.429	0.887	42.031
Akrobi	12	3	16.80	13.70	154.465	0.772	60.588
Nchiraa	19	1	15.80	15.65	147.59	1.069	74.662
Nchiraa	19	2	22.00	18.14	294.906	0.889	129.260
Nchiraa	19	3	26.50	12.92	341.724	1.029	168.179

Ofuman	31	1	17.00	15.40	174.881	0.988	85.019
Ofuman	31	2	25.00	18.76	440.044	1.038	232.064
Ofuman	31	3	31.80	17.56	608.464	1.052	311.770

PA: Plantation area, SA: Stand Age, Tnb: Number of trees, D_{bh}: Diameter at breast height, Ht: Height, Vs: stem volume, ρ: wood density and Mt: phtomass of tree

(Original source: Asomaning, 2006)

APPENDIX 3

Sample data sheet for height, diameter and fork measurement of Teak trees

TNB	REPLICATE	TREATMENT	SUB-TMT	PLANTING STOCK	DBH 1(CM)	DBH 2(CM)	FORK 1 (M)	HT (M)	BASE (M)	DIST(M)	RMKS
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											
19											
20											
21											
22											
23											
24											
25											
26											
27											
28											
29											
30											
31											
32											
33											
34											
35											
36											

APPENDIX 4

Sample data sheet for undergrowth carbon determination.

Type	Rep	Tmt	Sub-Tmt	Planting stock	Total Fresh mass (g)	Sample Fresh mass (g)	Sample Dry mass (g) W1 W2 W3	Total Dry mass (g)	Total Carbon Mg C ha^{-1}
Leaf litter									
Leaf litter									
Leaf litter									
Leaf litter									
Leaf litter									
Leaf litter									
Leaf litter									
Leaf litter									
Wood litter									
Wood litter									
Wood litter									
Wood litter									
Wood litter									
Wood litter									
Wood litter									
Wood litter									
Herbs/stem									
Herbs/stem									
Herbs/stem									
Herbs/stem									
Herbs/stem									
Herbs/stem									
Herbs/stem									
Herbs/stem									
Herbs/Root									
Herbs/Root									
Herbs/Roo									

T									
HERBS/ROOT									
HERBS/ROOT									
HERBS/ROOT									
HERBS/ROOT									
HERBS/ROOT									

APPENDIX 5

Sample data sheet for bulk density determination

LEVEL (CM)	REP	TMT	SUB-TMT	PLANTING STOCK	MASS FINE (G)	MASS COARSE (G)	TOTAL MASS (G)	VOLUME FINE $(CM)^3$	VOLUME COARSE $(CM)^3$	TOTAL VOLUME $(CM)^3$	BULK DENSITY GCM^{-3}
0-10											
10-20											
20-30											
30-40											
0-10											
10-20											
20-30											
30-40											
0-10											
10-20											
20-30											
30-40											
0-10											
10-20											
20-30											

30-40											
0-10											
10-20											
20-30											
30-40											
0-10											
10-20											
20-30											
30-40											
0-10											
10-20											
20-30											
30-40											

APPENDIX 6

Sample data sheet for soil carbon determination

LEVEL (CM)	REP	TMT	SUB-TMT	PLANTING STOCK	BULK DENSITY GCM^{-3}	ORGANIC CARBON %	SOIL CARBON MG C HA^{-1}
0-10							
10-20							
20-30							
30-40							
0-10							
10-20							
20-30							
30-40							
0-10							
10-20							
20-30							
30-40							
0-10							
10-20							
20-30							

30-40							
0-10							
10-20							
20-30							
30-40							
0-10							
10-20							
20-30							
30-40							
0-10							
10-20							
20-30							
30-40							

APPENDIX 7

Sample data sheet for biomass carbon determination

TNB	REPL	TMT	SUB-TMT	PLANTING STOCK	VOLUME DM^3	ABOVE GROUND MASS (KG)	BELOW-GROUND MASS (KG)	TOTAL CARBON MG C HA^{-1}
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								

17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								
31								
32								
33								
34								
35								
36								

APPENDIX 8

System carbon stock determinations

Biomass carbon stock: The average result for carbon analysis (47.48 %) of biomass carbon stock in Adu-Bredu *et al*., 2010.

Litter carbon stock: The average result for carbon analysis (29.98 %) of litter carbon stock in Adu-Bredu *et al*., 2010.

Herbaceous carbon stock: The average result for carbon analysis (37.46 %) of herbaceous carbon stock in Adu-Bredu *et al*., 2010.

APPENDIX 9

ANALYSIS OF VARIANCE

ANOVA: Effect burnt and un-burnt sites on survival of Teak trees.

	Burnt sites	Un-burnt sites
R1	49	53
R2	67	49
R3	66	42
R4	46	42

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
R1	2	102.09	51.045	6.02045
R2	2	115.28	57.64	163.0818
R3	2	108.33	54.165	278.7161
R4	2	87.5	43.75	8.6528

Burnt sites	4	227.78	56.945	119.2876
Un-burnt sites	4	185.42	46.355	28.09163

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Rows	209.9627	3	69.98757	0.90433	0.531969	9.276628
Columns	224.2962	1	224.2962	2.898197	0.187232	10.12796
Error	232.1749	3	77.39163			
Total	666.4338	7				

ANOVA: Effect fertilized and un-fertilized sites on survival Teak trees.

	Fertilized sites	Un-fertilized sites
R1	53	49
R2	53	62
R3	50	58
R4	39	49

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
R1	2	102.08	51.04	11.8098
R2	2	115.28	57.64	34.7778
R3	2	108.33	54.165	34.6945
R4	2	87.5	43.75	47.2392

Fertilized sites	4	195.83	48.9575	47.7222
Un-fertilized sites	4	217.36	54.34	45.7956

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Rows	209.975	3	69.9916	2.97505	0.19723	9.27663
Columns	57.9426	1	57.9426	2.4629	0.21458	10.128
Error	70.5786	3	23.5262			
Total	338.496	7				

ANOVA: Effect potted seedling and bare rooted stump planting stocks on survival of Teak trees.

	Potted	Stump
R1	66	36
R2	86	29
R3	69	39
R4	67	20

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
R1	2	102.08	51.04	445.81
R2	2	115.28	57.64	1621.08
R3	2	108.33	54.165	466.651
R4	2	87.5	43.75	1114.86

Potted	4	288.88	72.22	87.7809
Stump	4	124.31	31.0775	69.8762

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	209.975	3	69.9916	0.79839	0.57122	9.27663
Columns	3385.41	1	3385.41	38.6174	0.0084	10.128
Error	262.996	3	87.6655			
Total	3858.38	7				

ANOVA: Effect burnt and un-burnt sites on height of Teak trees.

	Burnt sites	Un-burnt sites
R1	9.15	10.10
R2	12.70	13.38
R3	11.04	12.31
R4	8.66	10.46

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
R1	2	19.24534841	9.622674	0.448174
R2	2	26.07467262	13.03734	0.228999
R3	2	23.3508887	11.67544	0.804906
R4	2	19.12090909	9.560455	1.63038

Burnt sites	4	41.5468825	10.38672	3.431919
Un-burnt sites	4	46.24493632	11.56123	2.401629

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	17.147146	3	5.715715	48.50736	0.004844	9.276628
Columns	2.7589637	1	2.758964	23.4144	0.016834	10.12796
Error	0.3534958	3	0.117832			
Total	20.259606	7				

ANOVA: Effect of fertilized and un-fertilized sites on height Teak trees.

	Fertilized sites	Un-fertilized sites
R1	9.16	10.17
R2	13.83	12.25
R3	11.86	11.26
R4	9.40	9.61

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
R1	2	19.32558	9.662792	0.508739
R2	2	26.08285	13.04143	1.247384
R3	2	23.12083	11.56042	0.182509
R4	2	19.01071	9.505357	0.023731

Fertilized sites	4	44.24854	11.06213	4.902253
Un-fertilized sites	4	43.29145	10.82286	1.373932

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	16.9807	3	5.660232	9.189386	0.05063	9.276628
Columns	0.114503	1	0.114503	0.185896	0.695458	10.12796
Error	1.84786	3	0.615953			
Total	18.94306	7				

ANOVA: Effect of potted seedling and bare rooted stump planting stocks on height Teak trees.

	Potted	Stump
R1	9.60	9.70
R2	13.18	12.40
R3	12.41	9.97
R4	9.66	9.03

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
R1	2	19.307004	9.653502	0.00506906
R2	2	25.583833	12.791916	0.30347555
R3	2	22.385429	11.192714	2.98307759
R4	2	18.691504	9.3457519	0.20245877
Potted	4	44.862527	11.215632	3.43614105

Stump	4	41.105242	10.27631	2.16671878

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	15.079147	3	5.0263825	8.71913286	0.054265776	9.2766282
Columns	1.764649	1	1.764649	3.06108991	0.178497973	10.127964
Error	1.729432	3	0.5764773			
Total	18.573228	7				

ANOVA: Effect of burnt and un-burnt sites on diameter of Teak trees.

	Burnt	Un-burnt
R1	9.16	9.38
R2	13.75	13.36
R3	11.04	13.09
R4	8.25	10.56

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
R1	2	18.54148	9.270742	0.024279
R2	2	27.11689	13.55844	0.075396
R3	2	24.13086	12.06543	2.090086
R4	2	18.80549	9.402746	2.661142
Burnt	4	42.20557	10.55139	5.907963

Un-burnt	4	46.38916	11.59729	3.779889

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	26.40046	3	8.800154	9.913449	0.045771	9.276628
Columns	2.187807	1	2.187807	2.464584	0.21446	10.12796
Error	2.663095	3	0.887698			
Total	31.25136	7				

ANOVA : Effect fertilized and un-fertilized sites on diameter of Teak trees.

	Fertilized sites	Un-fertilized sites
R1	9.17	9.39
R2	14.69	12.63
R3	12.46	11.31
R4	9.75	9.03

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
R1	2	18.55974026	9.2798701	0.02553213
R2	2	27.32647746	13.663239	2.11755467
R3	2	23.77321429	11.886607	0.65374167
R4	2	18.77633929	9.3881696	0.26378438
Fertilized sites	4	46.06876353	11.517191	6.53621998
Un-fertilized	4	42.36700776	10.591752	2.86228486

sites

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	26.84777616	3	8.9492587	19.9206141	0.0174847	9.27662815
Columns	1.712874473	1	1.7128745	3.81277515	0.1458979	10.1279645
Error	1.347738382	3	0.4492461			
Total	29.90838901	7				

ANOVA: Effect potted seedling and bare rooted stump planting stocks on diameter of Teak trees.

	Potted stocks	Stump stocks
R1	8.98	9.82
R2	13.75	13.11
R3	12.89	9.98
R4	9.25	9.67

Anova: Two-Factor Without Replication

SUMMARY	Count	Sum	Average	Variance
R1	2	18.79468	9.397338	0.352749
R2	2	26.86152	13.43076	0.204859

R3	2	22.86507	11.43254	4.228024
R4	2	18.92017	9.460083	0.086545
Potted	4	44.86674	11.21668	6.028112
Stump	4	42.5747	10.64367	2.721089

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	22.03211	3	7.344036	5.226456	0.103841	9.276628
Columns	0.656681	1	0.656681	0.467333	0.543284	10.12796
Error	4.215497	3	1.405166			
Total	26.90429	7				

ANOVA: Effect of burnt and un-burnt sites on stem volume of Teak trees

	Burnt sites	Un-burnt sites
R1	2767	3113
R2	8089	8041
R3	6083	7997
R4	2148	3920

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
R1	2	5880	2940	59858
R2	2	16130	8065	1152
R3	2	14080	7040	1831698

R4	2	6068	3034	1569992
Burnt sites	4	19087	4771.75	7875537
Un-burnt sites	4	23071	5767.75	6866366

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	42747041.5	3	14249014	28.90915	0.010274	9.276628154
Columns	1984032	1	1984032	4.025309	0.138476	10.12796448
Error	1478668	3	492889.3			
Total	46209741.5	7				

ANOVA: Effect of fertilized and un-fertilized sites on stem volume of Teak trees.

	Fertilized sites	Un-fertilized sites
R1	2721	3193
R2	10078	6330
R3	7617	6158
R4	3508	2579

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
R1	2	5914	2957	111392
R2	2	16408	8204	7023752

R3	2	13775	6887.5	1064341
R4	2	6087	3043.5	431520.5
Fertilized sites	4	23924	5981	12068411
Un-fertilized sites	4	18260	4565	3826485

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	43063795	3	14354598	9.319366	0.049696	9.276628
Columns	4010112	1	4010112	2.603466	0.205032	10.12796
Error	4620893	3	1540298			
Total	51694800	7				

ANOVA: Effect of potted seedling and bare rooted stump planting stocks on stem volume Teak trees.

	Potted stocks	Stump stocks
R1	2755	3293
R2	8449	6946
R3	8321	4172
R4	3057	2772

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
R1	2	6048	3024	144722
R2	2	15395	7697.5	1129505
R3	2	12493	6246.5	8607101
R4	2	5829	2914.5	40612.5
Potted stocks	4	22582	5645.5	10024412
Stump stocks	4	17183	4295.75	3455487

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	34161406	3	11387135	5.441197	0.098869	9.276628
Columns	3643650	1	3643650	1.741071	0.278666	10.12796
Error	6278289	3	2092763			
Total	44083346	7				

ANOVA: Effect of burnt and un-burnt sites on relative position of first of Teak trees.

	Burnt sites	Un-burnt sites
R1	0.51	0.55
R2	0.48	0.52
R3	0.53	0.49
R4	0.47	0.51

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
R1	2	1.063844	0.531922	0.000823526

R2	2	1.005609	0.502804	0.000823823
R3	2	1.012204	0.506102	0.000888745
R4	2	0.983021	0.491511	0.000842649
Burnt sites	4	1.992305	0.498076	0.000669054
Un burnt sites	4	2.072372	0.518093	0.000773226

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.001749	3	0.000583	0.678762548	0.621072	9.276628
Columns	0.000801	1	0.000801	0.932736292	0.405394	10.12796
Error	0.002577	3	0.000859			
Total	0.005128	7				

ANOVA: Effect of fertilized and un-fertilized sites on relative position of first of Teak trees.

	Fertilized sites	Un-fertilized sites
R1	0.55	0.52
R2	0.49	0.51
R3	0.49	0.53
R4	0.51	0.49

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
R1	2	1.067554	0.533777	0.000376113
R2	2	0.998549	0.499275	0.000158308
R3	2	1.01924	0.50962	0.000938178
R4	2	0.994859	0.49743	0.000264672
Fertilized sites	4	2.034763	0.508691	0.00075684
Un-fertilized sites	4	2.04544	0.51136	0.00037652

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.001677	3	0.000559	0.973322674	0.508606	9.276628
Columns	1.42E-05	1	1.42E-05	0.024807781	0.884851	10.12796
Error	0.001723	3	0.000574			
Total	0.003414	7				

ANOVA: Effect of potted seedling and bare rooted stump planting stocks on relative position of first of Teak trees.

	Potted stocks	Stump stocks
R1	0.53	0.55
R2	0.51	0.46
R3	0.51	0.50
R4	0.49	0.51

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
R1	2	1.073304	0.536652	0.000201349
R2	2	0.973078	0.486539	0.001335983
R3	2	1.0119	0.50595	8.11751E-05
R4	2	0.999904	0.499952	0.000239182
Potted stocks	4	2.04034	0.510085	0.000242511
Stump stocks	4	2.017846	0.504461	0.001254543

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.002697	3	0.000899	1.502816782	0.372968	9.276628
Columns	6.32E-05	1	6.32E-05	0.105737656	0.766408	10.12796
Error	0.001794	3	0.000598			
Total	0.004554	7				

ANOVA : Effect of burnt and un-burnt sites on biomass of Teak trees.

	Burnt sites	Un-burnt sites
R1	1320	1486
R2	4128	4089
R3	3092	4110
R4	1012	1906

Anova: Two-Factor Without Replication

SUMMARY	Count	Sum	Average	Variance
R1	2	2806	1403	13778
R2	2	8217	4108.5	760.5
R3	2	7202	3601	518162
R4	2	2918	1459	399618
Burnt sites	4	9552	2388	2185739
Un-burnt sites	4	11591	2897.75	1955078

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	12009820	3	4003273	29.10566	0.010174	9.276628
Columns	519690.1	1	519690.1	3.778389	0.147162	10.12796
Error	412628.4	3	137542.8			
Total	12942139	7				

ANOVA: Effect of fertilized and un-fertilized sites on biomass of Teak trees.

	Fertilized sites	Un-fertilized sites
R1	1295	1527
R2	5210	3161
R3	3927	3115
R4	1715	1216

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
R1	2	2822	1411	26912

	potted seedlings	Bare rooted stumps

R2	2	8371	4185.5	2099201
R3	2	7042	3521	329672
R4	2	2931	1465.5	124500.5
Fertilized sites	4	12147	3036.75	3432092
Un-fertilized sites	4	9019	2254.75	1056647

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	12108981	3	4036327	8.921788	0.052647	9.276628
Columns	1223048	1	1223048	2.703392	0.198682	10.12796
Error	1357237	3	452412.3			
Total	14689266	7				

ANOVA: Effect of potted and stump planting stocks on biomass of Teak trees.

R1	1310	1580
R2	4315	3510
R3	4282	2076
R4	1477	1306

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
R1	2	2890	1445	36450
R2	2	7825	3912.5	324012.5
R3	2	6358	3179	2433218
R4	2	2783	1391.5	14620.5
Potted stands	4	11384	2846	2817838
Stump stands	4	8472	2118	962738.7

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	9593397	3	3197799	5.487168	0.097855	9.276628
Columns	1059968	1	1059968	1.818821	0.270227	10.12796
Error	1748333	3	582777.7			
Total	12401698	7				

ANOVA: Effect of burnt and un-burnt sites on biomass carbon stock of Teak trees.

	Burnt sites	Un-burnt sites
R1	53.91	60.54
R2	167.76	172.57
R3	128.91	181.19
R4	41.52	76.93

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
R1	2	114.4493518	57.22468	21.93463
R2	2	340.3328378	170.1664	11.5493
R3	2	310.0955596	155.0478	1366.883
R4	2	118.449322	59.22466	626.7242
Burnt sites	4	392.1040457	98.02601	3651.802
Un-burnt sites	4	491.2230255	122.8058	3955.856

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	22023.957	3	7341.319	27.56374	0.011003	9.276628
Columns	1228.0715	1	1228.072	4.610921	0.121015	10.12796
Error	799.01919	3	266.3397			
Total	24051.048	7				

ANOVA: Effect of fertilized and un-fertilized sites on biomass carbon stock of Teak trees.

	Fertilized sites	Unfertilized sites
R1	52.86	62.26
R2	214.39	131.20
R3	169.04	132.51
R4	69.03	49.86

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
R1	2	115.121869	57.56093	44.10362
R2	2	345.5934014	172.7967	3459.818
R3	2	301.5563497	150.7782	667.2582
R4	2	118.8929753	59.44649	183.6688
Fertilized sites	4	505.327079	126.3318	6086.426
Unfertilized sites	4	375.8375164	93.95938	1941.019

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	21823.4272	3	7274.476	9.661065	0.047373	9.276628
Columns	2095.943352	1	2095.943	2.783574	0.193827	10.12796
Error	2258.905025	3	752.9683			
Total	26178.27558	7				

ANOVA: Effect of potted seedling and bare rooted stump planting stocks on biomass carbon stock Teak trees.

	Potted stocks	Stump stocks
R1	53.58	64.21
R2	175.60	152.65
R3	180.09	93.82
R4	59.82	53.57

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
R1	2	117.7841	58.89204	56.49786
R2	2	328.2442	164.1221	263.3099
R3	2	273.9173	136.9586	3721.378
R4	2	113.3901	56.69503	19.53518
Potted stands	4	469.088	117.272	4902.033
Stump stands	4	364.2477	91.06192	1975.774

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	17946.6343	3	5982.211	6.679593	0.076578	9.276628
Columns	1373.93594	1	1373.936	1.534104	0.303579	10.12796
Error	2686.78544	3	895.5951			
Total	22007.3557	7				

ANOVA: Effect of burnt and un-burnt sites on bulk density of Teaks trees.

	Burnt sites	Un-burnt sites
0-10	1.81	1.74
10-20	4.37	3.69
20-30	4.76	5.73
30-40	3.41	5.40

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
0-10	2	3.55	1.77	0
10-20	2	8.06	4.03	0.23
20-30	2	10.5	5.24	0.47
30-40	2	8.81	4.4	1.99
Burnt sites	4	14.3	3.59	1.73
Un-burnt sites	4	16.6	4.14	3.37

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	13.19215112	3	4.4	6.32	0.082159314	9.276628154
Columns	0.607845122	1	0.61	0.87	0.418993837	10.12796448
Error	2.088236155	3	0.7			
Total	15.8882324	7				

ANOVA: Effect of burnt and un-burnt sites on soil carbon stock of Teak trees

	Burnt sites	Un-burnt sites
0-10	46.71	53.66
10-20	62.76	68.43
20-30	78.23	103.07
30-40	33.25	43.48

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
0-10	2	100.4	50.19	24.2
10-20	2	131.2	65.6	16.1
20-30	2	181.3	90.65	309
30-40	2	76.74	38.37	52.3
Burnt sites	4	220.9	55.24	380
Un-burnt sites	4	268.6	67.16	678

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	3058.063362	3	1019	26.2	0.011842776	9.2766282
Columns	284.4182212	1	284.4	7.31	0.073593582	10.127964
Error	116.777514	3	38.93			
Total	3459.259098	7				

ANOVA: Effect of burnt and un-burnt sites on litter carbon stock of Teak trees.

	Burnt sites	Un-burnt sites
R1	1.11	0.89
R2	0.80	0.92
R3	0.56	1.47
R4	0.98	0.96

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
R1	2	2.006413178	1.003206589	0.024833444
R2	2	1.720255809	0.860127904	0.007772567
R3	2	2.02620784	1.01310392	0.411740471
R4	2	1.937264353	0.968632177	0.000104418
Burnt sites	4	3.447657212	0.861914303	0.057498092
Un-burnt sites	4	4.242483967	1.060620992	0.074148881

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.029458716	3	0.009819572	0.080602326	0.966200807	9.276628
Columns	0.078968696	1	0.078968696	0.648201436	0.479653306	10.12796
Error	0.365482203	3	0.121827401			
Total	0.473909615	7				

ANOVA: Effect of burnt and un-burnt sites on herbaceous carbon stock of Teak trees

Row Labels	Burnt sites	Un-burnt sites
R1	0.43	0.59
R2	0.56	0.17
R3	0.18	0.26
R4	0.34	0.10

Anova: Two-Factor Without Replication

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
R1	2	1.01796	0.508980656	0.013717665
R2	2	0.72286	0.361430059	0.075294233
R3	2	0.44049	0.220242679	0.002710015
R4	2	0.4463	0.223150285	0.02819388
Burnt sites	4	1.50693	0.376733593	0.024322005
Un-burnt sites	4	1.12067	0.280168247	0.047083919

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.112951713	3	0.037650571	1.115395547	0.465289408	9.276628
Columns	0.018649732	1	0.018649732	0.552497013	0.511216348	10.12796
Error	0.10126606	3	0.033755353			
Total	0.232867505	7				