KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

FACULTY OF RENEWABLE NATURAL RESOURCES

DEPARTMENT OF AGROFORESTRY

STUDIES ON THE ECOLOGY, CONSERVATION, CULTIVATION AND MANAGEMENT POTENTIAL OF *Thaumatococcus daniellii* FOR AGROFORESTRY SYSTEMS

BY

SAMUEL BOADI

B.Sc (HONS) NAT. RES. MGT. KNUST

OCTOBER, 2011

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A THESIS SUBMITTED TO SCHOOL OF GRADUATE STUDIES, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI IN FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY DEGREE IN AGROFORESTRY

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SAMUEL BOADI

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DECLARATION

I declare that except references to other people's work which have been duly cited, this thesis submitted to the School of Graduate Studies, Kwame Nkrumah University of Science and Technology, Kumasi for the Doctor of Philosophy Degree in Agroforestry under the supervision of Dr. Francis Ulzen-Appiah is my own investigation.

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SAMUEL BOADI DATE

(CANDIDATE)

…………………………………… ………………………

FRANCIS ULZEN-APPIAH (PhD) DATE

(SUPERVISOR)

……..…………………………….... ………………………

KWAME TWUM-AMPOFO (PhD) DATE

(HEAD OF DEPARTMENT, AGROFORESTRY)

ABSTRACT

As the healthiness of chemical sweeteners is often questioned, there is an anticipated increased demand for natural sweeteners like thaumatin, which is obtained from *Thaumatococcus daniellii*. Studies were therefore conducted on the conservation, site conditions, provenances, growth performance, yield potential of leaves and fruits as well as integration of *T. daniellii* into Agroforestry systems. The first study was conducted in the Western Region of Ghana on soil characteristics, fruit sources and conservation of *T. daniellii* in off reserves. Soil pH, N, P, K, Ca, Mg, Total base saturation and Effective cation exchange capacity and organic matter differed significantly among sites. Soil texture significantly differed among sites and ranged from silt loam to sandy loam. Major sources of fruits were predominantly from seven communities within Aowin-Suaman and Wassa Amenfi West districts. Also, no records of conservation, cultivation or integration of *T. daniellii* into farming systems were obtained for previous or current fruit supplying communities but for Samartex plantations.

The second study determined foliage harvesting effects on *T. daniellii* fruit yield (number and weight), flower production and specific leaf area. The study also estimated potential incomes that could be obtained from leaf and fruit collection. A randomized complete block design was used. Treatments involved harvesting and maintaining a specified petiole population per plot. The percentages of foliage harvest were: No harvesting (Control), 25%, 50% and 75%. Foliage harvest significantly influenced flowering. Mean number of flowers ranked as: Control - 18 > 25% - 6 ≥ 50% - 1 ≡ 75% - 0. No harvest stands produced significantly high number of fruits (11458/ha) compared to 8958/ha for 25%, 4792/ha for 50% and 4583/ha for 75% harvested stands. Total fruit weight ranged between 59.7 - 127.9 kg/ha. No significant differences in specific leaf area were obtained for all treatments. For both fruit and leaf collection, the highest total income was GH ¢ 24411.36 for 50% followed by GH ¢ 17480.40 for 75%, GH ¢ 15640.33 for 25% harvest stands and GH ¢ 153.48 for the no harvest stand.

The third study determined spacing and shade effects on survival, lamina length and width, petiole length and number of tillers. There were three shade levels provided by tree stands: *Leucaena* (73%), *Senna* (86%), *Carapa* (98%) and four spacing treatments: 0.75 m × 0.75 m, 1.0 m × 0.75 m, 1.0 m × 1.0 m, 1.25 m × 1.25 m. Shade significantly ($P < 0.001$) influenced survival, leaf sizes (lamina widths and lengths), petiole length and number of tillers. Survival were 71% for *Leucaena* > 60% for *Senna* > 20% for *Carapa*. Leaf sizes were also larger for 73% (width-17.6 cm, length-27.1 cm) than 86% shade (width-15.9 cm, length-25.2 cm) and 98% shade (width-11.4 cm, length-18.0 cm) levels. Similarly, significantly longer petioles, 43.6 cm, were obtained for 73% shade compared to 38.8 cm for 86% and 20.4 cm for 98% shade levels. Tillering decreased with increased shade. Similarly, spacing significantly influenced leaf sizes and petiole lengths.

The fourth study was on provenances and NPK fertilization on survival, lamina width and length, petiole length and diameter, and tiller production. Provenances differed significantly in lamina length, lamina width, petiole length and petiole diameter. Lamina lengths of provenances were Western-23.7 cm ≡ Volta-21.1 cm > Ashanti-17.2 cm. Lamina widths were Western-14.3 cm ≡ Volta-12.9 cm > Ashanti-9.0 cm. Petiole lengths were Western-37.7 cm ≡ Volta-36.1 cm > Ashanti-24.8 cm. Petiole diameters were Western-5.6 mm ≡ Volta-5.4 mm > Ashanti-3.8 mm. Fertilization also significantly enhanced the growth of lamina width, petiole diameter and tiller production.

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1.0 GENERAL INTRODUCTION

1.1 Background of study

Ghana's forests form an integral part of the rural economy, providing subsistence goods and services as well as items of trade. Collectively, forest goods other than extracted timber are referred to as non-timber forest products (NTFPs). Since the 1970s NTFPs have emerged to take their place among the many aspects of forest use that guide natural resource decision makers. In the early 1990s, NTFPs were mooted as potential alternative to deforestation and land conservation activities. This is because some NTFPs have strong market value. As such, it has been postulated that the long term value accruing from the harvest of these products could override the short–term gain of converting forests or individual trees to other uses such as timber, agriculture or plantations. Furthermore, the gathering, processing and trading in forest NTFPs provide a good source of supplementary income for many households (Falconer 1990; Falconer, 1992; Plotkin and Famolare, 1992 cited by Sunderland *et al*., 2004; Sunderland *et al*., 2004).

Thaumatococcus daniellii (Miraculous berry), a perennial herby plant which occurs in the wild, is one of the promising NTFPs whose economic potentials have not been fully exploited in Ghana. It is a forest understorey herb and belongs to the family Maranthaceae in the Zingiberales order of monocotyledon plants. The plant is native to Tropical West Africa. In Ghana it is widely distributed in secondary forests with humid conditions in the Volta, Eastern, Ashanti, and the Western Regions (Adansi and

Holloway, 1977). *Thaumatococcus daniellii* is popular in Ghana for its leaves which are collected and gathered and are widely used by traders and food sellers as packaging material to wrap vegetables, fish, cola nuts, soap and salt. They were also used to wrap cooked foods (notably rice, yams, beans, kenkey) and fried plantain (Falconer, 1992).

The fruits of *T. daniellii* contain creamy-white arils located at the apex of the seeds which contains a proteinous sweetener called thaumatin. This low-calorie extract, thaumatin, is reported to be the sweetest natural substance on earth and is about 2,500 – 3,500 times sweeter than sucrose or sugar. Thaumatin is a very complex and intensely sweet protein, natural and safe in use, with excellent characteristics for use in flavours (Abbiw, 1990; Swift *et al*., 2002; afrol News, 2003). Currently, the most sold low-calorie alternative to sugar is Nutra Sweet; a chemical based compound. As the healthiness of purely chemical products is often questioned, a purely natural product such as thaumatin is seen as a clear market winner. Alone the US market for low-calorie sweeteners is set at US$ 900 million annually (afrol News, 2003).

Samartex Timber and Plywood Company, is pioneering the commercial extraction of thaumatin for export in Ghana. The Company has established a thaumatin processing plant at Samreboi in the Western region. The main source of raw material for thaumatin production is the arils contained in the fruits of *T. daniellii* normally collected from the wild. Currently, the company buys fruits from gatherers from Volta and Western Regions of Ghana, and is actively integrating *T. daniellii* cultivation in its agroforestry projects.

There is also evidence that new marketing and processing companies are emerging in areas within the Western Region.

Despite several benefits obtained from the component parts of the plant, there are a number of problems regarding its exploitation. With the advent of plastic packaging materials, trading activities involving the gathering, collection and sale of *T. daniellii* leaves have declined thereby depriving some rural people of their source of income. Therefore, more attention will be directed towards gathering, collection and sale of fruits as alternative source of income. Collections of *T. daniellii* products are currently done in the wild which is time consuming and tedious. There is therefore the need to find ways of domesticating *T. daniellii* either as a sole crop or through its integration in agroforestry systems. In addition, seeds of *T. daniellii* have a very hard testa that makes water imbibitions difficult hence resulting in poor germination of seeds when used for propagation. This may also call for the use of vegetative propagating materials.

Notwithstanding these problems, the exploitation of wild sources of *T. daniellii* can be sustainable but would require

(i) Knowledge of the plants' growth and reproductive characteristics

(ii) The application of harvesting practices that permit adequate reproduction or regeneration of individual plants (Cunningham, 2000 cited by Sunderland *et al*., 2004) and

(iii) A shift from harvesting leaves to seed production and extraction of thaumatin.

Unfortunately, not much research has been carried out on *T. daniellii* with regard to its provenances, growth performance, yield potential of leaves or fruits, methods of propagation, as well as its integration into agroforestry systems. Therefore, the goal of this study is to conduct research on the above in order to facilitate the integration and management of *T. daniellii* in agroforestry systems as well as its commercial cultivation.

Tropical deforestation is attributed to rural poverty particularly in forest fringe communities. Therefore cultivation as well as collection of *T. daniellii* leaves and fruits must be seen as an alternative source of income to rural communities. By cultivating *Thaumatococcus daniellii*, rural farmers in Ghana can gain income and social benefits, whilst at the same time the aim of conserving natural forests is also achieved. Furthermore, the domestication and subsequent cultivation can also help achieve diversification of farm products as a strategy to minimize risks associated with traditional farming systems, which is a major objective of agroforestry systems. *T. daniellii* can be incorporated into some agroforestry systems since it grows in partially shady environment. Agroforestry land use system permits the integration of trees with crops and or animals such that the components interact with each other to enhance the productivity of the system. It is often seen as a possible panacea to land use problems encountered by most farmers in Ghana and must be encouraged to enhance their socio-economic well-being through the numerous benefits that can be obtained by practicing agroforestry.

1.1.1 General research questions

Generally, this study seeks to find answers to the following questions regarding the integration of *T. daniellii* in agroforestry systems as well as its commercial cultivation.

(i) What are the major sources of fruit supply to the thaumatin extraction plant at Samreboi?

(ii) What are the site/soil conditions and conservation status/strategies of *T. daniellii* outside forest reserves in the Western region?

(iii) What is the effect of foliage harvesting on the growth and seed yield of *T. daniellii*?

(iv) How would shade and spacing affect the growth of interplanted *T. daniellii* in tree stands?

(v) What is the early growth response of three provenances of *T. daniellii* to NPK fertilization under *Senna siamea* stand?

1.1.2 General objectives

These research questions lead to the following research objectives which were to determine:

(i) The major sources of fruit supply to the thaumatin extraction plant at Samreboi.

(ii) Soil/site conditions and conservation status/strategies of *T. daniellii* in off reserves in Western region

(iii) The effect of foliage harvesting on the growth and yield of *T. daniellii*

(iv) Effect of shade and spacing on growth performance of *T. daniellii* interplanted in tree stands

(v) Early growth response of three provenances of *T. daniellii* to NPK fertilization under *Senna siamea* stands

1.1.3 General hypotheses

These research questions lead to the following general hypotheses

(i) The sources of fruit supply do not have influence on the conservation of *T. daniellii*.

(ii) Natural stands of *T. daniellii* are found on similar soil/site conditions.

(iii) Foliage harvesting does not affect the growth and yield of *T. daniellii*.

(iv) Shade and spacing do not affect the growth of *T. daniellii* interplanted in tree stands.

(v) Source of planting material and NPK fertilization do not influence the growth of *T. daniellii*.

1.1.4 Study protocol and outline

The study protocol gives the background of each study or experiment as well as details of all experimental procedure and other activities that were carried out in order to achieve set objectives. The study protocol involves a review of literature, a survey and series of experiments as well as major conclusions organized into chapters 2 - 7 as outlined below:

(1) Chapter 2: - Literature review

(2) Chapter 3: - Soil characteristics, fruit sources and conservation status/strategies of *T. daniellii* in off reserves of the Western Region of Ghana

(3) Chapter 4: - Effect of foliage harvesting on the growth and yield of *T. daniellii*

(4) Chapter 5: - Effect of shade and spacing on the growth performance of *T. daniellii* interplanted in tree stands

(5) Chapter 6: - Early growth response of three provenances of *T. daniellii* to NPK fertilization under *Senna siamea* stand

(6) Chapter 7: - General conclusions

The experimental chapters (3 – 6) provide, a summary, brief introduction, specific objectives, detailed methodologies, results, discussion and conclusions of each specific study or experiment.

Chapter 2

2.0 LITERATURE REVIEW

2.1 Description of *Thaumatoccoccus daniellii*

Thaumatoccoccus daniellii is a rhizomatous, perennial and monocotyledonous herb propagating itself by rhizomes. It is a large plant typically 1 - 2.5 m tall at maturity. *Thaumatoccoccus daniellii* is unbranched with all axes (petioles) straight often overlapping from base. The petioles which are about 2 or 2.5 m long arise from the rhizomes depending on the age and environment of the plant. At the end of these long petioles are large broad and oval papery, tough, versatile leaves that are about 45 cm long and 30 cm broad. The leaves are ovate-elliptic rounded, truncate at the base, and shortly acuminate at the apex. The stems and leaves have scattered or short hairs (Yeboah *et al*., 2003; Hawthorne and Jongkind, 2006).

T. daniellii have lateral roots with short regular blunt pegs about 1mm long. The inflorescence (flowers) is close to the ground and are purplish often forming large clumps. They usually arise from the lowest node and may be simple or forked with spikes about 8 – 10 cm in length. The bracts are usually imbricate and about 3 – 4 cm in length. The sepals are broadly linear and about 2.5 cm long. As many as 10 – 12 purplish-pink flowers may form from each inflorescence but usually about 2 to 4 of these form matured fruits (Ekpe and Ottou, 2006; Hawthorne and Jongkind, 2006).

The fruits, usually greater than 1 cm, grow on short stalks close to the ground. It is trigonal or pyramidal in shape, maturing from dark green through brown to crimson or bright red colour when fully ripe. Fruit weighs between 6 and 30 g depending on the number of seeds within it. The seeds are black in colour with hard seed coat covered by a thin layer of sticky, transparent gel. Attached to the seed is a soft, fleshy juicy cap called an aril which contains the sweet substance called thaumatin. *Thaumatoccoccus daniellii* flowers most of the year but is most prolific from July until late October. Fruit formation, maturing and ripening occur from January until mid April (Ekpe and Ottou, 2006).

2.1.1 Ecology and Natural Distribution

Thaumatococcus daniellii grows throughout the hot, humid tropical rain forest and coastal zone of West Africa. Its natural habitat is the undergrowth of forest trees. *Thaumatoccoccus daniellii* is particularly found in southern parts of Ghana, Cote d'Ivoire and Nigeria. It is also known to exist in the Princess Islands, Angola, the Central African Republic, Uganda, Indonesia, Gabon, Congo, Cabinda, Principe and Sao Tome. In Ghana, it is distributed in secondary forests with humid conditions in the Volta, Eastern, Ashanti, Central and Western Regions (Yeboah *et al*., 2003).

Open forest canopy is reported to allow the development of a profuse growth of marantaceous forbs. *T. daniellii* stands are found in large clumps alongside roads in the forest or old gaps. Hence, there have been suggestions that *T. daniellii* may be a pioneer species. It occurs in areas with mean annual rainfall greater than 1500 mm and annual temperature ranging between 23°C - 26°C. Most description of sites with *T. daniellii* indicate shaded conditions of secondary forest or an over storey of cocoa or cola nut, or other perennial plantation crops. *Thaumatoccoccus daniellii* is also found in swampy areas or very wet soils, near water bodies, sandy soils and abandoned cocoa farms. The distribution as a whole suggests that *T. daniellii* is associated with ferrasols (FAO-UNESCO) corresponding to oxisols (USDA) (Hall and Swaine, 1976; Wojciech *et al*., 2005; Hawthorne and Jongkind, 2006).

2.1.2 Uses of *Thaumatoccoccus daniellii*

Thaumatoccoccus daniellii fruit berry contains a mealy pulp (thaumatin) in the mesocarp which is mostly used as a replacement for synthetic sweeteners in some countries. Industrially, thaumatin is an internationally recognized food additive and has high pharmaceutical potential in drugs, confectionaries and mineral drinks manufacturing as a sweetener or taste modifier in beverages, pet foods and chewing gums. The proteins thaumatin and monelin which are constituents of the aril belong to the most potent sweeteners known on molar basis. Some people also use the seeds as sweeteners by licking them to sweeten porridge or fermented palm wine (Yeboah *et al*., 2003; Swift *et al*., 2002; Arowosoge and Popoola, 2006; Ekpe and Ottou, 2006).

Thaumatoccoccus daniellii leaves are collected and gathered and are widely used by traders and food sellers as packaging material. The leaves are regularly used to wrap vegetables, fish, cola nuts, soap and salt. They were also used to wrap cooked foods, notably rice, yams, beans, kenkey (fermented maize dough) and fried plantain (Falconer, 1992). In Nigeria, the leaves are used for preserving kola nuts and as feed supplement to some ruminants including goats. The fibrous nature of the leaves enhances its use in combination with some other materials as roof thatching in hamlets and resorts. The stalk is used for weaving baskets, mat, fish traps, ornamental bags and also as sponge (Yeboah *et al*., 2003; Arowosoge and Popoola, 2006).

2.2. Non-Timber Forest Products (NTFPs)

2.2.1 Importance and Economic Potential

Non-timber forest products (NTFPs) are defined as all the biological materials (other than industrial round wood and derived sawn timber, wood chips, wood-based panels and pulp) that may be extracted from natural ecosystems, managed plantations, and be utilized within the household, be marketed, or have social, cultural or religious significance. Thus, non-timber forest products include plants used for food, forage, fuel, medicine, fibres, biochemicals as well as animals, birds, reptiles, fish and insects. for food, fur and feathers (Wickens, 1991; Chandrasekharan, 1995). The Non-timber forest products sector harbours a number of stakeholder groups with different interests, including collectors, local middlemen, urban traders, manufacturers, exporters and government agencies (Ojha, 2000). Non-timber forest product usage is less ecologically destructive than timber harvesting and the contributions made to rural livelihoods have increased awareness such that more intensive management of forests for such products could contribute to both development and biodiversity conservation objectives (Warner, 2008).

About US $ 90 billion worth of NTFPs are extracted worldwide every year. More than 300 million people, especially tribal and underprivileged are dependent primarily upon NTFPs for earning their livelihoods. Additionally, about US $ 11 billion worth of non-wood forest products (NWFPs) are internationally traded, and US $ 55 billion worth is traded within the national economies of the world. The rest is consumed in the local village economies. World Health Organization (WHO) estimate suggests that some 80% of the population of the developing world use NTFPs for health and nutritional needs (Tewari, 2000).

In areas distanced 10 km or less from forest reserves in the forest zone of Ghana, one or more members of approximately 202,000 or 38% of households obtain income from NTFP-based activities (Townson, 1995). In the Afadjato-Agumatsa area of the Volta Region of Ghana, *T. daniellii* is an important NTFP and the collection of its fruits has provided employment for several people with individuals collecting on the average 10 - 20 kg of fruit per day which were then sold at $ 0.39 per kilogram (Ekpe and Ottou, 2006). It has also been reported that from 1984 to 1991, the total production of arils from *T. daniellii* in Cote d' Iviore increased from 10,250 kg to 25, 600 kg. At an estimated average price for frozen arils of CFA Francs 4000/kg, this production earns between CFA Francs 40 and 100 million annually (US $ 160,000 to 400, 000) in exports to the UK (Bonnéhin, 1997).

With new emphasis on poverty alleviation and livelihood improvement in the national development agenda, NTFPs offer means to increasing welfare in an environmentally friendly way (Falconer, 1990). This could be achieved through agroforestry land use practices. Agroforestry places a strong emphasis on smallholder, low-input, multiple output systems and species that produce NTFP products which are amenable to integrated management. Thus systematic and scientific efforts need to be undertaken in a number of critical areas of NTFP development. These include identification of promising NTFP species and domestication of their wild forms, with due consideration of the cultural and social context of the species and their products (Nair and Merry, 1995).

2.2.2 Constraints to Management and Conservation

To date most research point to the fact that the contributions of forest products, particularly of products other than wood, are not adequately valued to reflect their importance (Falconer, 1990; Panayotou and Ashton, 1992; Chandrasekharan, 1995; van Andel and de Zylva, 2006). Although NTFPs are utilized locally, nationally and internationally through provision of significant jobs, subsistence income and materials for rural populations, their value is rarely reported in national and international statistics (Panayotou and Ashton, 1992; Ayuk *et al*., 1999). Consequently, information on the quality and value of NTFPs are either non-existent or unreliable and are mostly estimates (Nair and Merry, 1995).

Reasons contributing to the neglect of NTFPs include inadequate information on their economy and biology, insufficient established markets and irregular supply. Other factors include the difficulty to maintain standards, replacement by artificial substitutes, and inadequate technology to process and store their products and low net return to major trading interests (Panayotou and Ashton, 1992).

Additionally, inadequate information on the ecological productivity, growth forms, life history and conservation of the various species involved complicates management scenarios, the setting of conservation priorities and defining sustainable harvest levels (Ndangalasi *et al.*, 2007). This can lead to excessive extraction of forest products and impact negatively on the population dynamics of exploited plants, leading to changes in community structure and organization (Moegenburg and Levey, 2002). Such a situation could affect ecological processes from individual and population to community and ecosystem levels (Ticktin, 2004).

2.2.3 Conservation and Management Strategies

Resource management is the process, by which resources are allocated, regenerated, managed and conserved over time and space to meet the needs and aspirations of humankind. Management of NTFPs involves the collection, gathering, harvesting, utilization and management of resources within a given ecological, economic, social, political, institutional and legal framework. Conservation involves the preservation, regeneration, maintenance (Karki, 2001) and the wise exploitation of NTFPs in such a manner that their productive capacities are maintained to serve the needs of present and future generations.

Conservation and improved management of NTFPs can be achieved through policy reorientation. The impact of non-timber forest resources and their potential role in the rural and wider economy should be considered routinely and without exception during evaluation of development projects and land-use/forest policies formulation. Increased research on non-timber forest products with regard to their abundance, distribution, variation, ecology, reproductive biology, traditional and new methods of propagation, cultivation and use, identification of market and non-market value is also vital. Since the nature, use and importance of non-timber forest products are so closely related to local ecological, economic and socio-cultural conditions, most research should be location-specific (Wickens, 1991).

The higher the intensity of extraction of NTFPs, the less likely it is that they are extracted in a sustainable way. Also, the extraction of vegetative structures resulting in the death of individual plants providing the resource are less likely to be sustainable than the extraction of reproductive structures or plant exudates (Boot, 1997). Thus, where overexploitation is a current or potential problem, improved management of NTFP resources in their natural habitat is essential. This could be achieved by integrating NTFPs management with other forest uses. This can provide local benefits and make economically feasible a slower and more environmentally sustainable rate of timber extraction (Wickens, 1991; Ndangalasi *et al*., 2007). Additionally, resource management, through enrichment planting, cultivation and/or domestication can help overcome some challenges relating to supply, and result in the accumulation of larger quantities of a product (Stewart, 2003; Trauernicht and Ticktin, 2005; Marshall and Chandrasekharan, 2009). The availability of NTFPs per unit area can be enhanced by increasing populations and improving the yield of desirable species (Boot, 1997). Within the natural forest, increased populations is obtained by ensuring favourable micro-environmental requirements of the desired species, perhaps by the removal of competing species in a given area and/or by provision of extra light or shade (O'Connell *et al.*, 1983 cited by Wickens, 1991).

Furthermore, less wastage in the process of extraction and better regeneration of many non-timber forest products can be achieved by the development and application of improved harvesting techniques, appropriate equipment, training and skills development. Improved storage and transport methods for instance would reduce spoilage of raw and finished products. Producers of non-timber forest products, in particular small-scale operators, would receive greater returns from marketing their products if they were assisted in achieving consistent quality and protected from exploitation by intermediaries (Wickens, 1991).

These strategies and approaches to managing and trading NTFPs may help increase the level of success and degree of sustainability of NTFPs exploitation making it a more secured livelihood option for poor producers, processors and traders (Marshall and Chandrasekharan, 2009). However, owing to the varied factors involved, there is no single solution to the management requirements for NTFPs. It is therefore the responsibility of each nation to look at NTFPs in the total context of its economic and social development. Each nation therefore needs to work out a balance for the conservation and use of its tropical forest lands that is acceptable in this context (Poore, 1989 cited by Wickens, 1991).

2.3. Tree-Crop Interactions in Agroforestry Systems

2.3.1 Definition and Forms

Agroforestry refers to land-use systems in which trees or shrubs are grown in association with agricultural crops, pastures or livestock, and in which there are both ecological and economic interactions between the trees and other components (Young, 1997). Interaction is the effect of one component of a system on the performance of another component and/or the overall system. A major principle in agroforestry systems is to exploit the beneficial effects of the interactions between tree/crop components (Nair, 1993). In a given combination of trees with herbaceous plants, interactions can be complementary (the presence of one increases output from the other), supplementary (no mutual interactions), or competitive (the presence of one reduces output from the other) (Young, 1989).

2.3.2 Types and Factors Influencing Interactions

Ecological interactions between trees and crops are examined in terms of above and below ground utilizations of physical resources. Above ground interactions include changes in the microclimate, such as shading, temperature, wind speed and humidity. Possible below ground interactions include greater exploration for water and nutrients as well as competition for water and nutrients. The rate and extent to which biophysical resources are captured and utilized by agroforestry system components are determined by the nature and intensity of interactions between the components, the number, surface area, distribution and effectiveness of the individual elements within the canopy or root system of the species involved. The net effect of these interactions is often determined in terms of quantifiable responses as soil fertility changes, microclimate modification, water, nutrients, and light/shade availability and utilization, pest and disease incidence, and allelopathy (Ong *et al*., 1991, Ong *et al*., 1996, Rao *et al.*, 1998).

2.3.3 Complementary Interactions

The major tree–soil–crop interactions that affect crop yields in agroforestry systems are related mostly to chemical aspects of soil fertility, soil physical properties and water relations, and microclimate, especially shading. However, in many tropical systems, water or nutrient availability (e.g. acidic, leached or degraded soils) rather than light is the major limiting factor. In spatially mixed systems such as coffee and cacao plantations, upper storey trees provide nutrients, from litter fall and periodic prunings as well as shade to the lower storey tree crops. Shading modifies the microclimate through lowering surface soil and air temperature. This reduces soil evaporation and increases water available in the soil for transpiration by the crops. Consequently, the overall water use efficiency of the understorey crop increases (Ong *et al*., 1991; Ong *et al.*, 1996; Palm, 1995; Wallace, 1996; Rao *et al.*, 1998).

2.3.4 Competitive interactions

With regard to nutrient use, there is no certainty about the amount of nitrogen fixed by trees and shrubs and to what extent it is actually used or potentially available to the associated crop during various growth periods. Therefore, competition between the components may reduce or possibly override the otherwise positive aspects of such mixed plantations. Furthermore, little is known about the amount of nutrients released from added plant material that is taken up by the intercropped trees, rather than the crop (Palm, 1995; Ranganathan and de Wit, 1996).

Studies have reported 24 – 28% yield reductions when crops are associated with *Leucaena*. For example at Machakos, Kenya, roots of *Leucaena* and maize exploited water from the same horizons during the rainy season, with the result that intercropped maize capture less water than sole maize. Other *Leucaena* based systems indicated that its competitive nature and vigorous growth usually reduce the yield of associated crops. Yield reduction may be due to shading, competition for nutrients or water, or a combination of these factors. Similarly, tree competition within an alley cropping system significantly reduced photosynthetic radiation, growth and yield of individual soybean or corn plants growing nearer to tree rows (Chirwa *et al*., 1994; Jama *et al*., 1995; Howard *et al*., 1995 cited by Ong *et al*., 1996; Ong *et al*., 1996; Kho, 2000; Reynolds *et al*., 2007).

In alley cropping where tree density is high, beneficial effects of the trees on microclimate are negated by reductions in soil moisture due to increasing interception losses and tree transpiration. While investment in woody structure can improve the water economy beneath trees, it inevitably reduces the growth rate of the trees and thus increases the time required for improved understorey productivity (Ong and Leakey, 1999; Kho, 2000)

The challenge then is to develop systems and practices that ensure successful integration of multipurpose trees and crops/non-woody species into land use systems by enhancing complementary and supplementary interactions while reducing negative competition among the components (Huxley, 1996). The greatest opportunity for simultaneous agroforestry practices is therefore to fill niches within the landscape where resources are currently under-utilized by crops (Ong and Leakey, 1999).

2.4. Plant Responses to Ecological Factors and Management Practices

2.4.1 Plant Ecology

Plant growth, morphology and resource allocation is influenced by a number of factors including soil, water, sunlight, nutrient supply and utilization, plant spacing or density and its biomass removal in managed land use systems (Ong *et al*., 1996). The sum total of all factors and components that make up the natural system in a region is called an ecosystem. These include physical factors such as soil, water, sunlight, nutrients and energy that enable the system to function. It also includes plants that grow in an area to form a community (Hilts and Mitchell, 1999). High productivity or maximum attainable biomass for plant species depends primarily on light, water and nutrient availability as well as its ability to either capture or utilize these resources efficiently (Ong *et al*., 1996).

2.4.2 Light

Growth and development

Light is a morphogenic modifier that affects plant establishment, growth and development that should not be neglected for crop responses at the tree-crop interfaces

(Huxley, 1996; Poorter, 2001). Higher light availability results in larger plants and tropical forest species are differentiated in their growth responses to shaded understorey and gap conditions (Popma and Bongers, 1988). Numerous studies of annual crops and perennial species have demonstrated the existence of close correlations between dry matter production and cumulative intercepted radiation (Black and Ong, 2000). Species responses to light/shade conditions vary. For instance, *Thaumatoccocus daniellii* has a wide margin of light tolerance but it favoured canopy gaps in closed intact forests. However, extremes of light and shade are detrimental to its growth. Conversely, constant direct light has negative effects on *T. daniellii* growth through drying of the soil and thus reducing soil water content (Wojciech *et al*., 2005).

Productivity

Light influences growth responses in terms of size, leaf dynamics, morphology, architecture, carbon gain and allocation (Lopez-Toledo *et al*., 2008). In a study of solar radiation effects (20%, 50% or 80% of maximum solar radiation-MSR) on the productivity and nutritive value of a mixture of grasses and legumes established under a matured conifer, dry matter yields were greater for the 0.80-MSR treatment (Neel *et al*., 2008). Similarly, ten tropical plants under 0.9 - 2.3%, 2.1 - 6.1% and 38.6 - 53.4% light conditions revealed that plants with highest light availability had the highest dry weight and stem diameter than those that received less light (Popma and Bongers, 1988).

Tillering

Light can modify leaf growth and tiller appearance of certain plant species. For example, self-shading within a dense canopy at the tiller base corresponded with an increase of leaf length and decreased tillering (Bahmani, *et al*., 2000). The duration, intensity and spectral composition of light affect tillering of grass species such that reduced light intensity on sugarcane prevented secondary shoot development (Bonnett *et al*., 2005). Also, shade reduced tiller appearance rate of ryegrass. Consequently, the formation of primary tillers on the main shoot were indicated to be much less susceptible to shading than formation of higher order secondary and tertiary tillers (Bahmani, *et al*., 2000). Furthermore, herbage plants grown under lower light levels were smaller, had fewer numbers of tillers and produced less dry matter compared with plants with higher levels of radiation (Neel *et al*., 2008). At low irradiance, shoots (leaves) retain more of the limiting amount of photosynthate, leaving less carbon for root growth. Hence, allocation of photosynthate to above-ground parts increases with decreasing irradiance and vice versa with increased irradiance (Duriyaprapan and Britten, 1982; Grubb *et al*., 1996; Poorter and Nagel, 2000; Poorter, 2001). It can be said that the allocation of more photosynthate to above-ground parts increases with decreasing irradiance could reduce tiller production.

Leaf characteristics

Studies have shown that the features of a leaf are influenced by light. Bougainvillea plants exposed to 0% (direct sunlight), 30%, 50% and 75% shading, attained the greatest leaf size under 30% and 50% shading, whereas 0% shading showed the lowest value (Saifuddin *et al*., 2010). Among two garlic cultivars subjected to different shading treatments, an increase in light intensity reduced leaf length and size of epidermal cells. The thickness of leaf increased with light intensity and resulted in corresponding gains in leaf dry weight per unit area. The effects of shading on final leaf size were related to cell numbers and dimensions (Rahim and Fordham, 1991). Also, shade increased final leaf length of ryegrass through increased leaf elongation rate and duration (Bahmani, *et al*., 2000). With respect to leaf structure, variations in leaf morphological traits governed by patterns in light availability have functional significance. However, ecosystem properties such as nutrient availability might also impact light-driven structure-function relationships (Stephens *et al*., 2009).

Leaf inclination angles generally decrease with increasing leaf age. This, generally attributed to increases in both lamina weight and area, can alter the bending momentum exerted on the petiole and change lamina and/or petiole inclination angles. Therefore, in order to optimize the interception of photosynthetic active radiation, sunflower plants for instance invests part of the captured energy in synthesizing petiole structural supporting material (Hernández, 2009).

A study of light regimes (24, 43, 58 and 100% transmission) on Cocksfoot (*Dactylis glomerata* L.) revealed that fully expanded leaf and pseudo-stem height increased by 30% and the leaf width declined by 22% with decreasing light intensity (Peri *et al*., 2004). Also, the morphological responses four of stoloniferous herbs (*HydrocotyIe vulgaris* and *Lamiastrum galeobdolon*) to levels of light in indicated that petiole extension was more responsive to light conditions in *Hydrocotyle* than in *Lamiastrum* (Peri *et al*., 2004). Plastic responses in the lengths of stolon internodes and petioles are therefore important for the capture of light in a patchy environment as petiole elongation may lift shaded blades into higher light zones (Dong, 1995).

The effect of different levels of shading of sweet pepper under high solar radiation (> 600 cal $cm^{-2}day^{-1}$) at 2 different spacing revealed that reduced light intensity increased plant height and leaf size. However, shading inhibited lateral shoots development on the main stem below the first terminal flower. The changes in plant development due to shading affected fruit set, number of fruits per plant and fruit location on the plant (Rylski and Spigelman, 1986).

Plant establishment

Low light availability within stands resulting from dense canopies leads to litter build up which may affect seedling survival and growth. Seeds germinating under dense litter mats often have high mortality rates due to expending all energy reserves in attempts to penetrate the litter. Surviving seedlings are however often severely etiolated or elongated, which can increase susceptibility to physical damage. Litter also may affect seedling growth through the release of chemicals and nutrients. With increasing litter depth, a larger concentration of nutrients or toxins may be leached from litter. Thus, soils covered with deep litter may have a different chemical environment than soils under shallower depths. Plants, susceptible to these toxins, during early seedling growth often record initial slow growth rates and reduced final total biomass (Jeffery, 1997).

2.4.3 Nutrition and fertilization

Plant nutrition encompasses ability of soils to provide plants with required nutrients as well as plant responses to nutrients supplied either from the soil or externally applied fertilizers. Soil fertility maintenance is essential in achieving and maintaining high crop yields over a period of time (Makinde and Ayoola, 2010). There is therefore the need to ensure sufficient supply and utilization of nutrients in agro-ecosystems. In some agroforestry systems, it has been proposed that, for example, hedgerows alone may be able to sustain yields for at least five years on high-fertility soils. However, hedgerow systems without fertilizers invariably show a rapid and progressive decline in yields and eventually reach low-level equilibrium on low-fertility soils (Young, 1997).

Significant positive interactions exist between hedgerows and fertilizers, the former maintaining soil physical properties and providing balanced nutrients and the latter giving the bulk nutrient supply. Hence, the strategic application of small amounts of fertilizers has been recommended to be sufficient to sustain production in alley cropping systems (Young, 1997). To this effect, the use of mineral fertilizers has proven to be more convenient than the use of organic fertilizers (Makinde and Ayoola, 2010). For effective fertilizer application, it is recommended that large amounts of fertilizers are not applied all at once. Several smaller doses should be given and timed to coincide with the demands of crop plants (Müller-Sämann and Kotschi, 1994). Most fertilization studies have used N, P and K fertilizers either as single (straight fertilizers) or their combinations (compound fertilizers) to enhance crop growth.

Several studies have reported on the relationship between plants growth characteristics and nutrient supply. However, plant responses to fertilization vary due to the differences in growth patterns, environmental conditions, type, method and quantity of fertilizer applied. For instance, the relatively slow growth response of *Eriophorum vaginatum* to fertilization was presumed to reflect the fact that most resources that support its growth in a given year were supplied from stores of resources acquired previously (Shaver and Chapin III, 1995). On the other hand, a study on *Erica tetralix* and *Calluna vulgaris*, for three growing seasons revealed that total above ground biomass for both species increased with increasing nutrient availability (Aerts, 1989). Similarly, nitrogen application on *Michelia champaca* resulted in a significant collar diameter increment and total dry matter production than unfertilized seedlings (Hoque *et al*., 2004).

Fertilization with NPK (19:19:19) at rates of 0.0 g, 2.5 g and 5.0 g monthly applied six times in two growing seasons revealed a significant increment in leaf length and width for both seasons. Fertilization with 5.0 g per plant gave the highest leaf length (40.36 and 40.35 cm) and width (2.83 and 2.87 cm) compared to the unfertilized plants in both seasons, respectively (El-Naggar and El-Nasharty, 2009). Different rates of NPK fertilization further revealed that fertilization significantly increased leaf length of onion varieties. Fertilization rate (150: 100: 50 NPK kg/ha) produced the longest leaf length (47.69 cm) but the unfertilized control significantly produced the lowest leaf length (30.80 cm) (Ghaffoor *et al*., 2003). Also, NPK fertilization is reported to be frequently responsible for the tillering responses among *Eriophorum vaginatum* (Shaver and Chapin III, 1995). Furthermore, among wheat, significantly increased tiller production was observed with NPK application than control fields (Rehman *et al*., 2010).

However, at low nutrient and water availability, plants shift allocation towards roots, leaving less for the shoots (leaves). Consequently, leaf growth is limited by the supply of nutrients and water and less photosynthate are incorporated above-ground. These shifts could be adaptive mechanism to enable plants to capture resources that most strongly limit growth. The excess photosynthates are then transported to the root, enhancing root growth relative to that of shoots (Robert, 1997; Poorter and Nagel, 2000).

2.4.4 Spacing and density

At the management level, plant growth and development including the height, flowering and fruiting pattern is directly affected by density or spacing (Huxley, 1996; Ozer, 2003), although the precise response may be species and cultivar specific (Leitch and Sahi, 1999). Responses to varied spacing/density differ among several cultivated crops depending on the spatial arrangement, plant growth characteristics and management objectives. With many crop species, compensatory mechanisms such as tillering or branching allow similar levels of dry matter accumulation per unit area to be achieved from a range of planting densities (Bahmani *et al*., 2000).

Among cotton plants, spacing altered plant architecture, photosynthetic efficiency of leaves, boll size and fruit production pattern (Hakoomat *et al*., 2009). Increased density in linseed (*Linum usitatissimum*), restricted the growth of individual plants, resulting in shorter stems with fewer smaller leaves, shoots and capsules. However, the increased numbers of plants per unit area at these higher densities more than compensated for the reduction in individual plant size, leading to significant increases in dry matter production per unit area (Leitch and Sahi, 1999). Among four varieties of groundnut, closer spacing significantly resulted in the highest dry matter production whereas wider spacing resulted in least dry matter production during a three year study. The lesser dry matter production recorded under wider spacing could be due to the less plant population (Chandrasekaran *et al.*, 2007). Furthermore, a study on high density planting (45cm × 60cm) of statice (*Limonium sinuatum*) resulted in superior growth and flower quality, but inferior yields (Deshpande *et al*., 2001).

2.4.5 Herbivory or defoliation

Herbivory plays a central role in the organization of plant communities and evolution of their constituent species (Ticktin, 2004). One important form of herbivory is defoliation, the removal of leaves (Lee and Bazzaz, 1980). Several artificial defoliation studies have been conducted on woodland herbs, and responses have been so variable that no general patterns appear to be discernible relative to life-history strategies or phylogeny (Whigham and Chapa, 1999). When a portion of plant material is harvested, the nature and quantity of nutrients and/or photosynthetic capacity removed, and the potential for survival depend on the kind of material harvested. This excludes seed or fruit harvesting that also involves damage to other parts of the plants, which often occurs during fruit harvest (Ticktin, 2004). Tolerance can involve various mechanisms that allow plants to cope with herbivore damage such as compensatory growth, storage and relocation of nutrients, and regulation of photosynthetic activity (Moser and Schütz, 2006).

Defoliation reduces plant leaf area directly but in some crops it can lead ultimately to increased leaf area. The removal of younger leaves can prolong the life of older leaves. On the other hand, newly expanded leaves formed after defoliation compete with older leaves for solar radiation, mineral nutrients and assimilate with the result that the leaves begin to senesce in sequence according to age (Hay and Walker, 1992). Generally, herbivory reduces seed and biomass production per plant and increases level of mortality. However, plants whose tillers have high leaf elongation rate will accumulate sward leaf area index more quickly after defoliation and result in basal shading. This causes a shift in light quality and associated tiller bud suppression earlier in their re-growth cycle (Bahmani *et al*., 2000).

For *Caragana korshinskii*, compensation for fruit production after above-ground partial shoot removal resulted in increased fruit set, decreased fruit abortion, increased seed number per pod and higher individual seed biomass. These responses were achieved by (1) drawing upon more non-structural carbohydrate from roots to supply flower bud development and the flush of new foliage; (2) supplying more photosynthetic assimilation to fruit development owing to increases in leaf-level photosynthetic rates (Fang *et al*., 2006). On the other hand, defoliation on ruderal herb, *Barbarea vulgaris*, revealed that seed production was not influenced among injured plants in the first year (Martínková *et al*., 2008). Similarly, single clipping did not affect above ground biomass production in *G. urbanum* and *P. purpurea* (Moser and Schütz, 2006).

A study on *Rorippa palustris* revealed that defoliation and removal of axillary buds induced growth of new shoots from root buds (Martínková *et al*., 2004). However, 3-year defoliation study of *Tipularia discolor* showed that 100% and 50% leaf removal resulted in a cessation of flowering within 1 year, a progressive decline in below-ground biomass, and increased mortality (Whigham and Chapa, 1999).

In a study on *Lonicera japonica* more carbon was allocated to secondary leaves and stems after 1 yr due to unlimited herbivory. Total biomass accumulation and greater allocation to leaves and stems indicate a compensatory response to herbivory by *L. japonica*. However, if herbivory occurs during leaf emergence or if a plant is unable to increase allocation to form more leaf tissue, this potential for growth is reduced or even eliminated. Therefore, plants usually respond to defoliation by replacing leaf tissue, and changing intrinsic biomass allocation patterns (Schierenbeck *et al*., 1994). A study on the response of two grass species to a gradient of defoliation intensities, from 0 to 100% aboveground biomass removal, showed the same aboveground growth regardless of defoliation intensity due to stimulation of relative growth rate by defoliation. Thus, aboveground compensatory responses represent a key feedback process resulting in constant aboveground growth regardless of defoliation intensity (Oesterheld, 1992).

Harvesting of leaves may have a negligible effect on the plant population being exploited if: (i) individual plants are not killed in the process; (ii) a sufficient number of healthy leaves are left on each plant for photosynthesis; (iii) the reproductive structures and apical buds are not damaged, and (iv) sufficient time is allowed between successive harvests for the plant to produce new leaves. The harvesting of roots, bulbs and bark usually kills or fatally weakens the exploited plant species (Ndangalasi *et al.*, 2007).

2.5 Specific leaf area

Specific leaf area (SLA) is defined as the total leaf area divided by the total leaf weight (Gunn *et al*., 1999) or a measure of leaf area per unit dry mass invested (Reich *et al*., 1998, Wilson *et al*., 1999). It is also defined as the light-catching area deployed per unit of previously photosynthesized dry mass allocated (Vendramini *et al*., 2002). Specific leaf area is one growth parameter that shows responses to defoliation as well as resource allocation patterns among some plant species. It reflects the expected return on previously captured resources (Wilson *et al*., 1999). Specific leaf area is a concept used in the analysis of whole plant growth (Gunn *et al*., 1999) and is regarded as one of the major contributors to resource capture, usage and availability (Vendramini *et al*., 2002).

Specific leaf area has been correlated with variables such as net photosynthesis, relative growth rate, leaf structure and yield. The partitioning of carbon between different leaves and within leaves between transport carbohydrate, storage carbohydrate and structural carbon (C) gives a basis for understanding changes in leaf weight and hence SLA of plants. These pools of C vary over different timescales and may contribute to changes in specific leaf area calculated for individual leaves. Variation in inorganic compounds may also cause changes in specific leaf area for individual leaves, but the abundance of C make its partitioning and metabolism a strong candidate for controlling changes in specific leaf area (Gunn *et al*., 1999).

Leaf age and light is also reported to influence SLA of barley plants. At the same physiological age, leaves which developed in low light had a higher individual specific leaf area than those which developed in high light. Reducing the light available to the whole plant also increased the SLA of leaves which were fully expanded at the time of treatment imposition. The increase in SLA in both newly expanded and expanding leaves because of shading was due to lower structural weight of the leaves. There was a decrease in individual specific leaf area with increasing leaf age due to an increase in structural dry weight that made older leaves heavier (Gunn *et al*., 1999). Conversely, for several plant species, no significant differences in SLA existed between recently matured leaves and older leaves (Poorter and De Jong, 1999). Thus, decreasing SLA is associated with greater allocation of biomass to structural components of the leaf rather than metabolic components, with greater internal shading (Reich *et al*., 1998).

2.6 Soil/Site-Plant foliage nutrient relations

For a species to be chosen for cultivation, the special conditions for planting need to be evaluated involving a description of the physical, edaphic and climatic factors for the site (Boland, 1986). In this review, a site is used in a restricted sense to mean the soil conditions within which plants grow. Plant growth rates depend on the environment, supply of nutrients and other suitable conditions (Porter and Lawlor, 1991). Hence, soil testing has been recommended to be a comparatively rapid procedure for obtaining information on nutrient availability, salinity and pH in soils as a basis for recommending fertilizer application (Marschener, 1995). On the other hand, plant chemical analysis using vegetative organ (leaves, veins, petioles, young shoots etc) provide information regarding plant demand for certain elements, and is variable with species and age (Davidescu and Davidescu, 1982).

Through foliage analysis of several plants, the normal order of magnitude of nutrients is as follows: N > K > P > Mg > Ca (Motsara and Roy, 2008). However, several other studies have reported varied results perhaps due to the numerous factors involved in the uptake and utilization of plant nutrients. In South-western Australia, a survey on selected nutrient concentration in the shoots of plants was ranked in the order: N > K > Ca > Mg > P (Foulds, 1993) while Foliar nutrient concentration decreased in order of: N = 2.48% > Ca = 1.52% > K =1.15% > P = 0.18% > Mg = 0.50% > K= 0.15% has also been reported among orchards (Zatylny and ST-Pierre, 2006). Studies on mean foliar macronutrients of *Quercus robur* leaves from two different sites followed a sequence in the order of magnitude: N = 22.37 mg g^{-1} > K = 7.77 mg g^{-1} > Ca = 6.57 mg g^{-1} > P = 1.6 mg g^{-1} > Mg = 1.35mg g^{-1} (Dı´az-Maroto *et al*., 2009).

Soil fertility research has often relied on empirical correlations between increases in shoot growth or nutrient content and chemical measurements on samples of the soil (Cummings, 1989; Barber, 1995; Bowman *et al*., 2003; Zatylny and ST-Pierre, 2006). Correlations between foliar nutrient concentrations and soil nutrient availability have been found in multiple ecosystems. These relationships have led to the use of foliar nutrients as an index of nutrient status and to the prediction of broad scale patterns in ecosystem processes (Townsend *et al*., 2007). For instance, a study involving two species, *Pinus radiata* and *Cupressus lusitanica* revealed that with the exception of Ca in *C. lusitanica*, foliar K, Ca and Mg were correlated with their respective soil exchangeable cation measures. For both species significant relationships between foliar nutrients and 0 –10 cm layer soil properties from unfertilised plots were evident for total N and available P (Davis, *et al*., 2007).

Several other studies have often reported lack of correlation, or at best only a weak correlation, between foliar and soil nutrient levels. For instance lack of correlation between soil and foliar nutrients of *Quercus robur* have been reported (Dı´az-Maroto *et al*., 2009). However, consistent positive correlation between soil test values and plant yield has often been reported for only calcium (Cummings, 1989) probably due to the immobility of calcium in plant cell. Foliar Ca and Mg levels have been identified to be dependent on their corresponding levels in soil than foliar K (Ouimet *et al*., 1995).

Several factors operate to expedite or retard the release of nutrients to plants (Brady, 1990). This explains the often lack of correlation between foliar and soil nutrient levels. A study of three herbaceous species attributed the lack of a correlation between soil N and P supply and their respective foliar concentrations to the probable buffering between soil nutrient supply and foliar nutrient concentrations by belowground nutrient storage in plants and the use of organic N by plants (Bowman *et al*., 2003).

Additionally, soil test normally assays only the top portion of the rooting volume where the concentration of most nutrients in soil solution is only a portion of the exchangeable nutrients. In the case of Ca, which primarily moves by mass flow, environmental factors have quite a different effect on it as compared to other nutrients like K that move primarily through diffusion. Hence, an increase in evapotranspiration and increased water loss would tend to increase a mass flow nutrient, such as Ca, compared to K (Cummings, 1989).

Soil-foliar nutrient relationship is also influenced by the percentage saturation of the exchange complex by specific nutrient cations. High percentage nutrient saturation of cations results in their comparatively easy and rapid displacement. The complementary ions held on the colloids also influence the uptake of a given cation. The strength of adsorption of different cations is in the following order, $Al^{3+} > Ca^{2+} > Mg^{2+} > K^{+} = NH_4^{+} > Na^{+}$. Consequently, a nutrient cation such as K^+ is less tightly held by the colloids if the complementary ions are Al^{3+} and H^+ (acid soils) than if they are Mg^{2+} and Na^+ (neutral to alkaline soils). The loosely held K^+ ions are more readily available for absorption by plants or for leaching in acid soils (Brady, 1990). In Ghana, generally, foliar nutrient concentrations of P and Mg have been reported to be lowest in species naturally found in wet evergreen forest zone of Ghana where the soils are mostly acidic (Veenendaal *et al.*, 1996).

Nutrient antagonisms, a phenomenon in which certain soil nutrients cause inhibition of uptake of some cations by plants, also influence soil and foliar nutrient relationships. Thus, potassium uptake by plants is limited by high levels of calcium in some soils. Likewise, high potassium levels also limit the uptake of magnesium even when significant quantities of magnesium are present in the soil (Brady, 1990; Osaki *et al.*, 2003). Also, as K uptake increases Mg uptake decreases (Zas, 2003) because the presence of K in plants affects the translocation of Mg from the roots to plant top (Mayland and Wilkinson, 1989). The relationships between foliage element concentrations in red spruce and soil chemical properties studied revealed significant negative correlations between the concentrations of the major divalent cations (i.e. Ca, Mg, Mn) and K in the foliage suggesting a possible antagonism between the mono- and divalent cations for uptake from the soil (Fernandez and Struchtemeyer, 1984). High levels of other cations such as magnesium, ammonium, iron, aluminium and especially potassium, will also reduce the calcium uptake in some crops.

2.7 Agroforestry multipurpose trees

Definition

In the context of agroforestry, multipurpose tree species are trees and shrubs which are deliberately kept and managed for more than one preferred use, product, and/or service; the retention or cultivation of these trees is usually economically but also sometimes ecologically motivated, in a multiple output land use system (Nair, 1993). Agroforestry covers a wide range of associations of herbaceous and woody plants grown together under man-managed conditions (Huxley, 1983). Agroforestry aims to create interactions between woody perennials, herbaceous crops or pastures, and their biotic and abiotic environments which increase the overall productivity of the land use system and/or its sustainability (Schroth, 1995).

Function-soil fertility

A major service function of trees in agroforestry systems is their maintenance of soil fertility. Trees minimize leakage of nutrients from the system and recycle them, prevent soil erosion and thereby positively influence the growth of associated plants and are the biological premise of agroforestry systems (Ranganathan and de Wit, 1996). Existing evidence suggests that there are five mechanisms by which trees ameliorate soils. They may: (1) fix atmospheric nitrogen through symbiotic relationships and thus enrich the soil, (2) act as nutrient pumps accumulating ions from a large volume of soil and depositing those ions in a smaller volume of surface soil, (3) produce large quantities of biomass and enrich the soil with organic matter, (4) moderate soil temperature and moisture extremes, and (5) their rhizosphere effect may enhance nutrient availabilities (Fisher, 1990).

Supply of nutrients

When nutrients are limiting, total yield can be increased when trees (i) access nutrients at depth, laterally in non-cropped zones or from chemically occluded forms that are inaccessible to crops, and (ii) capture nutrients that would otherwise be leached due to incomplete 'synchrony' of supply and demand (providing a 'safety net' so that the system is less 'leaky') (Cannell *et al.*, 1996; Allen *et al.*, 2004). Fine roots also supply nutrients to intercropped plants through root turnover and dieback, caused by pruning aboveground biomass as well as mycorrhizal associations (Palm, 1995).

Acquisition of resources unavailable to crops by trees tends to increase biomass production and subsequently improve soil fertility by increasing soil organic matter levels, soil physical properties and temporarily reducing soil acidity (Cannell *et al.*, 1996). Conversely, surface accumulation of organic matter increases and pH decreases as stands grow. Stand growth further causes litterfall increases and canopy closure such that soil microclimate becomes less favourable for organic matter decomposition (Alriksson and Olsson, 1995).

Soil erosion control

Trees assist in checking runoffs and erosion. Through the interception of eroded sediment in the field, nutrients or soils which would otherwise be lost are retained (Sanchez, 1987). Soil erosion control is due to surface mulch, increased water infiltration rates due to soil structure improvement and more complete water use (Cannell *et al.*, 1996; Kho, 2000). For instance soil moisture content under both *Leucaena* and *Flemingia* hedgerows was reported to be higher than under sole maize rows in the alleys throughout a growing season (Chirwa *et al*., 1994).

Currently, calls for the use of indigenous woody and non-woody species in agroforestry systems in Ghana are yielding positive response. Practices involving a combination of indigenous economic fruit trees such as *Cola nitida*, *Spondias mombim*, *Tetrapleura tetraptera*; timber species such as *Terminalia superba*, *Miliacia excelsa*, *Terminalia ivorensis*, *Peptidniastrum africanum*; and vines like *Piper nigrum* as well as herbaceous plants like *Thaumatococcus daniellii* are being practiced in parts of the Western Region of Ghana. This notwithstanding, little information is available with regard to the use of tree species like *Carapa procera* in agroforestry systems. Sections 2.6.1, 2.6.2 and 2.6.3 present a review of literature on multipurpose tree involved in this research.

2.7.1 *Leucaena leucocephala*

Description and ecology

Leucaena leucocephala is a shrub or tree which grows up to 18 m tall. It is forked when shrubby and branches strongly after coppicing, with greyish bark and prominent lenticels. The leaves are bipinnate with 4 - 9 pairs of pinnae which vary in length up to 35 cm, with a large gland (up to 5 mm) at the base of the petiole. The leaflets are about 11 - 22 pairs/pinna, acute and each with dimension of 8 - 16 mm × 1 - 2 mm. *Leucaena leucocephala* bears numerous flowers that possesses globose heads with a diameter of 2 - 5 cm. Each flower bear 10 stamens per flower and its pistils are 10 mm long. It produces pods that bear about 18 - 22 seeds per pod and are brown at maturity (Shelton *et al.*, 1998).

Leucaena occurs naturally in southern Mexico and is widely distributed throughout the tropics. *Leucaena* grows naturally on shallow limestone soils, coastal sands and seasonally dry, vertisol soils of pH 7.0 - 8.5. In exotic locations it requires well-drained soils with pH above 5.5, or above 5.0 where aluminium saturation is very low. *Leucaena* tolerate moderate salinity and alkalinity but intolerant of soils with low pH, low P, low Ca, high aluminium saturation, high salinity and water logging or extended periods of flooding for more than 3 weeks. *Leucaena* prefers sub-humid and humid climates of 650 - 1,500 mm and up to 3,000 mm annual rainfall and tolerates up to 7 months dry season. *Leucaena* requires temperatures of 25 - 30 ºC for optimum growth and grows readily to 50% photosynthetic active radiation (PAR) (Hughes, 1998).

Uses

Young green pods can be split open and the fresh immature seeds eaten raw or cooked as a food (Shelton and Brewbaker, 1998). The juice of the root is used to treat diarrhea and dysentery (Manandhar, 2002). It is highly valued as ruminant forage and as a fuel wood by farmers throughout southeast and central Asia and Africa (Fuwape, 1993). *Leucaena* is the most commonly researched species for alley farming systems (Shelton and Brewbaker, 1998). *Leucaena leucocephala* is estimated to fix 100 - 500 kg nitrogen (N) ha/year or more in pure stands, and 75 - 100 kg when grown in hedgerow intercropping (Young 1997). It is planted in hedgerow systems with grass for cattle production in Northern Australia, and as a hedgerow species in parts of Southeast Asia (Pandey *et al*., 2006) and Africa. *Leucaena* is also used as a shade tree over coffee and cocoa (World Agroforestry Centre, 2009). It is grown in dense rows as a living fence and used to support vine crops such as pepper and passion fruit. However, in the semiarid highlands of East Africa, hedgerow intercropping with *Leucaena* has limited potential for improving crop yield or overall land productivity (Jama *et al*., 1995).

2.7.2 *Senna siamea*

Ecology and distribution

Senna siamea is a medium sized evergreen and non-nitrogen-fixing leguminous tree in the family Leguminosae. It rarely exceeds 20 m height and 50 cm diameter at breast height at maturity. It is commonly called Thailand shower, minjiri, or kassod. Senna has a dense, evergreen, irregular, spreading crown, a crooked stem, and smooth, grayish bark that is slightly fissured longitudinally. Its young branches have fine hairs. The leaves are pinnately compound with an even leaf arrangement of 7 - 10 pairs of ovate-oblong leaflets 7 - 8 cm long and 1 - 2 cm wide. Its flowers are yellow, borne in large terminal panicles that are often 30 cm long. The flowering period is long, and flowers may often be found at various seasons. The fruit is a flat pod 15 – 25 cm long, thickened at both sutures, containing many seeds (Hassain, 1999).

Senna grows in many environments, but it grows particularly well in lowland tropics with mean annual rainfall of 500 - 2800 mm, and a mean minimum and maximum temperature of 20^{o}C and 31^{o}C respectively. In semiarid environments with mean annual rainfall of 500 -700 mm it will grow only where its roots have access to groundwater and where the dry season does not exceed 4 - 6 months. *Senna* tolerates well drained lateritic or limestone soils and moderately acid soils. It also grows well in deep, well drained, rich soils with pH 5.5 - 7.5 (World Agroforestry Centre, 2009).

Uses

It is widely planted in many Southeast Asian countries for erosion control, windbreaks, shelterbelts, fuel wood, and pole wood. *Senna* is a good ornamental tree for planting along roadsides. It is also used in alley cropping, intercropping and hedgerows. Sena is planted as a shade tree in cocoa, coffee and tea plantations (Young, 1997; Hassain, 1999). *Senna* is also used in traditional medicine particularly managing constipation associated with a number of causes including surgery, childbirth and the use of narcotic pain relievers. The leaves and back are used as anti-malaria drugs when decocted (Smith, 2009). Though, *Senna* is not leguminous, phosphorus uptake from the soil is often facilitated by heavy root infection by vesicular arbuscular mycorrhizae (VAM) (Habte, 1995). *Senna siamea* is known to hold large amounts of nitrogen in its foliage (National

Association of Sciences, 1980). However, hedgerow intercropping with *Senna* may have limited potential for soil fertility improvement because of the low biomass produced and the slow decomposition of its biomass relative to that of *Leucaena* (Jama *et al*., 1995).

2.7.3 *Carapa procera*

Distribution and ecology

Carapa procera is a lower-canopy tree that belongs to the family Miliaceae and can grow up to a height of 30 m tall. The mature stems are fairly straight, usually fluted with small buttresses and diameter range of 0.6 - 0.9 m. *Carapa* is a monoecious species that produce up to several hundred large (5 - 10 cm diameter) ovoid capsule fruits, composed of five, rarely six, sub-woody valves containing 3 - 6 seeds each. At maturity, the heavy fruits break open by dropping beneath the maternal tree. The seeds are known to be dispersed by caviomorph rodents, mainly Agoutis (*Dasyprocta leporina*) and Acouchis (*Myoprocta exilis*) (Doligez and Joly, 1997; Forget and Jansen, 2007).

Carapa prefers a light-textured soil, an altitude range of 0 - 1200 meters above sea level and mean annual rainfall of 1500 - 3200 mm. The rotation period is between 25 – 30 years for timber (World Agroforestry Centre, 2004). *Carapa* is found in South America in Surinam (local names *Karaba* or *Krapa*), French Guiana (*Carapa*), and the northern Brazilian Amazon (*Andiroba).* It is also widely distributed in West Africa in countries like Ghana, Sierra Leone, Liberia, Ivory Coast and Nigeria and in Central Africa; Angola and Zaire extending eastward to Uganda (Doligez and Joly, 1997; Forget and Jansen, 2007).

Uses

The seed endosperms of *Carapa* contain approximately 50% fats/oils and the oil extracted from its seeds is a valued NTFP of Guianan and Amazonian rainforests. The oils are traditionally and commercially extracted for use in insect repellents and cosmetics (Forget and Jansen, 2007). The oil is also used in treating arthritis, rheumatism, pulmonary troubles, veneral diseases and as antidotes to venomous stings or bites. Its back is used as genital stimulants/depressants and in treating paralysis, convulsions and spasm. The twigs are used as chew sticks (Burkill, 1985). The wood is used for making furniture and flooring, stairs, mouldings, interior window frames, veneer and musical instruments. However, exterior application of the timber is restricted by the lower durability (Forest Stewardship Council, 1996).

2.8 Provenance

Definition

Provenance can be defined as the original geographic source of seed, pollen or propagules. It is also a term given to a plant propagule obtained from a particular site or region (Galloway, 2001; Ræbild and Graudal, 2004; O'Brien *et al*., 2007). Wide environmental variation often occurs within the natural range of a plant species. Adaptation of a species to this variation may produce different morphological and physiological characteristics, resulting in the development of ecotypes (Teklehaimanot *et* *al*., 1998). These variations in physiology and morphology can influence germination of seeds (Schütz and Milberg, 1997; Bischoff *et al*., 2006); suckering or rooting of vegetative materials (Dick *et al*., 1996); and the growth and survival of plants (van Tienderen, 1992; O'Brien *et al*., 2007).

Provenances of *Fraxinus pennsylvanica* Marsh and *Quercus rubra* L., tree species exhibited morphological and physiological variations which were related to their habitat (Teklehaimanot *et al*., 1998). Also, marked geographic variation in germination, morphology and ecological responses were found among four seed populations of *Leucochrysum albicans* (Gilfedder and Kirkpatrick, 1994). These variations in maternally derived traits can result in size hierarchies and differential fitness of individuals within a population. Thus, understanding and identification of maternal effects has important consequences for the study of plant distributions both within and between populations and communities (Roach and Wulff, 1987).

Survival

Survival and plant height are regarded as key variables when evaluating species and provenances since they indicate the adaptability of the provenance to the environment at a trial site. In line with this, no significant differences in survival percentage among *Acacia nilotica* provenances were reported (Ræbild and Graudal, 2004). Similarly, among *Polylepis australis* seedlings from two woodland areas, survival did not show any relationship with seed provenance. However, initial decline in survival was attributed to stresses associated with transplanting (Renison *et al*., 2005). Conversely, significant differences in survival were reported for *Eucalyptus marginata* seedlings distributed in two provenances (O'Brien *et al*., 2007). Also, an evaluation of *Acacia senegal* revealed that survival was significantly influenced by provenances (Ræbild *et al*., 2003).

Plant weight and seed size

An evaluation of *Acacia senegal* revealed that total dry weight was significantly influenced by provenances (Ræbild *et al*., 2003). Also, *Dalbergia sissoo* populations scattered over its entire natural range in India differed in seed length, seed width, seed weight and seedling dry weight. These differences in morphological traits were influenced by seasonal variation of respective sources spread over an immense geographical area, experiencing varied environmental conditions (Vakshasya *et al*., 1992).

Leaf characteristics

Seeds obtained from four populations of, *Leucochrysum albicans*, in Tasmania demonstrated significant differences between provenances in leaf length, leaf width and leaf area. These variations were related to edaphic and climatic conditions of the source of planting material (Gilfedder and Kirkpatrick, 1994). Furthermore, an evaluation of *Acacia senegal* revealed that crown area and basal area were significantly influenced by provenances (Ræbild *et al*., 2003). Also, significant differences in leaf size between provenances for field grown foliage of *Fuchsia excorticata* were observed (Sweetapple and Nugent, 1999). Conversely, a study on two provenances of *Fagus orientalis* and *Fagus sylvatica* revealed significant differences for petiole length, leaf length and leaf area, but no significant differences in leaf width were observed (von Wuehlisch and Gailing, 2004).

Plant height

Significant differences between seed provenances and associated variation in heights were reported for *Albizia lebbek* trees from 12 provenances (Toky *et al*., 1996), *Quercus robur* (Harmer, 2000) and *Eucalyptus marginata* (O'Brien *et al*., 2007). Furthermore, shoot length of *Pongamia pinnata* revealed significant differences due to provenance and ranged between 3.33 cm and 21.00 cm (Ramesh, 2007). Contrastingly, no significant differences in height were reported among provenances of *Eucalyptus microtheca* (Tuomela *et al*., 2000) and *Acacia nilotica* (Ræbild and Graudal, 2004).

Chapter 3

3.0 SOIL CHARACTERISTICS, FRUIT SOURCES AND CONSERVATION OF *T. daniellii* IN OFF RESERVES OF THE WESTERN REGION OF GHANA

Summary

This study was conducted in the Western Region of Ghana to determine the (i) major sources of fruits and constraints to supply, (ii) level of cultivation and conservation strategies in off reserves, and (iii) soil/site conditions that support natural *T. daniellii* stands. The study communities were Nkrankrom (N 05°32.028□, W 002°37.017□), Benda Nkwanta (N 05° 30.364□, W 002°31.638□) and Benda (N 05°32.353□, W 002°32.320□). Data was collected through formal and informal interviews, focus group discussions and direct field observations of natural stands. Soils of natural stands were sampled for determination of selected physical and chemical properties. The study revealed that fruits were predominantly supplied from seven communities within Aowin-Suaman and Wassa Amenfi West districts. The long duration and distances covered during fruit collection resulting from low fruiting and reduction in stands of *T. daniellii* are major constraints to fruit collection and supply. Also, no records of conservation, cultivation or integration of *T. daniellii* into farming systems were obtained for previous or current fruit supplying communities but for Samartex plantations. The lack of efforts at conservation or cultivation of *T. daniellii* cast a doubt about future sustainable fruit supply from the wild as demand for thaumatin increases. Soil chemical properties; pH, N, P, K, Ca, Mg, TBS, ECEC, organic matter differed significantly among sites except for Na. Also, soil physical property, texture, significantly differed among sites but bulk density did not vary among sites. *T. daniellii* can be said to be adaptive and can grow at different sites with varied chemical properties but desirable physical properties.

3.1 Introduction

Current information on the sources of *T. daniellii* fruits point to the fact that most collections are still done in the wild. As a result, there is not enough knowledge on the site/soil conditions that support its growth as well as other areas outside forest reserves where stands of *T. daniellii* contribute to fruit supply. In Ghana, the Western region is currently a major source of fruits to the thaumatin extraction plant in Samreboi. The market for thaumatin is expected to expand in the future and continuous dependence on supplies from the wild will not be sustainable if its cultivation by local farmers is not encouraged. There is therefore the need to find out the possible areas of occurrence and soil / site characteristics, types and scale of cultivation by farmers and as well ascertain factors that can encourage farmers to cultivate *T. daniellii*.

Soil properties such as soil reaction (pH), moisture, bulk density, texture and levels of organic matter, N, P, K, Ca, Mg, as well as micronutrients affect the growth of plants. A combination of these factors among others determines where and how well a plant grows. In addition, the availability of plant nutrients in different concentrations in plant biomass can also be used to establish a relationship between soil nutrient status and plants ability to uptake them. This can also help to determine the specific plant nutrients that *T. daniellii* requires for its growth and fruit development. Such information would be very useful since any efforts geared toward encouraging large scale cultivation would be done on off reserves due to entry restriction in forest reserves. Also, knowledge of the conservation status/strategies of *T. daniellii* are very essential for understanding its sustainability in off reserves and to justify the necessity for conservation.

3.1.1 Study Objectives

The specific objectives of this study were to determine:

(i) The distribution, major sources and constraints to fruit supply to the thaumatin industry

(ii) The level of *T. daniellii* cultivation, its conservation strategies and to assess the potential for its cultivation by farmers

(iii) The soil/site conditions that support growth of natural stands of *T. daniellii*

3.2 Materials and Methods

3.2.1 Study sites

Three communities were selected in the Western Region based on their current or previous roles in the supply of fruits to the thaumatin plant as well as reported occurrence of the *T. daniellii* stands in these communities. The selected communities were Nkrankrom (N 05°32.028′, W 002°37.017′), Benda Nkwanta (N 05° 30.364′, W 002°31.638′) and Benda (N 05°32.353′, W 002°32.320′). Nkrankrom is located in Aowin/Suaman district which lies in the mid-western part of the Western Region of Ghana. The capital of the district is Enchi. On the other hand, Benda and Benda Nkwanta are located within Wassa Amenfi West district with Asankragua as the district capital.

3.2.2 Data Collection Methods

Reconnaissance surveys were initially conducted in selected areas to identify presence of *T. daniellii* and for the assessment of habitats. Data was subsequently gathered through, interviews, field visits, laboratory analysis and photography which involved documenting with digital camera images of areas where natural stands of *T. daniellii* occur. The study was gender as well as culture sensitive and participatory in approach. Some of the field diagnostic tools were employed separately or in combination to obtain the best task results. The details of the various activities carried out to gather data are presented as follows.

Interviews/Group discussions

Data was gathered using participatory research methods involving formal and informal interviews with key resource persons as well as focus group discussions within selected communities. The group for each discussion comprised 6 - 12 individuals who were mainly farmers, fruit collectors and leaf collectors (Appendix 1a). The discussions were designed to capture qualitative and quantitative information about their involvement in *T. daniellii* fruit collection, sale, and local knowledge on its distribution, as well as its level of cultivation and conservation. The groups were constituted to ensure the participation of both genders.

The discussion was coordinated by a facilitator using structured open ended and non leading questions. During discussions, individuals expressed their views freely whiles all group members were allowed to share their thoughts on responses that came up in order to ensure that views reflected the opinion of the whole group. Three focus group discussions were conducted in Nkrankrom and Benda Nkwanta on 6^{th} and 7^{th}, and 27^{th} respectively whiles two were held in Benda on 28^{th} October, 2009.

Further interviews were conducted with officials of the Agroforestry and Thaumatin Department of Samartex Timber and Plywood Company focusing on the various sources of *T. daniellii* fruit supply, the current state of supplies as well as how trading of *T. daniellii* is done. On the whole, information gathered reflected the opinions of a total 74 people who participated in the focus group discussions plus key informant interviews.

3.2.3 Field methods

Stand characterization

Direct field observations and measurements were conducted on cultivated and fallow lands in selected communities to ascertain how farmers are conserving *T. daniellii* on the farms.

Plant density and height

The numbers of *T. daniellii* petioles present on randomly marked plots (1.0 m^2) were counted to determine plant density. Height measurements of *T. daniellii* stands were recorded using measuring tape and then categorized into height classes.

Percentage relative abundance (PRA)

The percentage relative abundance (PRA) for *T. daniellii* in identified patches was calculated using the following formula (Odebiyi *et al*., 2004) but modified to suit the objectives of this study.

$$\text{PRA} = \frac{[\text{Number of stands in the size-class x 100}]}{\text{Total number of stands}} \qquad \textit{Eqn 3.1}$$

The modified form of the equation 3.1 is presented as equation 3.2 below

$$\text{PRA} = \frac{[\text{Number of petioles in the height-class / m}^2 \text{ x 100}]}{\text{Total number of plants / m}^2} \qquad \textit{Eqn 3.2}$$

Percentage relative abundance (PRA) of farm and fallow lands were computed for the height classes from sites in Benda, Benda Nkwanta and Nkrankrom using equation 3.2. The concept behind PRA was to determine the abundance of matured *T. daniellii* populations which was then used as an index of conservation on selected sites. Hence, matured populations were classified as those with plant height exceeding 1.0 m as most fruiting populations surveyed were at least 1.0 m tall.

Tree data

The tree/shrub population and type of species usually associated with *T. daniellii* stands were determined by head count. Tree diameters at breast height (dbh) were measured using diameter tape. Tree heights were also determined using a hagameter.

Soil and foliage Sampling

Soil samples were collected from natural stands of *T. daniellii* at Benda, Benda Nkwanta and Nkrankrom. Three plots (1.0 m^2) were randomly demarcated within each site supporting natural stands of *T. daniellii*. Three soil samples were collected using soil auger to a depth of 0 – 15 cm and 15 – 30 cm from each plot (Appendix 1b). The samples for each site were mixed in a clean container and three sub-samples for each site were taken for laboratory analysis. Soil cores were also collected using bulk density sampler for bulk density determination. Foliage of *T. daniellii* (young and old) was also sampled on each of the three plots from which soil sampling was done. Foliage samples were air dried and milled. Three sub-samples of foliage from each site were then taken for laboratory analysis.

3.2.4 Laboratory Methods

Soil analyses

Soils were analyzed for N, P, K, Ca, Mg, pH and organic matter. Effective cation exchange Capacity (ECEC), total exchangeable bases (TEB) and percentage base saturation were also determined. Soil nitrogen was determined using Kjeldahl method. Available phosphorus was determined using Bray's No 1 method. Available Potassium was calculated by determining the potash content in ammonium acetate extractant of soil sample using the flame photometer. Exchangeable Calcium and Magnesium were determined by the Versenate (EDTA) method. Soil bulk density was determined by dividing the weight of oven dry soil by volume of the soil. Soil texture was determined using Bouyoucos Hydrometer method (Motsara and Roy, 2008).

Foliar analyses

The foliage of *T. daniellii* was analyzed for N by Kjeldahl method while P, K, Ca and Mg were determined using the dry ash method. This involves dissolution of plant residues ashed at 500 - 600°C in dilute HCl. The acid-digested or dry-ashed plant sample was then used to determine required nutrients using a flame photometer (Motsara and Roy, 2008). All laboratory analyses were conducted at the Soil Research Institute of the Council for Scientific and Industrial Research (CSIR), Kumasi, Ghana.

3.2.5 Data Analysis

Data collected on sources of fruits supplies, plant density/m^2, percentage relative abundance (PRA) and scale of cultivation of *T. daniellii* are presented in section 3.3 Observed natural stands on farms and off reserves are represented using figures or plates. Based on information gathered, the potential for cultivation or integration of *T. daniellii* into farming systems was assessed using the SWOT analysis. This method permitted the assessment of identified factors grouped under the following headings: strengths (S), weaknesses (W), opportunities (O) and threats (T). The matrix presents in a simple format the factors that need to be considered in the quest to promote the cultivation of *T. daniellii*.

Data on selected soil chemical and physical properties as well as foliage nutrient levels from the different communities were subjected to analysis of variance test using a Completely Randomized Design (CRD). Mean comparison was done using Tukey’s mean separation technique using statistical software Statistix 8 (United States Department of Agriculture/Natural Resources Conservation Service, 2007). Regression analyses were used to establish correlation between soil and foliage nutrient (N, P, K, Ca and Mg) levels using Microsoft Excel 2003.

3.3 Results and Discussion

3.3.1 Sources of fruit supply

The study confirmed that *T. daniellii* populations occur predominantly in the Aowin Swaman and Wassa Amenfi districts of the Western Region of Ghana (Figure 1). Though some of the fruits were obtained from nearby forest reserves, discussants of the focus group discussions indicated that major supplies of fruits come from off reserves or fallow lands.

Communities in the Western region that mostly supplied fruits to the thaumatin extraction plant from 2007 and 2009 included Nkrankrom, Mottoso, Old Yaakese, Benda, Benda Nkwanta, Kokoase, Amoaku, Hiamatuo, Adumkrom, Samreboi and Aggreyso (Figure 2). However, records indicate that supplies from some of these communities have halted since November, 2008. Together, seven of these communities supplied a total of about 3.88 tons of fresh fruits estimated at GH¢1,162.56 for a period of 11 months from November, 2008 to September, 2009 (Figure 2) (Source: Thaumatin Department, Samartex).

The people in these communities were aware that fruits of *T. daniellii* had market value though few of them were involved in its collection and sale. Comparatively, most communities currently supplying fruits were closer to Samreboi than those no longer doing so. This emphasizes the important role played by distance in the supply of fruits to the thaumatin extraction plant.

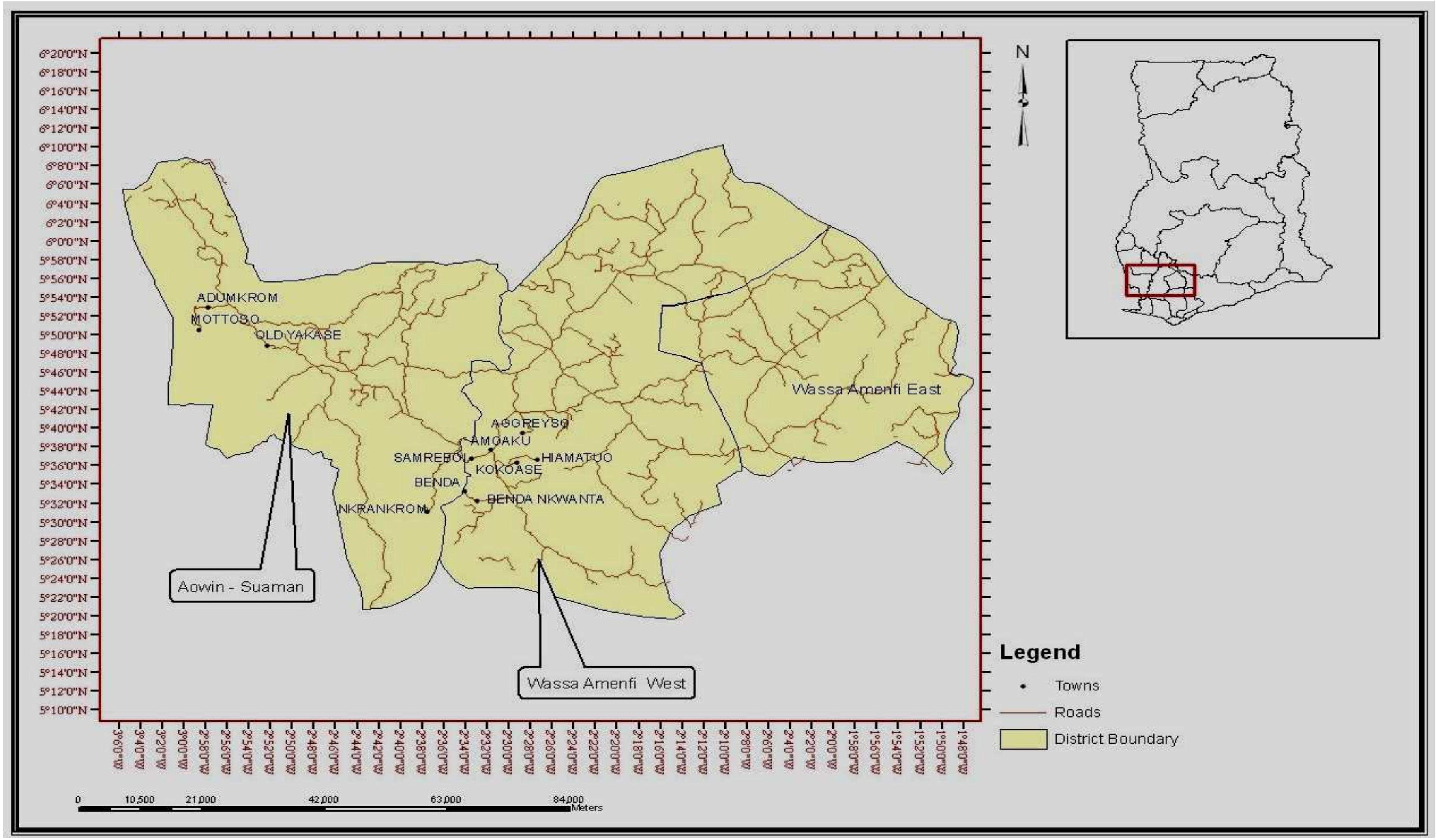

Figure 1. Map of Districts and Communities in the Western Region involved in the supply of *T. daniellii* fruits to thaumatin extraction plant at Samreboi, Ghana

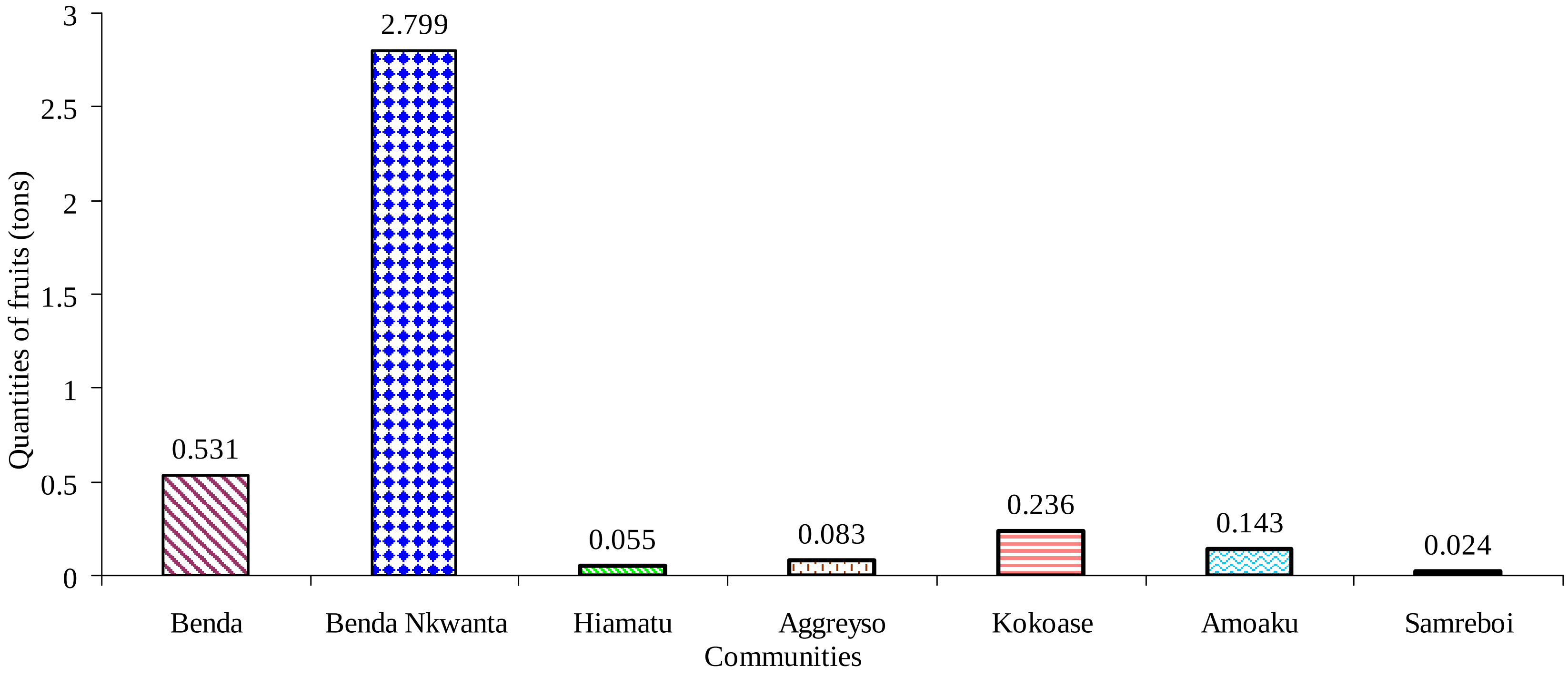

Figure 2. Estimated quantities of fruits supplied by communities from November, 2008 to September, 2009 in the Western Region (Source, Thaumatin Department, Samartex, Samreboi, Ghana)

Collectors from Benda and Benda Nkwanta currently dominate list of suppliers because of their ability to transport collected fruits on foot to the extraction plant. Consequently, fruit supplies from Nkrankrom had halted with few individuals who supplied fruits for a period ranging from 3 weeks to 3 years. Current fruit collectors from Benda and Benda Nkwanta have been involved in this trade for a period of 1 – 6 years (Appendix 1c and 1d).

Fruit collectors averagely use five days to collect between 10 – 50 kg of fruits and obtain between GH¢ 3 – 15 per week depending on how much time and efforts individuals devote to fruit collection. Based on this it could be projected that collectors obtain between GH¢ 156 – 780 annually. This provides an additional or alternative source of income to households as well as employment in these communities. Similarly, studies from the Afadjato-Agumatsa area of the Volta Region of Ghana, revealed that *T. daniellii* fruits collection provide employment for several people with individuals collecting 10 – 20 kg of fruit per day which were then sold at GH¢ 0.56/kg (Ekpe and Ottou, 2006).

3.3.2 Constraints to fruit collection and supply

One major challenge faced by fruit collectors is the distance covered during fruit collection. Fruit collectors indicated that fruit production is generally low in natural stands of *T. daniellii*. Consequently, they move from one distant stand to another making collection tedious as well as time consuming complementing earlier reports on the challenges involved in obtaining fruits (Yeboah *et al*., 2003). The situation has been worsened by the continuous expansion of cocoa farms in these communities. Participants indicated that areas that support stands of *T. daniellii* also have the capacity to support productive cocoa farms. This has encouraged large scale clearance of *T. daniellii* stands for cocoa establishment. To date increases in cocoa production have been mainly through expansion of cocoa farms in the forest areas. The main cocoa-producing region in Ghana is presently the Western region, which produces more than 50% of total annual production (Anim-Kwapong and Frimpong, 2003). This has therefore reduced sources of fruit collection.

Though the sale of fruits provided income to collectors, they registered their displeasure about the current price (GHp 30/kg) at which fruits are purchased by Samartex owing to the challenges they go through during fruit collection. Some revealed their intension to stop fruit collection notwithstanding the monetary benefits obtained. This may however impact negatively on fruit supplies if the purchase price is not reviewed.

The cost of transporting collected fruits is also a major reason why most collectors have stopped supplying fruits. Others reported of animal attacks such as snakes and wasps since *T. daniellii* stands provide a suitable abode for such animals and expressed their fears over their previous encounter with some of these animals. This is also a reason why most farmers clear it from their farms.

3.3.3 Conservation and cultivation strategies

Information gathered from the focus group discussions within the selected communities as well as interviews with Samartex officials revealed that there is currently no cultivation or integration of *T. daniellii* into land use systems in these three communities or other communities that supplied fruits to the company. Current efforts to encourage conservation and cultivation of *T. daniellii* are only limited to Samartex plantations. Consequently, most participants demonstrated no knowledge on how to effectively grow and manage *T. daniellii* in land use systems since it is still regarded as a weed except for fruit collectors. The inadequate information on the ecological productivity, growth forms, life history and conservation of species such as *T. daniellii* complicates management scenarios, the setting of conservation priorities and defining sustainable harvest levels (Ndangalasi *et al.*, 2007).

Currently, no other agency or institution apart from Samartex is promoting cultivation or integration as well as management of *T. daniellii* into farming systems. However, majority of participants demonstrated keen interest in cultivating *T. daniellii* in the future if encouraged particularly with the guarantee of ready market and a good price. Notwithstanding this interest expressed, most farmers were not prepared to integrate *T. daniellii* into their cocoa farms. For smallholder cocoa farmers, cocoa contributes about 70 - 100% of their annual household incomes (Anim-Kwapong and Frimpong, 2003). They revealed that the cultivation of *T. daniellii* on their farms would interfere with the cocoa growth, decrease yields and subsequently reduce annual incomes. However, it has been proposed that the surest way to maintain Non-Timber Forest Products is through the integration of their management with other forest uses. This is because their integration with timber management can provide several benefits and enhance a slower or more environmentally sustainable rate of timber extraction (Wickens, 1991; Ndangalasi *et al*., 2007). With majority of farmers disapproving of sole cultivation, they suggested *T. daniellii* cultivation with either oil palm or tree plantations.

Participants, mainly farmers, revealed that its growth competes with the growth of trees and other associated crops such as *Xanthosoma sagittifolium* (cocoyam), *Manihot spp* (cassava), *Dioscoria spp* (yam) and *Musa paradisiaca* (plantain) and reduce yields. Farmers cited observed cases of high attrition among cocoa trees on farms where *T. daniellii* were allowed to thrive over a period of about two to three years. Field observation also revealed that the underground rhizomes and roots of *T. daniellii* are concentrated in the 0 – 30 cm soil layer. Hence, attempts to cultivate it with shallow rooted crops could result in competition between *T. daniellii* and the associated crops. Other farmers also emphasized that its presence on farms affects uptake of applied fertilizers to the detriment of cocoa trees. Due to the massive concentration of *T. daniellii* rhizomes and roots within 0 – 30 cm depth of soils, farmers complained that nutrients supplied through fertilization are quickly absorbed by *T. daniellii* and consequently reduces the productivity of cocoa trees.

Thaumatococcus daniellii has been described as difficult to eliminate from farms and other land use systems. However, respondents admitted that natural populations over the years have continued to dwindle due to farm expansion as well as bush fire which was indicated as a major environmental factor that facilitates attrition of underground rhizomes.

3.3.4 Stand characteristics and distribution

Nature of distribution

Discussants revealed that *T. daniellii* is distributed as fragments or patches of dense stands (Appendix 2a) on off reserves, fallow lands or secondary forests and is less prevalent in forests with closed canopies. Open forest canopy is reported to allow the development of a profuse growth of marantaceous forbs (Hall and Swaine, 1976) and complements earlier suggestions that it may be a pioneer species (Wojciech *et al*., 2005). The largest patch size was identified at Benda (124.5 m^2) followed by Benda Nkwanta (90.0 m^2) and Nkrankrom (56.0 m^2) (Table 3.1).

The growth characteristics of *T. daniellii* was likened to that of ginger (*Zingiber officinale*) which is also rhizomatous and regarded as fast growing, aggressive or colonizing plant; and produces several tillers through underground stems. Participants who were mainly farmers and fruit collectors indicated that *T. daniellii* is normally found in swampy areas or very wet soils, near water bodies, sandy soils and abandoned cocoa farms and is in agreement with an earlier report (Wojciech *et al*., 2005).

Majority of the participants also agreed that *T. daniellii* preferred low lying areas with moist but well drained soils and emphasized that dense stands are rarely found on hilly areas. Fruit collectors confirmed that majority of fruiting populations are found on flat or gently sloping lands since such sites are repository of nutrients from higher ground. The influence of slope on the growth of *T. daniellii* is consistent with the report that steep land was not conducive to the growth of *T. daniellii* and often results in low quality fruit and leaves (Wojciech *et al*., 2005).

Table 3.1. Stand characteristic of *T. daniellii* populations from three sites

	Sites					
	Benda		Benda Nkwanta		Nkrankrom	
	Fallow land	Farmland	Fallow land	Farmland	Fallow land	Farmland
Height classes (m)	Percentage relative abundance (%)					
< 0.5	-	10.00	-	44.00	-	96.77
0.5 – 0.9	18.75	70.00	2.70	56.00	11.11	3.23
1.0 – 1.9	28.13	20.00	16.22	-	13.89	-
2.0 – 2.9	31.25	-	37.84	-	25.00	-
≥ 3.0	21.88	-	43.24	-	50.00	-
Population / m^2	32	10	37	25	36	31
Average plant height (m)	1.9	0.8	2.6	0.5	2.7	0.3
ǂ Patch size (m^2)	124.5	-	90.0	-	56.0	-

- No value obtained

ǂ Values only obtained for natural stands or fallow lands

Though most people indicated that *T. daniellii* flourishes on very wet soils, fruit collectors particularly indicated that fruiting stands or populations are found on very well drained soils or soils not submerged under water. This could be due to the reason that excessive moisture or water inhibits flower formation or cause flower attrition and subsequently lower fruit formation.

Plant population

Generally, plant population/m^2 was higher on fallow lands than farmlands. *Thaumatococcus daniellii* populations on fallow lands were Benda Nkwanta (37 m^{-2}), Nkrankrom (36 m^{-2}) and Benda (32 m^{-2}) (Table 3.1). Population on farmlands were: Nkrankrom (31 m^{-2}) > Benda Nkwanta (25 m^{-2}) > Benda (10 m^{-2}). Comparatively, fruiting populations seemed dominant on fallow lands or off reserves than farmlands. Farmers unwillingness towards the cultivation or integration of *T. daniellii* into agro-ecosystems within study communities was revealed by the low petiole populations recorded on farmlands (Table 3.1). Most populations identified on farms were naturally regenerating stands surviving persistent clearance (Appendice 2b, 2c and 2d).

Plant height

Average *T. daniellii* heights were higher on fallow lands than farmlands. Heights of populations on fallow lands ranged between 0.4 – 3.8 m for Benda, 0.9 – 3.9 m for Benda Nkwanta and 0.6 – 4.5 m for Nkrankrom. Also, plant heights on farmlands ranged between 0.3 – 1.4 m for Benda, 0.2 – 0.9 m for Benda Nkwanta and 0.1 – 0.6 m for Nkrankrom. Irrespective of the patch size, stand heights of *T. daniellii* were higher for Nkrankrom (2.73 m) than Benda Nkwanta (2.62 m) and Benda (1.90 m). This could be attributed to differences in stand ages or anthropogenic activities such as harvesting of leaves or clearing of stands.

Percentage relative abundance (PRA)

The total percentage relative abundance (PRA) of mature populations on fallow lands were Benda Nkwanta (97.3), Nkrankrom (88.9) and Benda (81.3) (Table 3.1). The dominance of matured population at Benda Nkwanta is indicative of the high level of participation in fruits collection and supply by the inhabitants as shown in Figure 2. Hence, though no deliberate attempt is being made to conserve *T. daniellii* on fallow lands, its populations at Benda Nkwanta seem to be better protected than Nkrankrom and Benda perhaps due to the economic benefits obtained through fruit sales. Fifty percent of populations on fallow lands at Nkrankrom were equal to or more than 3.0 m as compared to 43.2% and 21.9% for Benda Nkwanta and Benda respectively. This could be attributed to the non-disturbance of natural populations at Nkrankrom since fruit collection is dormant. Whereas no matured populations were found on farmlands at Benda Nkwanta and Nkrankrom, 20% of stands at Benda were matured (Table 3.1).

Associated trees/shrubs

With regard to associated tree/shrub species, those mentioned by participants within the three communities include pioneer secondary forest species such as *Macaranga barteri* (Opam), *Musanga cecropioides*, *Cecropia peltata* (Odwuma), *Rauvolfia vomitoria* (Kakapenpen) and *Uapaca* spp (Kontan). Other species such as *Cola nitida* (Bese), *Rufus rufus* (raffia), Rattan (*Calamus* spp) and non-woody weed *Chromolaena odorata* (Acheampong) have also been identified growing in association with *T. daniellii* patches.

Table 3.2. Field identified tree/shrub species associated with *T. daniellii* stands

Communities	Scientific name	Local name	Tree heights (m)	Diameter at breast height (cm)
Benda	*Musanga cecropioides*	Odwuma[1]	24.5	18.0
	**Alchornea cordifolia*	Gyama[1]	4.1	4.8
Benda Nkwanta	*Antiaris toxicaria*	Kyenkyen[1]	52.0	23.0
	Funtumia elastica	Fruntum[1]	16.0	6.7
	Albizia zygia	Okoro[1]	28.0	29.7
	**Alchornea cordifolia*	Gyama[1]	6.8	5.1
Nkrankrom	*Musanga cecropioides*	Odwuma[2]	30.0, 24.4	15.3, 8.2
	Macaranga barteri	Opam/Epam[1]	15.0	18.6
	**Alchornea cordifolia*	Gyama[1]	6.2	10.1

Superscript numbers represent number of individual species identified

The presence of theses species in association with *T. daniellii* emphasizes the perception that most collections are currently done in either off reserves or disturbed forests/fallow lands.

Field identified tree/shrub species associated with *T. daniellii* stands in the three selected communities are presented in Table 3.2. Height of tree/shrub species ranged between 4.1 – 52.0 m whiles diameter at breast height ranged between 4.8 – 18.0 cm. *Alchornea cordifolia* (Gyama) was the only species identified within all *T. daniellii* stands.

3.3.5 Potential for cultivation or integration

The potential for cultivation or integration of *T. daniellii* into farming systems is presented in a matrix in Figure 3 based on factors classified as strengths (S), weaknesses (W), opportunities (O) and threats (T) (SWOT). Three main factors were considered as strengths that could promote or facilitate the cultivation of *T. daniellii*. Firstly, majority of discussants revealed that *T. daniellii* stands occur in several areas unexploited. This is a strong indication that supplies from natural sources can continuously sustain market demand within the short to medium term before a shift towards dependence on cultivated stands. Availability of such stands could also serve as sources for germplasm collection for *T. daniellii* propagation materials. Furthermore, the availability of thaumatin processing plant at Samreboi and ready market for collected fruits serve as a source of guarantee to farmers willing to cultivate *T. daniellii*. One significant factor that could facilitate future cultivation of *T. daniellii* is the high interest expressed by farmers towards its cultivation.

Strengths:

1. Availability of natural stands to supply propagating materials or fruits
2. Availability of processing facility and ready market for collected fruits as well as finished products.
3. High interest among farmers to cultivate *T. daniellii*.

Weaknesses:

1. Inability of natural stands to produce enough fruits and longer fruiting duration.
2. High cost of transporting collected fruits to buying centres.
3. Lack of storage facilities or preservation methods for fruits collected each week.
4. Dearth of information on agronomic and management practices or appropriate land use system.

Opportunities:

1. Capacity to produce enough quality planting materials from available germplasms.
2. Develop agronomic practices for its cultivation or integration into recommended farming systems through research.
3. Enhanced interest in fruit collection or cultivation through increased purchase price and organized markets.

Threats:

1. Decline in the *T. daniellii* population through expansion of cocoa farms could impact negatively on future fruit collection and supplies.
2. Declining interests among collectors due to low prices, high transportation costs and lack of storage facilities for collected fruits.

Figure 3. SWOT matrix assessing the potential for cultivation or integration of *T. daniellii* into farming systems

Irrespective of the above factors, other factors termed weaknesses could hinder the cultivation of *T. daniellii*. Poor and long fruiting duration of natural stands, usually after two years, could discourage cultivation using propagating materials from such sources. Moreover, the high cost of transporting fruits to buying centres also discourages collectors who fail to gather enough fruits. Aside these, fruit collectors complain about lack of storage facilities or preservation methods for fruits collected since most fruits collected rot within a week of collection. Also, the low level of agronomic information needed to effectively cultivate *T. daniellii* can retard efforts towards encouraging its cultivation. Owing to these, farmers who are uncertain about the fruiting patterns of stands could feel insecure to cultivate *T. daniellii*.

Notwithstanding these weaknesses, opportunities exist for the production of quality planting materials as well as the development of agronomic or management practices for recommended agroforestry systems. Purchase prices can be increased to encourage farmers to cultivate it for additional income. New marketing schemes could also be developed to facilitate the collection and purchasing of fruits.

Considering all these factors, some major threats to the cultivation or integration of *T. daniellii* into farming systems include the decline and possible extinction of natural populations. This could be a setback to germplasm collection and subsequent production of quality propagules. Other threats include; the declining interests among collectors due to the current low purchasing prices, high transportation costs and lack of storage facilities for collected fruits.

3.3.6 Soil properties and foliar nutrient relationships

3.3.6.1 Soil chemical properties

Selected soil chemical properties within the upper 0 – 30 cm depth of profile differed significantly ($P < 0.001$) among sites for all parameters except Na (Table 3.3). The pH of soils at Benda Nkwanta (5.30) were significantly ($\alpha = 0.05$) less acidic than that of Benda (4.77) and Nkrankrom (4.10). Similarly, total base saturation of soils at Benda Nkwanta (87.53%) were significantly ($\alpha = 0.05$) higher compared to Benda (82.03%) and Nkrankrom (65.07%). Exchangeable acidity was significantly higher for soils at Nkrankrom (9.10 ppm) than Benda (7.99 ppm) and Benda Nkwanta (5.60 ppm) (Table 3.3).

However, comparable available P were obtained for soils at Nkrankrom and Benda Nkwanta and were significantly ($\alpha = 0.05$) lower than soils at Benda. Similarly, Magnesium in soils at Nkrankrom (3.79 ppm) and Benda (4.05 ppm) were significantly ($\alpha = 0.05$) lower values than soils at Benda Nkwanta (8.68 ppm) (Table 3.3).

Soil N did not differ significantly ($\alpha = 0.05$) between Benda and Benda Nkwanta but were significantly ($\alpha = 0.05$) lower compared to Nkrankrom (Table 3.3). Soil K, Ca, total exchangeable bases (TEB) and effective cation exchange capacity (ECEC) did not differ significantly ($\alpha = 0.05$) between Benda and Benda Nkwanta but were significantly ($\alpha = 0.05$) higher than Nkrankrom (Table 3.3).

Table 3.3. Selected soil chemical properties (0 – 30 cm) of *T. daniellii* stands from three sites

				[†]Sites				
Soil properties	DF	F value	Pr-value	Nkrankrom	Benda	Benda Nkwanta	Mean	Rank/Grade
pH 1:1 H_20	2	244.0	0.0000***	4.10^{c} (0.06)	4.77^{b} (0.04)	5.30^{a} (0.00)	4.72 (0.05)	Acidic -Very acidic
N (ppm)	2	28.7	0.0008***	1900.00^{a} (81.65)	1433.3^{b} (66.66)	1233.30^{b} (66.67)	1522.2 (90.26)	Moderate
Available P (ppm)	2	156.0	0.0000***	1.25^{b} (0.16)	4.47^{a} (0.16)	0.83^{b} (0.16)	2.18 (0.23)	Low
K (ppm)	2	52.0	0.0002***	2.53^{b} (0.11)	4.87^{a} (0.11)	5.07^{a} (0.30)	4.16 (0.28)	Low - moderate
Ca (ppm)	2	65.9	0.0001***	9.80^{b} (0.90)	26.70^{a} (0.00)	24.93^{a} (2.50)	20.48 (1.62)	Low
Mg (ppm)	2	39.0	0.0004***	3.79^{b} (0.28)	4.05^{b} (0.38)	8.68^{a} (0.53)	5.51 (0.62)	Low
Na (ppm)	2	0.12	0.8882^{ns}	0.84^{a} (0.04)	0.88^{a} (0.04)	0.88^{a} (0.10)	0.86 (0.09)	-
Total exchangeable bases (TEB)	2	63.3	0.0001***	16.96^{b} (0.89)	36.50^{a} (0.41)	39.56^{a} (2.48)	31.01 (2.18)	-

Table 3.3. Continued

Soil properties	DF	F value	Pr-value	Sites[†] Nkrankrom	 Benda	 Benda Nkwanta	Mean	Rank/Grade
Exchangeable Acidity (Al+H)	2	96.2	0.0002***	9.10 ^{a} (0.43)	7.99 ^{b} (0.08)	5.60 ^{c} (0.03)	7.56 (0.36)	-
ECEC (ppm)	2	61.1	0.0003***	26.06 ^{b} (1.30)	44.50 ^{a} (0.36)	45.15 ^{a} (2.89)	38.57 (2.31)	Moderate
Total Base Saturation (%)	2	636	0.0000***	65.07 ^{c} (0.43)	82.03 ^{b} (0.32)	87.53 ^{a} (0.69)	78.21 (0.71)	-
Organic Matter (%)	2	90.1	0.0000***	2.93 ^{a} (0.02)	2.16 ^{b} (0.00)	2.16 ^{b} (0.08)	2.41 (0.07)	Moderate

*** Significant at 0.001 probability level. ^{ns} not significant

[†]Means with different superscript alphabets in a row are significantly different ($\alpha = 0.05$) using Tukey's separation technique

Rank/grade as determined by Soil Research Institute, Kumasi Ghana, - Rank/grade unavailable

Numbers in parenthesis represent standard error of means

On the contrary, Nitrogen (1900 ppm) was significantly ($\alpha = 0.05$) higher at Nkrankrom compared to Benda (1433.3 ppm) and Benda Nkwanta (1233.3 ppm). Also, significantly ($\alpha = 0.05$) higher organic matter were recorded at Nkrankrom whereas Benda Nkwanta and Benda recorded the same values. On the contrary, Na did not differ significantly ($\alpha = 0.05$) among sites (Table 3.3).

Rankings provided by Soil Research Institute, CSIR, showed that pH (4.1 – 5.3) from sites ranged between very acidic or acidic suggesting that *T. daniellii* thrives on soils which do not fall within the reported pH range (5.5 – 7.5) of most cultivated soils. Ranges of effective cation exchange capacity (ECEC) (26.06 – 45.15 ppm), exchangeable K (2.53 – 5.07 ppm), N (1900.0 – 1233.3 ppm) and organic matter (2.93 – 2.16%) were ranked moderate. Also, ranges of exchangeable Ca (9.80 – 24.93 ppm), Mg (3.79 – 8.68ppm) and available P (1.25 – 0.83 ppm) were ranked low (Table 3.3). Low availability of P confirms reports on tests done for most soils and may be attributed to the high acidity (Driscoll, 1990, Fitzpatrick, 1990). The general fertility trend is presented as Benda Nkwanta > Benda > Nkrankrom.

3.3.6.2 Soil physical properties

Bulk density

Soil bulk density did not differ significantly ($P > 0.05$) among sites. Bulk density of soils at Nkrankrom, Benda and Benda Nkwanta were 0.79 gcm^{-3}, 0.99 gcm^{-3} and 1.02 gcm^{-3} respectively. The bulk density values were within the reported range for most soils i.e.

1.0 – 2.0 gcm^{-3} which attests to the fact that the distribution of *T. daniellii* might be strongly linked to sites with desirable physical characteristics (Table 3.4).

Texture

Soil texture differed significantly ($P < 0.001$) among sites. Mean comparison of soil separates (Table 3.4) revealed that the proportion of sand was significantly ($\alpha = 0.05$) higher for soils at Benda Nkwanta (65.18%) than for both Benda (56.14%) and Nkrankrom (27.34%). However, silt proportions were significantly ($\alpha = 0.05$) higher for soils (55.32%) at Nkrankrom than 35.84% at Benda and 27.48% at Benda Nkwanta. Also, clay proportions of soils, 17.35% at Nkrankrom were significantly ($\alpha = 0.05$) higher than 8.02% at Benda and 7.35% at Benda Nkwanta. The lack of significant ($\alpha = 0.05$) differences between proportions of clay at Benda and Benda Nkwanta may suggest that soils could have been formed from the same parent materials or influenced by the same soil formation processes.

Soils supporting *T. daniellii* stands were mainly silt loam or sandy loam (Table 3.4). Fine – textured surface soils such as silt loams, clays and clay loams generally have lower bulk density than sandy soils. Solid particles of silt loams, clays and clay loam soils tend to be organized in porous grains or granules, especially if adequate organic matter is present. This condition assures high total pore space and low bulk density (Brady, 1990). With reference to the obtained results, soils at Nkrankrom were mainly silt loam with a significantly ($\alpha = 0.05$) high organic matter content than Benda and Benda Nkwanta (Table 3.4). This could have accounted for the lower bulk density (0.79 gcm^{-3}) at Nkrankrom.

Table 3.4. Selected soil physical properties (0 – 30 cm) of *T. daniellii* stands from three sites

Properties	DF	F value	Pr-values	†Sites			Mean
				Nkrankrom	Benda	Benda Nkwanta	
Bulk density (gcm^{-3})	2	1.19	0.366^{ns}	0.79 (0.14)	0.99 (0.09)	1.02 (0.10)	0.93 (0.16)
Soil separates (%)							
Sand	2	869	0.000***	27.34 ^{c} (0.98)	56.14 ^{b} (0.34)	65.18 ^{a} (0.40)	49.55 (0.95)
Silt	2	198	0.000***	55.32 ^{a} (1.39)	35.84 ^{b} (0.47)	27.48 ^{c} (0.97)	39.55 (1.43)
Clay	2	105	0.000***	17.35 ^{a} (0.67)	8.02 ^{b} (0.01)	7.34 ^{b} (0.66)	10.9 (0.77)
Textural class				Silt loam	Sandy loam	Sandy loam	

*** significant at 0.001 probability level, ^{ns} not significant at 0.05 probability level

†Means with different superscript alphabets in a row significantly differ (α = 0.05) using Tukey's mean separation technique

Parenthesised numbers represent standard errors of means

3.3.6.3 Foliar Nutrients concentration

Foliar N, P, K and Mg were not similar ($P < 0.05$) among sites. However, foliar Ca differed significantly ($P < 0.05$) among sites (Table 3.5). Generally, the mean foliar nutrients from all sites followed a similar pattern in an increasing order which is a deviation from Ca < Mg < P < K < N as reported for most crops (Motsara and Roy, 2008). Comparatively, foliar nutrient concentrations of P have been reported to be lowest in species naturally found in wet evergreen forest zone of Ghana (Veenendal *et al*., 1996). In contrast, foliar Ca was significantly ($\alpha = 0.05$) lower for Nkrankrom (1900.00 ppm) than Benda (2166.70 ppm) which was similar to Benda Nkwanta (2000.00 ppm) (Table 3.5).

The levels of N, P, K, Ca, Mg in *T. daniellii* foliage are within the optimal range of nutrients in plants (Motsara and Roy, 2008) and possibly depict the efficiency of uptake of these nutrients by *T. daniellii*. The result obtained is inconsistent with similar studies conducted on other plants. In South-western Australia, a survey on selected nutrient concentration in the shoots of plants was reported in the order: N > K > Ca > Mg > P (Foulds, 1993). Among orchards, foliar nutrients decreased in the order: N > Ca > K > P > Mg > K (Zatylny and ST-Pierre, 2006). Similarly, studies on mean foliar macronutrients of *Quercus robur* from two different sites followed a sequence in the order of magnitude: N > K > Ca > P > Mg (Dı´az-Maroto *et al*., 2009).

Table 3.5. Selected foliar nutrients of *T. daniellii* stands from three sites

				Sites			
Nutrients (ppm)	DF	F value	Pr-value	Nkrankrom	Benda	Benda Nkwanta	Mean
N	2	2.72	0.1442^{ns}	21933.00	28367.00	23567.00	24622
				(1166.70)	(2992.49)	(1419.35)	(2867.1)
P	2	0.17	0.8503^{ns}	1733.30	1666.70	1733.30	1711.1
				(66.67)	(33.33)	(145.30)	(133.33)
K	2	3.95	0.0805^{ns}	5166.70	5300.00	6933.30	5800
				(819.24)	(152.75)	(202.76)	(700.26)
Ca	2	4.90	0.0548*	1900.00^{b}	2166.70^{a}	2000.00^{ab}	2022.2
				(0.00)	(33.33)	(100.00)	(86.07)
Mg	2	0.75	0.5114^{ns}	2666.70	2666.70	2300.00	2544.4
				(222.78)	(284.81)	(152.76)	(345.34)

Significant at 0.05 probability level, ^{ns} not significant at 0.05 probability level

Means with different superscript alphabets in a row are significantly different (α = 0.05) using Tukey's mean separation technique

Parenthesised numbers represent standard errors of means

Variations in results obtained from these studies could be attributed to factors such as site/soil conditions, differences in species requirements and uptake of specific nutrients as well as the nature and age of foliage sampled for analysis. Also, interactions between some absorbed nutrients influence the concentration of others within foliage tissues. For instance, as K uptake increases Mg uptake decreases (Zas, 2003) because the presence of K in plants affects the translocation of Mg from the roots to plant shoots (Mayland and Wilkinson, 1989).

Consistently high N values, 28367.00 ppm for Benda, 23567.00 ppm for Benda Nkwanta and 21933.00 ppm for Nkrankrom as compared to other nutrients were observed. Thaumatin is a protein sweetener and the high concentration of N in the foliage of *T. daniellii* could be an indicator of the significant role that N plays in thaumatin synthesis.

3.3.6.4 Correlation between selected soil and foliar nutrients

Linear regressions (Table 3.6) of soil and foliar N, P, K, Ca, and Mg of *T. daniellii* sites revealed no significant correlation between soil N and foliar N ($R^2 = 0.091$, P = 0.431). There was also no significant correlation between available soil P and foliar P ($R^2 = 0.030$, P = 0.653). Lack of a correlation between soil and foliar N and P, could probably be attributed to buffering between soil nutrient supply and foliar nutrient concentrations by belowground nutrient storage in plants and the use of organic N by plants (Bowman *et al*., 2003). Also, no significant correlation was found between exchangeable soil and foliar K ($R^2 = 0.20$, P = 0.226). Similarly, no significant ($R^2 = 0.12$, P = 0.361) correlation existed between exchangeable soil and foliar Mg (Table 3.6).

Table 3.6. Linear relationship between selected soil and foliar N, P, K, Ca, Mg from *T. daniellii* sites

Nutrient	Pearson correlation coefficient(r)	Coefficient of determination (R^2)	Standard errors	Probability values
Soil N(ppm) / Foliar N(ppm)	0.18	0.03	4413.45	0.637 ^{ns}
Available P(ppm) / Foliar P(ppm)	0.17	0.03	152.94	0.653 ^{ns}
Soil K(ppm) / Foliar K(ppm)	0.45	0.20	1080.14	0.226 ^{ns}
Soil Ca(ppm) / Foliar Ca(ppm)	0.70	0.49	112.7	0.035*
Soil Mg(ppm) / Foliar Mg(ppm)	0.35	0.12	410.72	0.361^{ns}

* significant correlation at 0.05 probability level, ^{ns}-not significant correlation at ($P < 0.05$)

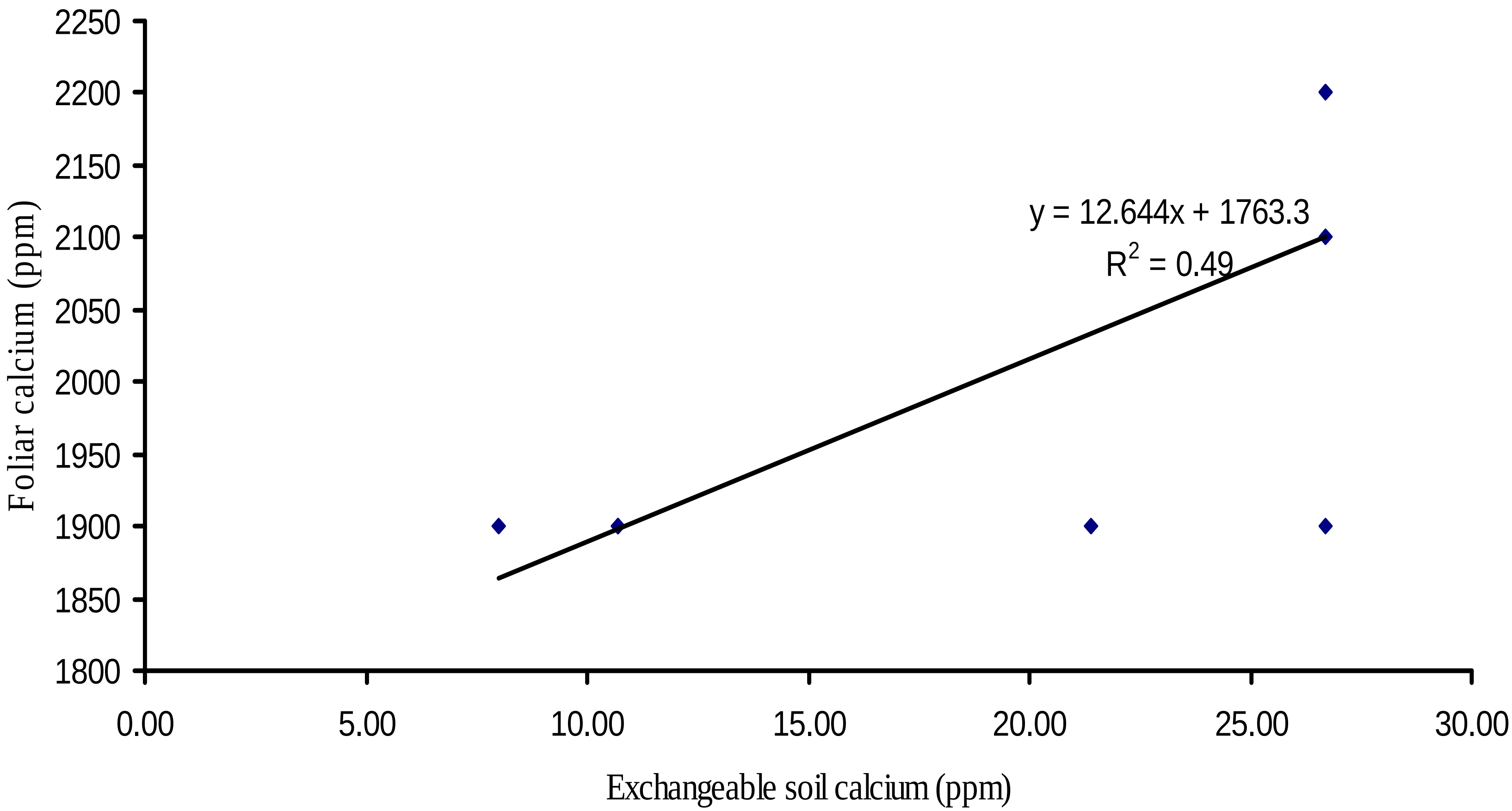

Figure 4. Linear relationship between soil exchangeable and foliar calcium concentration

In contrast, there was a significant ($R^2 = 0.49$, $P = 0.035$) positive correlation between exchangeable soil and foliar Ca (Table 3.6 and Figure 4). Foliar Ca and Mg levels have been identified to be dependent on their corresponding levels in soil than foliar K (Ouimet *et al*., 1995). The result of this study corroborates reports of consistent positive correlation between soil Ca and plant Ca (Cummings, 1989). This could be due to the immobility of Ca in plant cells once they are fixed and causes it to accumulate over time. This could account for the significant positive correlation reported between soil Ca and foliar Ca ($R^2 = 0.493$, $P = 0.035$) of *T. daniellii* sites (Table 3.6 and Figure 4).

Some studies that attempt to relate soil nutrient to foliage nutrients reported varied and inconsistent results. There was no relationship between topsoil and foliar N, P, K, Ca and Mg in *Quercus robur* forests (Díaz-Maroto *et al*., 2009). On the other hand, a significant positive correlation for K and P was obtained between foliage and soil nutrients in red spruce (Fernandez and Struchtemeyer, 1984). Also, significant relationships between foliar and 0 – 10 cm layer soil N, P, K, Ca and Mg have been reported among *P. radiata* (Davis *et al*., 2007). Both between and within species, nutrient differences have been attributed to the available concentrations in the rooting medium. However, there is often a great variation within species of concentrations of nutrients in relation to age, season and/or climatic gradients, soil type and nutrient gradients (Foulds, 1993). This could account for the inconsistent and varied reports for such studies.

Several factors operate to expedite or retard the release of nutrients to plants. Nutrient uptake for instance is influenced by a phenomenon called nutrient “antagonisms” in which some soil nutrients inhibit the uptake of some cations by plants (Brady, 1990; Osaki *et al*., 2003). Hence, the lack of significant correlation between soil and foliar N, P, K, Mg reported in this study could also be attributed to the above phenomenon.

Significant negative correlations have been reported between the concentrations of the major divalent cations Ca and Mg and K in the foliage of red spruce suggesting a possible antagonism between the mono- and divalent cations for uptake from the soil. Thus K uptake by plants could therefore be limited by high levels of Ca in some soils. Likewise, high K levels could limit the uptake of Mg even when significant quantities of Mg are present in the soil (Fernandez and Struchtemeyer, 1984; Brady, 1990).

Furthermore, the uptake of cations by plants is also influenced by its percentage saturation on the exchange complex. A high percentage saturation of a particular cation facilitates its easy and rapid displacement (Brady, 1990). In this study, soil Ca constituted more than half of exchange complexes: 54% at Nkrankrom, 77.95% at Benda and 58.45% at Benda Nkwanta and could have contributed to the significant positive correlation between soil and foliar Ca. For example, red spruce trees with the highest foliage concentrations of Ca were also noted to be growing on soils which were producing the best growth rates (Fernandez and Struchtemeyer, 1984).

3.4 Conclusions

The first objective of this study was to determine the distribution, major sources and constraints to fruit supply to the thaumatin industry outside forest reserves.

At the end, it was revealed that fruits supplied to the thaumatin extraction plant were predominantly supplied from seven communities within Aowin-Suaman and Wassa Amenfi West districts of the Western Region. The communities were Benda, Benda Nkwanta, Kokoase, Amoaku, Hiamatu, Samreboi and Aggreyso. This indicates that fruit collection is not a very popular activity despite the availability of ready market as well as its potential to provide alternative household incomes. The long duration and distances covered during fruit collection due to reduction in natural stands are major constraints to fruit collection and supply. Other constraints include high cost of transporting fruits to receiving station, decaying of fruits after few days of collection and the high incidence of animal/insect attacks on collectors. Therefore, the continuous reduction in the number of individuals who supply fruits over the years could be attributed to these constraints.

The second objective was to determine the level of *T. daniellii* cultivation, conservation and the potential for cultivation. It was found that there was no conservation and cultivation or integration of *T. daniellii* into farming systems in all the communities previously or currently involved in fruits supply. In addition to the keen interest expressed by farmers, a guarantee of good price, ready market, supply of seedlings and provision of agronomic information were identified as some fundamental factors that could enhance future cultivation or integration into other land uses. The lack of efforts at conservation or cultivation of *T. daniellii* in fruit supplying communities cast a doubt about future sustainable fruit supply from the wild as demand for thaumatin increases.

In terms of soil/site conditions that support natural stands of *T. daniellii*, soil chemical (pH, N, P, K, Ca, Mg, TBS, ECEC, organic matter, organic carbon) and physical (texture) properties significantly differed among sites except for Na and bulk density. Soils supporting *T. daniellii* stands studied were mainly silt loam or sandy loam with bulk density values within the reported range for most soils of 1.0 – 2.0 gcm^{-3}. Though *T. daniellii* thrived on acidic soils, foliar N, P, K, Ca, Mg concentrations were within acceptable levels and possibly depicts the efficiency of nutrient uptake. Therefore, *T. daniellii* can be said to be adaptive and can grow at different sites with varied chemical properties but desirable physical properties.

3.5 Recommendations

One major limitation to the study outcome on site conditions is its restriction to just three sites. This makes it difficult to make a firm conclusion with respect to site parameters for extrapolation to other sites supporting *T. daniellii* stands. It is therefore recommended that further studies be carried out on other sites supporting the growth of *T. daniellii* to assist in obtaining comprehensive information on site specific conditions that support optimum growth and fruit yields of *T. daniellii*.

Chapter 4

4.0 EFFECT OF FOLIAGE HARVESTING ON THE GROWTH AND YIELD OF *Thaumatococcus daniellii*

Summary

This experiment was conducted at Oda-Kotoamso (N 05º 52□, W 002º 29□) in the Western Region of Ghana. The objectives were to determine foliage harvesting effects on *T. daniellii* fruit yield (number and weight) over 64 weeks, flower production over 12 weeks and specific leaf area at week 64. The potential incomes that could be obtained from leaf and fruit collection were also determined. A randomized complete block design with three harvest treatments plus a control was used. Treatments involved harvesting petioles with leaves and maintaining a specified population per plot at 16 weeks interval. The percentage foliage harvest treatments were: No harvesting (Control), 25%, 50% and 75%. This study revealed that foliage harvest significantly ($P < 0.001$) influenced flowering. Mean number of flowers of the harvest levels were: Control - 18 > 25% - 6 ≥ 50% - 1 ≡ 75% - 0. Foliage harvest also significantly influenced fruit number. No harvest treatment produced significantly high number of fruits (11458/ha) compared to 8958/ha for 25%, 4792/ha for 50% and 4583/ha for 75% harvested treatment. Total fruit weight was not influenced by foliage harvest and ranged between 59.7 - 127.9 kg/ha. No significant differences in specific leaf area were obtained at week 64 for all treatments. Specific leaf area ranged between 143.87 cm ^{2}g $^{-1}$ and 148.93 cm ^{2}g $^{-1}$. This could indicate a high compensatory growth of *T. daniellii* in response to foliage harvest. For both fruit and leaf collection, the highest total income was GH ¢ 24411.36 for 50% followed by GH ¢ 17480.40 for 75%, GH ¢ 15640.33 for 25% harvest treatment and GH ¢ 153.48 for the no harvest treatment. The results suggest that management of *T. daniellii* for both leaf and fruit collection could be more beneficial than for sole fruit collection.

4.1 Introduction

The gregarious nature of *Thaumatococcus daniellii* leads to the formation of dense stands that form closed canopy beneath the forest floor. This could lower light penetration to the base of the plant where flowers are borne and reduce fruit yield. *Thaumatococcus daniellii* is known to bear about 10 - 12 flowers with only 2 and rarely 3 - 4 maturing to form fruits and that the role of light regimes in flowering is not known (Yeboah *et al*., 2003). It has therefore been proposed that one way of manipulating light penetration to improve yield of *T. daniellii* stands is through cautious harvesting of ‘extra’ leaves. Studies on orchards have shown that harvesting most matured leaves can increase yield. This is because extra leaf area does not necessarily result in an increase in productivity and that old leaves are less efficient in photosynthesis. Therefore, by removing these leaves, new and more efficient leaves can grow (Rayburn, 1993).

Thaumatococcus daniellii can be exploited for its foliage and fresh fruits. However, it has been suggested that foliage removal impacts negatively on growth and fruiting without enough scientific information on the extent to which foliage harvesting affect fruit yields. Studies have shown that plants may partially, fully or overcompensate for tissue loss. However, the mechanisms underlying compensation are not well understood and still need to be researched (Fang *et al*., 2006). Also, metabolic growth and reproductive responses to simulated herbivory can be much different from the response to natural herbivory (Baldwin 1990 cited by Schierenbeck *et al*. 1994).

To date, little is known about how *T. daniellii* foliage harvesting can affect its growth, flowering and fruiting. Economically, scant information is available on the potential income that could be obtained from exploiting *T. daniellii* for its foliage and fruits. The study aimed to develop an appropriate management practice that could ensure the derivation of multiple products from *T. daniellii* such as leaves for domestic sale or as fodder for farm animals without adverse effects on fruit production.

Specifically, the study determined the effect of foliage harvesting on flowering, fruit yield (number and weight) and specific leaf area. The potential incomes that could be obtained from leaf and fruit collection were also determined. The study hypotheses were that controlled foliage harvests would neither reduce flowering, fruit yield nor stimulate compensatory growth with respect to specific leaf area of *T. daniellii*. It was also hypothesized that management of *T. daniellii* stands for both leaf and fruit collection could be more profitable than for sole fruit collection.

4.2. Materials and Methods

4.2.1 Site description

The experiment was carried out at Oda-Kotoamso (N 05° 52′, W 002° 29′) a town located at about 10 km North of Asankragua, the district capital of Wassa-Amenfi West in the Western Region of Ghana under a mixed stand of tree plantation. The area lies in the hot humid tropical rain forest zone with an annual rainfall between 1400 – 2000 mm. There are two distinct rainy seasons from April to July and from September to November. The highest rainfall is recorded in June and July. There is a short period of dry season from December to March. A dry easterly wind, the Hamattan blows in January and February. The average annual temperature is 26°C. The plantation consists of several species including *Entandrophragma angolense*, *Ceiba spp*, *Miliacia excelsa*, *Terminalia superba*, *Khaya ivorensis*, *Khaya senegalensis* and *Antrocaryon micraster*. The crown diameter of the stand ranged from 2.0 m – 17.0 m. Also, diameter at breast height and plant height ranged from 0.12 m – 0.45 m and 17.0 m – 57.0 m respectively.

4.2.2 Experimental design

Plots of dimension 3 m × 4 m (12 m^2) were laid in 6 year old established stands of *T. daniellii* under the mixed stand of trees in November, 2009. The experimental set up was a randomized complete block design with three harvest treatments plus a control. There were four treatment blocks. Plots were thinned to uniform petiole population of 142 before the treatments were imposed. Treatments involved harvesting petioles with leaves and maintaining a specified population per plot out of 142 at 16 weeks interval for 64 weeks. The percentage foliage harvest treatments with the remaining population after harvest were: T_1 = No harvesting, T_2 = 25% (106), T_3 = 50% (71) and T_4 = 75% (36).

4.2.3 Data collection

Data was collected on fresh weight of harvested petioles with leaves out of the 142 petioles, fruit number and fruit fresh weight from November, 2009 – February, 2011 (64 weeks) at 16 weeks interval. Number of flowers per treatment plot was monitored over 12 weeks from November, 2010 to February, 2011 between weeks 48 and 64 at 3 weeks interval.

For specific leaf area (SLA) determination, 10 uniformly sized leaves were harvested from each plot at week 64. The leaf area of each leaf was determined using the ADC BioScientific Leaf Area Meter. The leaves were then oven dried at 60 ºC for dry weight determination. Average leaf area and dry weight per treatment were then calculated. Specific leaf area was calculated using the formula (Gunn *et al*., 1999) below:

$$\text{Specific Leaf Area (SLA)} = \frac{\text{Average leaf area (cm}^2\text{)}}{\text{Average leaf dry weight (g)}} \qquad \textit{Eqn. 4.1}$$

4.2.4 Data analyses

Data obtained on total fruit number and fruit fresh weight per plot over 64 weeks was converted to per hectare and subjected to analysis of variance. Total number of flowers over 12 weeks and specific leaf area at week 64 were subjected to analysis of variance. All analyses and mean comparisons were done with the aid of statistical software package, Statistix 8 (United States Department of Agriculture / Natural Resources Conservation Service, 2007). Also, total fresh leave weight and fruit fresh weight as well as estimated incomes that could be obtained were tabulated. Percentage reduction in fruit yield was calculated using the formula below

$$\text{Percentage fruit yield reduction} = 100\% - \frac{[\text{Total fruit yield for harvest treatment} \times 100]}{[\text{Total fruit yield for control}]} \qquad \textit{Eqn. 4.2}$$

4.3 Results and discussion

4.3.1 Flower production

Foliage harvest had significant ($P < 0.001$) effect on flowering over 12 weeks. Significantly ($\alpha = 0.05$) higher number of flowers, 18 was produced for no harvest treatment compared to 6 for 25%, 1 for 50% and 0 for 75% harvest treatments (Table 4.3). Flower production decreased over time from November - February (Figure 4.1). This could indicate that flowering peaks in the dry season and decreases towards the onset of the rainy season. Responses to herbivory increase with increase frequency of defoliation and the removal of *Primula veris* leaves resulted in a decrease in flowering for 2 years (Whigham and Chapa, 1999). In this study, the control treatment consistently produced flowers over the 12 weeks and no treatment stand recorded consistent flower production.

Similarly, a study of *Tipularia discolor* showed that 100% and 50% leaf removal resulted in a cessation of flowering within 1 year, a progressive decline in below-ground biomass, and increased mortality (Whigham, 1990 cited by Whigham and Chapa, 1999). This study reveals that 75% foliage harvesting resulted in no flower production over the 12 weeks (Figure 4.1). Even though flowering was observed for 25% (6) and 50% (1) foliage harvest, fruit set was zero. This could be due to high rate of abscission among young flowers, limited pollination or limited nutrients during the dry season (November – February) (Pandey and Sinha, 2006) on such stands.

Table 4.3 Effect of foliage harvest on flowering over 12 weeks

				[†] Treatment means				
Parameter	DF	F value	Pr-values	Control (T_1)	25% (T_2)	50% (T_3)	75% (T_4)	Mean
Number of flowers	3	24.04	0.000***	18^a (8.87)	6^b (1.58)	1^b (0.76)	0^b (0.00)	6 (2.15)

*** Significant at 0.001 probability levels

Numbers in a row with different alphabets are significantly different at α = 0.05, [†] Values compared are to the nearest whole number

Parenthesized numbers represent standard errors of means

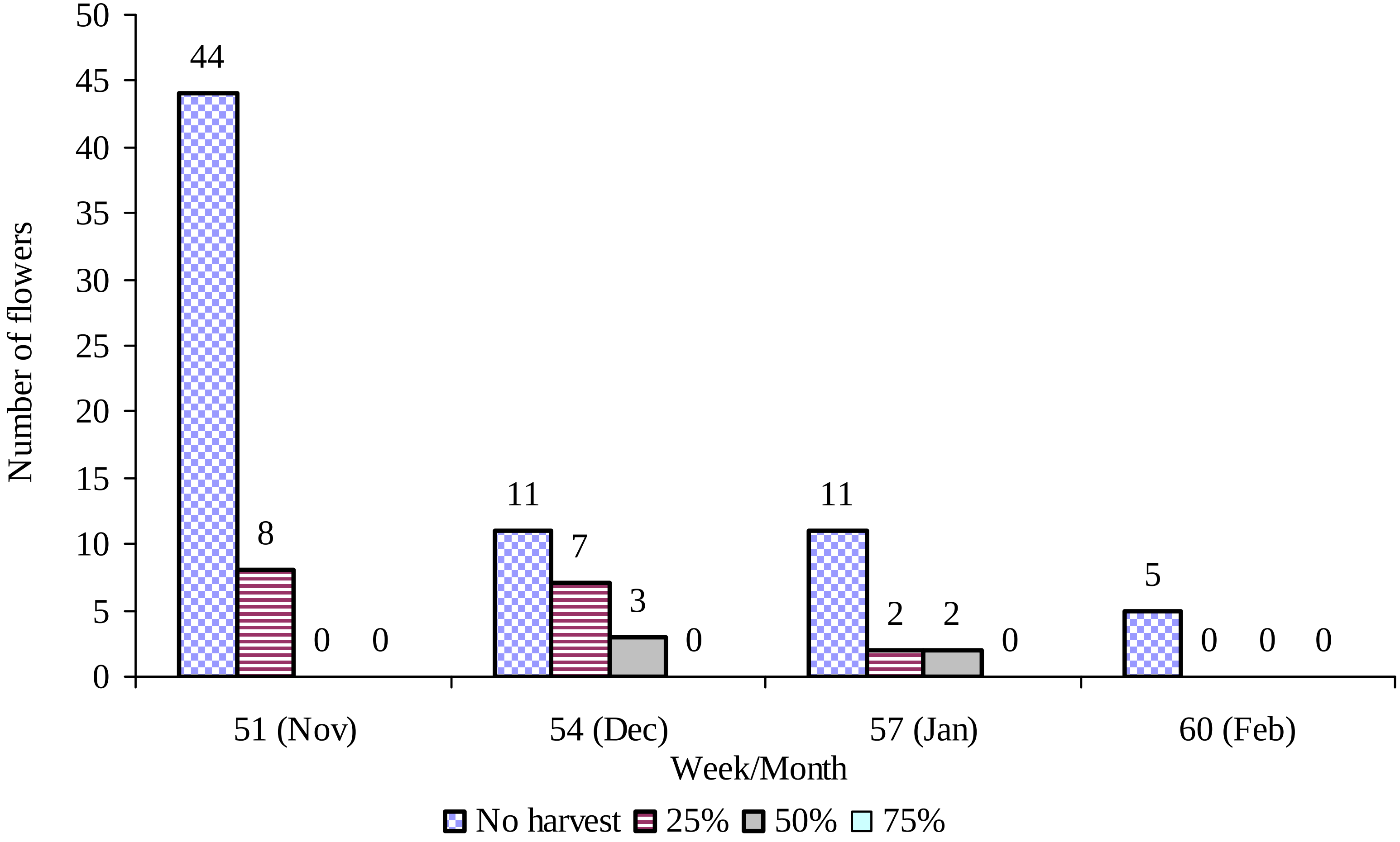

Figure 4.1 Pattern of flowering from week 51 - 60 in response to foliage harvesting

4.3.2 Effects of foliage harvest on total fruit number and weight

Foliage harvest significantly ($P < 0.05$) influenced fruit number over 64 weeks (Table 4.4). No harvest treatment significantly ($\alpha = 0.05$) produced the highest number of fruits (11458/ha). Fruit numbers, 11458/ha for no harvest and 8958/ha for 25 % harvest treatment were similar but were significantly ($\alpha = 0.05$) higher than 4792/ha for 50 % and 4583/ha for 75 % harvest treatment (Figure 4.2). Contrastingly, foliage harvest revealed no significant ($P > 0.05$) effect on total fruit weight over 64 weeks (Table 4.3). Mean fruit weight of the various harvest levels were 127.90 kg/ha for no harvest, 86.65 kg/ha for 25%, 63.91 kg/ha for 50% and 59.72 kg/ha for 75% harvest treatments.

Generally, as foliage harvest intensity increased, fruit number reduced (Figure 4.1). A report indicated that plants stressed by defoliation may react by decreasing seed production (Lee and Bazzaz, 1980). As such, severe aboveground biomass damage of ruderal herb *Barbarea vulgaris* resulted in seed number decline with increasing severity of injury (Martínková *et al*., 2008). However, a study on *Caragana korshinskii* reported compensation for fruit production after above-ground partial shoot removal resulted in increased fruit set, decreased fruit abortion, increased seed number per pod and higher individual seed biomass. These responses were achieved by (1) drawing upon more non-structural carbohydrate from roots to supply flower bud development and the flush of new foliage; (2) supplying more photosynthetic assimilation to fruit development owing to increases in leaf-level photosynthetic rates (Fang *et al*., 2006).

Table 4.4 Effect of foliage harvest on total fruit number and total fruit weight over 64 weeks

Parameter	Degree of Freedom	F value	Pr-value	Mean	Coefficient of Variation
Fruit number / ha	3	4.42	0.036*	7447.80 (2252.9)	42.78
Fruit weight (Kg / ha)	3	2.15	0.163^{ns}	84.55 (30.10)	50.34

*Significant at 0.05 probability level, ^{ns} Not significant at 0.05 probability level
Numbers in parenthesis represent standard errors of means

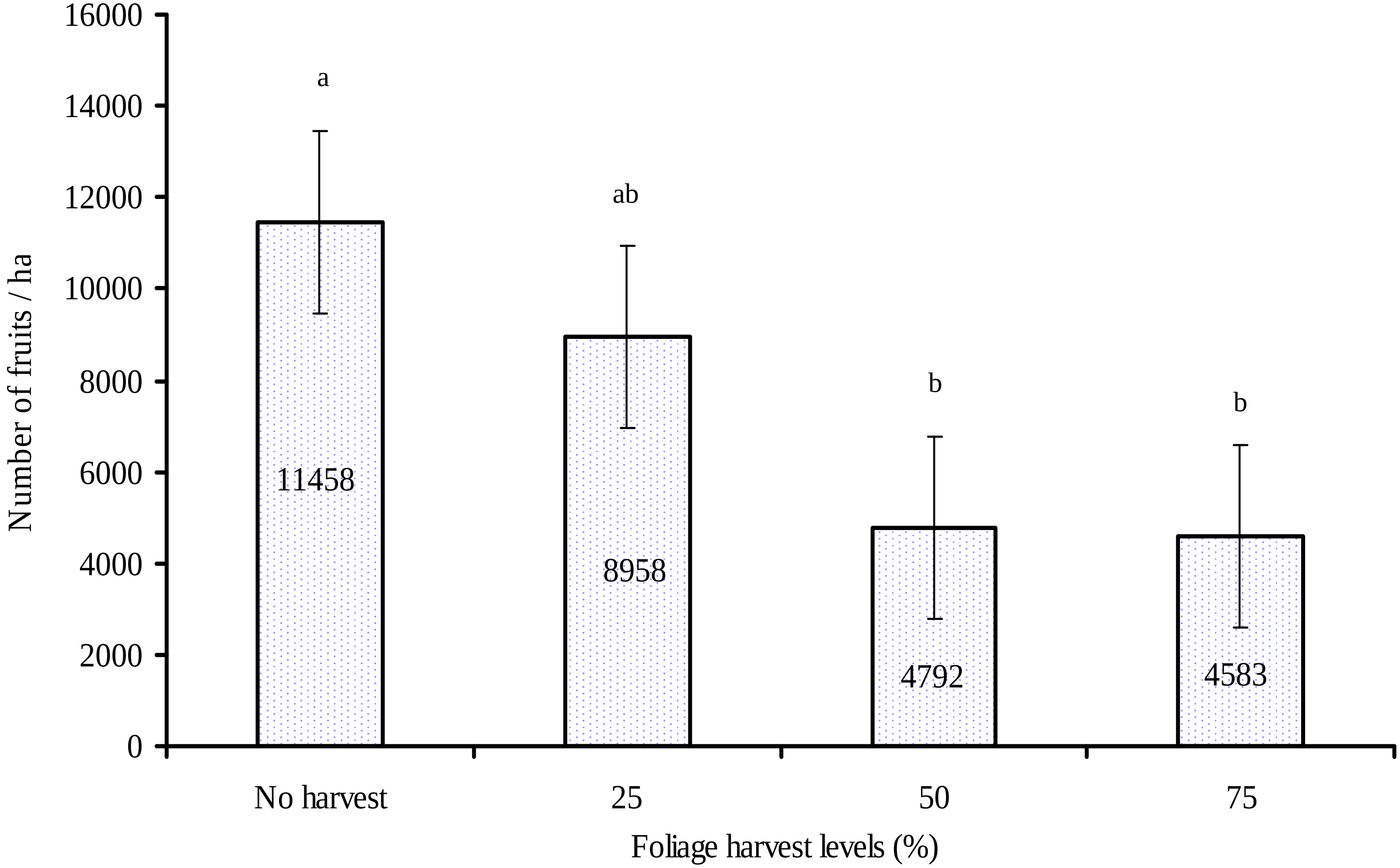

Figure 4.2 Effect of foliage harvest on total fruit number over 64 weeks

Foliage harvest could enhance light penetration to the base of *T. daniellii* stands. However, this reduces leaf area (Hay and Walker, 1992) and could cause a decline in photosynthate production. With the exception of the control treatment, 25%, 50% and 75% foliage harvest treatments experienced rapid shedding of matured leaves whiles new ones developed. However, newly expanded leaves compete with older leaves for solar radiation, mineral nutrients and assimilate such that leaves begin to senesce in sequence according to age (Hay and Walker, 1992). Such young leaves, possibly, invest more resources into vegetative growth to the detriment of fruit production on harvested stands. Thus, the apparent availability of enough matured foliage on control treatments could have facilitated the capture of light for synthesis and photosynthate accumulation needed for fruiting. This could explain why control stands significantly produced more fruits than harvested stands.

Harvesting of leaves may have a negligible effect on exploited plant population if: (i) individual plants are not killed in the process; (ii) a sufficient number of healthy leaves are left on each plant for photosynthesis; (iii) the reproductive structures and apical buds are not damaged, and (iv) sufficient time is allowed between successive harvests for the plant to produce new leaves (Ndangalasi *et al.,* 2007). Additionally, collecting too many leaves from an individual can reduce the number of new ones, and perhaps flowers and fruits, produced (Anderson, 1998). Results of this study suggest that, though individual plants were not killed, “high” foliage harvest (50% - 75%) probably reduced leaf population to the extent that only few matured leaves remained for photosynthesis. Furthermore, the harvesting could have caused extensive damage to reproductive structures for fruit production. In a related study, injury significantly affected seed production and also the life cycle of *Barbarea vulgaris.* Seed production was lower in injured plants than in intact plants (Martínková *et al*., 2008).

Foliage harvesting had no significant effect on fruit weight though fruit number was significantly affected. This could imply that though control plots produced more fruits, the sizes of fruits could have been smaller than other harvested treatments. A related study of harvest regimes on five varieties of summer squash (*Cucurbita pepo* L.) reported significant influences on fruit size. One variety produced bigger fruits in the rainy season when leaves were harvested compared to no leaf harvest. This was attributed to high disease incidence in the rainy season resulting in diseased older leaves in the 'no harvest' compared with several new leaves that emerged in the 'leaf harvest,' which might have photosynthesized more efficiently than older diseased leaves (Yeboah *et al*., 2010). For *T. daniellii*, possible differences in fruit sizes could be due to increased demand to support varied populations. Hence, no harvest treatment, in addition to fruiting, could have also channelled more resources to support physiological activities of large populations.

4.3.3 Specific leaf area

Foliage harvest revealed no significant ($P < 0.05$) differences in treatment means with respect to specific leaf area (SLA) at week 64. Mean specific leaf area ranged between 143.87 cm ^{2}g $^{-1}$ and 148.93 cm ^{2}g $^{-1}$ (Table 4.5). Similarly, a study conducted on several plant species revealed no significant differences in SLA between recently matured leaves and older leaves (Poorter and De Jong, 1999).

Table 4.5 Effect of foliage harvest on specific leaf area at week 64

Parameter	DF	F value	P-values	†Treatment means				Mean
				Control (T_1)	25% (T_2)	50% (T_3)	75% (T_4)	
Specific leaf area (cm ^{2}g $^{-1}$)	3	0.86	0.498^{ns}	143.9 ^{a} (1.95)	144.4 ^{a} (3.17)	148.9 ^{a} (3.39)	148.5 ^{a} (1.45)	146.4 (4.09)

^{ns} not significant at 0.05 probability level

†Numbers in a row with different alphabets are significantly different at α = 0.05

Parenthesized numbers represent standard errors of means

Specific leaf area is the light-catching area deployed per unit of previously photosynthesized dry mass allocated and is a major contributor to resource capture, usage and availability (Vendramini *et al*., 2002). The partitioning of transport carbohydrate, storage carbohydrate and structural carbon between and within different leaves gives a basis for understanding changes in leaf weight and hence SLA of plants (Gunn *et al*., 1999). Hence, decrease in SLA has been associated with greater allocation of biomass to structural components of the leaf rather than metabolic components (Reich *et al*., 1998).

Specific leaf area also reflects expected return on previously captured resources (Wilson *et al*., 1999). In line with this, a study on *Lonicera japonica* indicated the allocation of more carbon to secondary leaves and stems due to unlimited herbivory. Therefore, total biomass accumulation and greater allocation to leaves and stems indicate a compensatory response by *Lonicera japonica*. Thus, plants usually compensate for defoliation by replacing leaf tissue, and changing intrinsic biomass allocation patterns (Schierenbeck *et al*. 1994). In a study on the response of two grass species to a gradient of defoliation intensities, from 0 to 100% aboveground biomass removal, plants showed the same aboveground growth regardless of defoliation intensity due to stimulation of relative growth rate by defoliation. Aboveground compensatory responses represent a key feedback process resulting in constant aboveground growth regardless of defoliation intensity (Oesterheld, 1992).

Therefore, lack of significant differences among harvest and no harvest treatments in specific leaf area of *T. daniellii* could suggest that harvested stands possibly supplied more photosynthate to leaf development owing to decreases in leaf-level photosynthetic rates whereas control treatments possibly invested in producing more flowers, fruits and below ground storage. Thus significantly higher number of flowers and fruits were obtained for no harvest treatments than harvested treatments.

However, the development and contribution of new photosynthetic active leaves on harvest stands aided in channelling more photosynthate into relatively low number of flowers produced. As a result, fruits produced on harvested stands could be larger or heavier than those for no harvest stands. This could account for the lack of significant differences in total fruit weight between harvested and no harvested stands.

4.3.4 Potential incomes from leave and fruit harvest

Fruit income

The potential income that could be generated from leave and fruit harvest over 64 weeks is presented in Table 4.6. Incomes from fruits increased with reduced foliage harvest intensity. Compared to the control, there was a 32.3% reduction in fruit yield for 25% foliage harvest, 50.0% reduction for 50% harvest and 53.3% reduction for 75% harvest.
In some varieties of summer squash (*Cucurbita pepo* L.), 2% – 45% reductions in fruit yield for ‘no leaf harvest’ and ‘leaf harvest’ treatments was similarly reported. For this study, no harvest stands of *T. daniellii* gave the highest fruit income of GH ¢ 153.48 but decreased to GH ¢ 103.98 for 25% and GH ¢ 76.69 for 50% harvests. The lowest income of GH ¢ 71.66 was obtained at 75% harvest (Table 4.6).

Table 4.6 Estimated incomes from fruit and leave harvest of *T. daniellii* stands over 64 weeks

Treatments	Total fruits (Kg / ha)	Fruit income @ GH ¢ 0.3 / Kg	Total harvested leaf (Kg / ha)	Leaf income @ GH ¢ 0.55 / 0.694 Kg	*Total income GH ¢ / ha
Control	511.60	153.48	0	0	153.48
25%	346.62	103.98	19,982.53	15,536.35	15,640.33
50%	255.64	76.69	31,298.75	24,334.67	24,411.36
75%	238.86	71.66	22,390.77	17,408.74	17,480.40

*Total income = Fruit income + leaf income, @ = at

GH ¢ = Ghana cedi, Kg / ha = Kilogram per hectare

Leaf income

While no income was generated for control stands from leaf harvest, the highest leaf income of GH ¢ 24,334.67 was obtained for 50% harvest over the 64 weeks. This suggests that 50% leaf harvest of stands could be sufficient to sustain enough leaf production over an extended period of time. Leaf income from 75% harvest stands, GH ¢ 17,408.4, was higher than GH ¢ 15,536.35 from 25% harvest treatments. However, 75% harvesting was detrimental to fruit production and resulted in the lowest income of GH ¢ 71.66 for fruit production (Table 4.6).

Total income

The highest total income was GH ¢ 24,411.36 for 50% harvest treatment followed by 75% and 25% harvest treatments with incomes of GH ¢ 17480.40 and GH ¢ 15,640.33 respectively. The lowest total income, GH ¢ 153.48 was obtained for the control due to lack of supplementary income from leaf harvesting (Table 4.6). The results suggest that management of *T. daniellii* for both leaf and fruit collection could be more economically beneficial than for sole fruit collection. This is because incomes that accrue from leaf harvest could compensate for incomes lost due to reductions in fruit yield.

4.4 Conclusions

This study was conducted on *T. daniellii* to determine the effect of foliage harvesting on flowering over 12 weeks, fruit yield (number and weight) over 64 weeks and specific leaf area at week 64. The study also determined the potential incomes that could be obtained from leave and fruit collection.

It was found that foliage harvest significantly influenced flowering. Mean number of flowers of the different harvest levels were: No harvest - 18 > 25% - 6 ≥ 50% - 1 ≡ 75% - 0. Thus, the hypothesis that foliage harvest does not affect flowering was rejected.

Foliage harvest also significantly influenced fruit number. No harvest stands produced significantly high number of fruits (11458/ha) compared to 8958/ha for 25%, 4792/ha for 50% and 4583/ha for 75% harvested stands. Therefore, the hypothesis that foliage harvest does not affect fruit number was rejected.

Total fruit weight was not influenced by foliage harvest. Mean fruit weights of the various harvest levels per hectare ranged 59.7 - 127.9 kg. Hence, the hypothesis that foliage harvest does not affect fruit weight was accepted.

No significant differences in specific leaf area were obtained at week 64 for all treatments. Mean specific leaf area ranged between 143.87 cm ^{2}g $^{-1}$ and 148.93 cm ^{2}g $^{-1}$. This could indicate a high compensatory growth of *T. daniellii* in response to foliage harvest. Therefore, hypothesis that foliage harvest does not stimulate compensatory growth was rejected.

For both fruit and leaf collection, the highest total income was GH ¢ 24411.36 for 50% followed by GH ¢ 17480.40 for 75% and GH ¢ 15640.33 for 25% harvest treatments. The lowest total income, GH ¢ 153.48, was obtained for the control due to lack of supplementary income from leaf harvesting. The results suggest that management of *T. daniellii* for both leaf and fruit collection could be more beneficial than for sole fruit collection.

4.5 Recommendations

This study tested the effects of three foliage harvest levels (25%, 50% and 75%) plus no harvest on the growth and yield of *T. daniellii*. Currently, information on other harvest levels and their effects on *T. daniellii* growth and fruit yield are unavailable. It is therefore recommended that further studies be conducted using different harvesting rates.

A major limitation to the study is that income projections are gross estimates based on the assumption of a ready market for both leaves and fruits. It does not take into consideration losses incurred through rejection of rotten fruit by buyers, drying of foliage as well as transportation costs. These, among other economic factors, when duly considered in a study can help ascertain the actual potential incomes that could be obtained through the exploitation of *T. daniellii* fruits and leaves.

Chapter 5

5.0 EFFECT OF SHADE AND SPACING ON THE GROWTH PERFORMANCE OF *T. daniellii* INTERPLANTED IN TREE STANDS

Summary

This experiment was conducted at the FRNR research farm (06º 41’N, 01º 37’W), Kumasi, Ghana to determine spacing and shade effects on survival, lamina length, lamina width, petiole length and number of tillers of *T. daniellii* over 40 weeks. Research plots of *T. daniellii* seedlings were established within stands of *Leucaena leucocephala*, *Senna* siamea and *Carapa procera.* A factorial experiment in a completely randomized design with two factors, shade and spacing, was used. There were three shade levels provided by tree stands: *Leucaena* (73%), *Senna* (86%), *Carapa* (98%) and four spacing treatments: 0.75 m × 0.75 m (VHD), 1.0 m × 0.75 m (HD), 1.0 m × 1.0 m (MD), 1.25 m × 1.25 m (LD). Shade significantly ($P < 0.001$) influenced survival, leaf sizes (lamina widths and lengths), petiole length and number of tillers. Ranking for survival were 71% for *Leucaena* > 60% for *Senna* > 20% for *Carapa*. Leaf sizes were also larger for 73% (width-17.6 cm, length-27.1 cm) than 86% (width-15.9 cm, length-25.2 cm) and 98% (width-11.4 cm, length-18.0 cm) shade levels. Similarly, significantly longer petioles, 43.6 cm, were obtained for 73% shade compared to 38.8 cm for 86% and 20.4 cm for 98% shade levels. Tillering decreased with increased shade and were 13 for 73%, 10 for 86% and 1 for 98% shade levels. Also, spacing significantly influenced leaf sizes and petiole lengths but had no significant effect on survival and tiller production at week 40. Leaf sizes were (width-15.4 cm, length-24.3 cm) for LD, (width-15.5 cm, length-23.2 cm) for VHD, (width-14.9 cm, length-23.8 cm) for HD and (width-14.0 cm, length-22.5 cm) for MD. Petiole lengths were 37.1 cm for VHD > 33.7 cm for LD ≡ 33.4 cm for MD ≡ 32.8 cm for HD spacing. These results suggest that high (98%) shading can be detrimental to the establishment of *T. daniellii* under tree stands and significantly reduce survival, tiller production and growth of planted seedlings regardless of the spacing.

5.1 Introduction

Several Agroforestry systems involve the growing of woody perennial and non-woody herbaceous plants on the same land unit at the same time such that the components share environmental resources including light. Light is a major morphogenic modifier which affects plant establishment, growth and development (Huxley, 1996; Poorter, 2001). Variation in morphological traits and photosynthetic potentials associated with light conditions can determine whole-plant function (Stephens *et al*., 2009). Therefore, there are ways in which woody and non-woody plants can be arranged spatially, and in various proportions, so as to incorporate both different planting densities and different levels of intimacy between the various plant components in Agroforestry systems (Huxley, 1996).

At the management level, plant growth and development including the period of growth, flowering and fruiting pattern are directly affected by density or spacing (Ozer, 2003). *Thaumatococcus daniellii* stands easily spread and close canopy which may prevent enough light from penetrating to the base of the plant where flowers and fruits are borne. Plant spacing influences stand closure. This ultimately determines plant density which is highly associated with yield potential and optimum plant density per unit area needed to determine maximum plant productivity. Additionally, plant yield is a function of inter and intra plant competition and there is considerable scope for increasing yield by adjusting plant population to an optimum level (Chandrasekaran *et al*., 2007).

Current plantations of *T. daniellii* in the Western Region have been established at a recommended spacing of 0.75 m × 0.75 m. However, few scientific studies have investigated how varied shading and spacing affect the growth of *T. daniellii* when interplanted in tree based systems. This research studied how the survival, lamina length, lamina width, petiole length and tillering of *T. daniellii* was influenced by shading and spacing under stands of *Leucaena leucocephala, Senna siamea* and *Carapa procera*. The hypotheses of the study were that survival, lamina length, lamina width, petiole length and tillering of *T. daniellii* were not dependent on shade and spacing conditions within stands of *L. leucocephala, S. siamea* and *C. procera*.

5.2. Materials and Methods

5.2.1 Site description

The research was conducted at the Faculty of Renewable Natural Resources (FRNR) research farm, Kumasi, Ghana. The study area lies between longitude 06º 41'N and latitude 01º 37'W with an altitude of 278 m above sea level. The area lies within the moist semi-deciduous forest zone of Ghana. The prevalent soil type is the Forest Ochrosols (Ferric Acrisol – FAO, 1976) and belongs to the Asuansi series which belongs to the Bomso / Nta-Offin association (Adu and Asiamah, 1992). Rainfall is bimodal with peaks in June and October separated by a distinct dry period from December to February. The mean annual rainfall ranges between 1,300 and 1,600 mm. The temperature ranges from 22° to 31°C with an average of 26 °C. Site vegetation was an open canopy secondary forest consisting of semi-deciduous tree and shrub species of the *Celtis-Triplochiton* association (Hall and Swaine, 1981). Previous land use was small scale agriculture with very short fallows or continuous cropping of maize, cassava and plantains.

Tree stands

Carapa stand was established in 1986 at a spacing of 5 m × 5 m. Current tree height and diameter ranged between 6.3 – 33.3 m and 6.3 – 42.3 cm respectively. Since its establishment, no harvesting has been done. *Leucaena leucocephala* and *Senna* siamea stands spaced at 1 m × 2 m and 2 m × 2 m, respectively were established in April 1988. Both stands were first harvested in 1990. *Leucaena* and *Senna* stands which cover 0.26 ha and 0.14 ha respectively were subsequently coppiced in 1992 after which sections of the stands were harvested in 1993 and 1994 for cultivation. These stands were further coppiced in 1995. The stem diameter range for *Leucaena* was 4.8 – 11.0 cm and 8.1 – 18.1 cm for *Senna*. Height ranged between 9.7 – 15.6 m for *Leucaena* and 22.2 – 28.3 m for *Senna*.

5.2.2 Experimental design

Research plots of dimension 4 m × 4 m (16 m^2) were established on 25th September, 2008 within stands of *Leucaena leucocephala*, *Senna* siamea and *Carapa procera. T. daniellii* seedlings were obtained from established stands at Samartex Timber and Plywood Company in the Western Region of Ghana. The experimental set up was a factorial in a completely randomized design with two factors (shade and spacing) and three replications (3 × 4 × 3). There were three levels of shade: 73%, 86% and 98% provided by *Leucaena*, *Senna* and *Carapa* stands respectively. The four spacing treatments with their respective plant populations were: Very high density (VHD) = 0.75 m × 0.75 m or 22,500/ha, High density (HD) = 1.0 m × 0.75 m or 18,750/ha, Medium density (MD) = 1.0 m × 1.0 m or 15,625/ha and Low density (LD) = 1.25 m × 1.25 m or 10,000/ha.

5.2.3 Data collection and analytical methods

Climatic data and shade percentages

Mean monthly rainfall, temperature and relative humidity data of study site during study period were obtained from the meteorological station of the Faculty of Agriculture, KNUST. Illumination for each stand was measured at ten different locations using the Extech light meter on 9th January, 2009. Average light measurement was then calculated for each stand. Total sun illumination was determined outside the stands. Percentage illumination within stands was then calculated using the formula below:

$$\frac{\text{Average illumination within stands}}{\text{Total sun illumination}} \times 100 \qquad \textit{Eqn. 5.1}$$

The shade percentage was calculated by subtracting percentage illumination from 100%.

Plant growth parameters

Data was collected on survival, lamina width, lamina length, petiole length and number of tillers at four weeks interval for 40 weeks from March to December, 2009. Survival was determined per head count of seedlings on each plot and subsequently converted to percentage. Lamina length was measured from tip to the base of the leaf and lamina width was measured at the widest extent of leaf. Petioles were measured from the base of the plant to the lower pulvinus.

Data obtained was subjected to analysis of variance and mean separation done using Tukey's separation techniques using the statistical package SAS (SAS Institute, 2007).

Analysis was based on mixed – model equation below.

$$y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \square_k + e_{ijk} \qquad \textit{Eqn. 5.2}$$

Where

y_{ijk} is the $(ijk)^{\text{th}}$ observation,

μ is the general mean,

α_i is the effect of the i^{th} level of factor A (shade),

β_j is the effect of the j^{th} level of factor B (spacing),

$(\alpha\beta)_{ij}$ is the $(ij)^{\text{th}}$ interaction effect of factors A and B,

$\square_k$ is the k^{th} replication effect, and

e_{ijk} is the random error component

Soil chemical properties

Three plots of dimension 1 m × 1 m were randomly located within Leucaena, *Senna* and *Carapa* stands and three soil sample cores were collected at two depths: 0 – 15 cm and 15 – 30 cm (3 × 3 × 2). Samples of the two soil depths from each stand were bulked and three sub-samples taken for analyses for soil pH, N, P, K, Ca, Mg, organic carbon and organic matter. Effective cation exchange Capacity (ECEC), total exchangeable bases (TEB) and percentage base saturation were also determined. All analyses were done at the (CSIR)-Soil Research Institute, Kumasi, Ghana. Results of soil chemical properties were analyzed using a Completely Randomized Design (CRD) based on the fixed effect model equation 5.3.

$$y_{ij} = \mu + \tau_i + \varepsilon_{ij} \qquad \textit{Eqn. 5.3}$$

Where

y_{ij} is $(ij)^{th}$ observation,

μ is the overall mean,

τ_i is the i^{th} treatment effect and

ε_{ij} is the random error component

Analysis of variance (ANOVA) and mean comparison was done using Tukey's separation techniques with the aid of statistical software, Statistix 8 (USDA/NACS, 2007).

5.3. Results and discussion

5.3.1 Climatic conditions of study site

The mean monthly temperature, humidity and rainfall of study site during data collection period (March – December, 2009) are presented in Figure 5.1. An average temperature of 26.9 ºC was recorded over the 40 weeks study period. Minimum and maximum temperatures of 25.2 º C and 28.1 º C were recorded in August (Week 20) and March (Week 4) respectively. Average rainfall of 4.37 mm per month was recorded during the study period (March – December). Minimum and maximum rainfall of 0.6 mm and 12.3 mm were recorded in August (Week 24) and June (Week 16) respectively. Average relative humidity of 85.9% was recorded over the 40 weeks. Minimum and maximum relative humidity of 81.0% and 90.0% were recorded in May (Week 12) and August (Week 24) respectively.

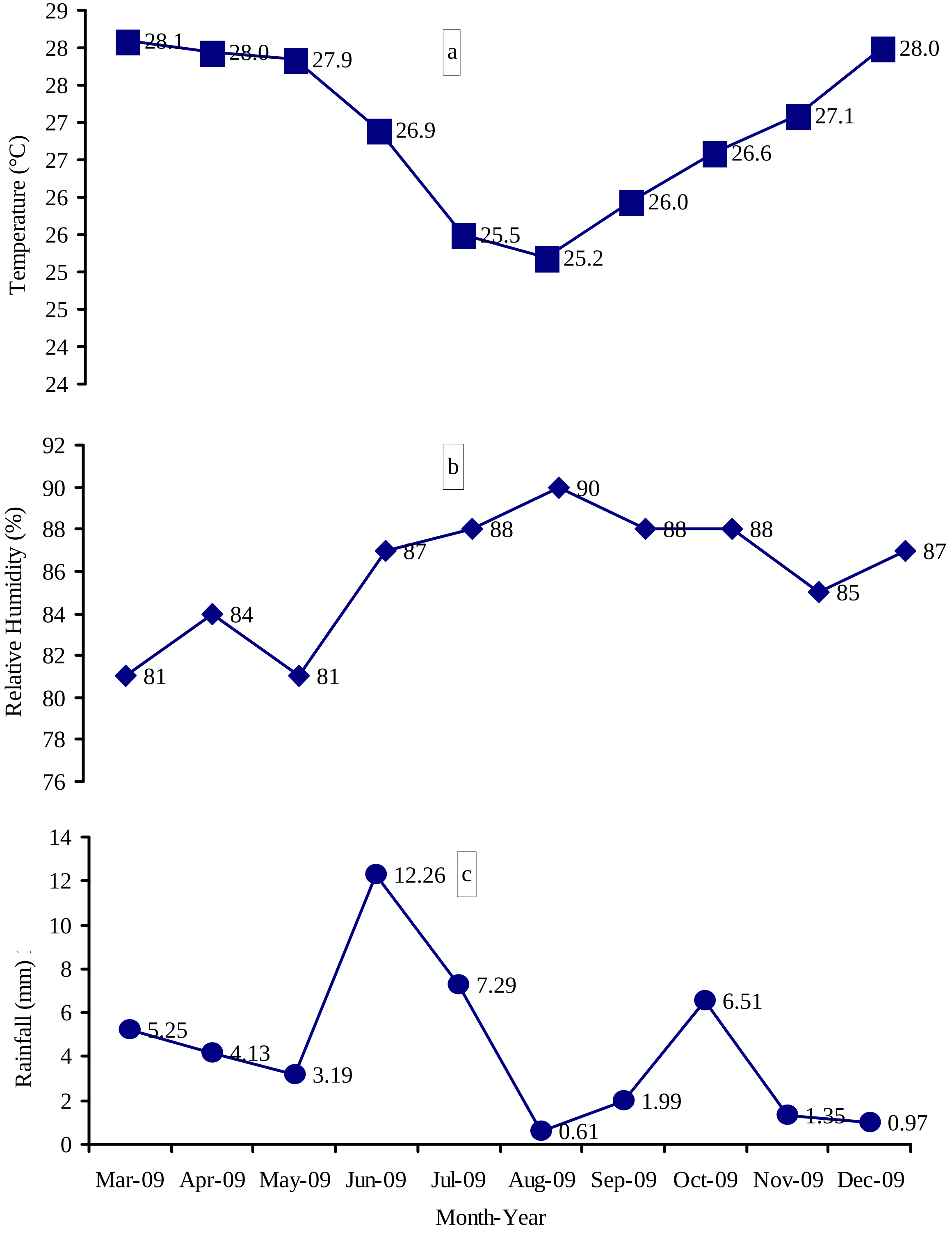

Figure 5.1 Site climatic data (a. Temperature, b. Relative humidity, c. Rainfall) during study period.

5.4 Soil chemical properties

Soil pH, N, P, K, Ca and Mg differed significantly ($P < 0.001$) among stands. Also, effective cation exchange capacity (ECEC) and organic matter (OM) differed significantly ($P < 0.001$) among stands. The soils were very acidic. Generally, Nitrogen was moderate but OM was high. Phosphorus, K, Ca and ECEC were low among stands (Table 5.1).

Soil pH was significantly ($\alpha = 0.05$) lower under both *Leucaena* and *Senna* than *Carapa*. Nitrogen decreased in the order 0.16 for *Senna* ≡ 0.14 for *Leucaena* > 0.09 for *Carapa*. Similarly Mg decreased in the order 1.18 for *Senna* ≡ 1.34 for *Leucaena* > 0.80 for *Carapa*. A similar trend was obtained for K where *Senna* and *Leucaena* had comparatively higher levels than *Carapa* (Table 5.1). *Senna siamea* though not a nitrogen fixing tree, is known to hold large amounts of nitrogen in its foliage (National Association of Sciences, 1980) and possibly accounts for the lack of significant difference between *Senna* and nitrogen fixing, *Leucaena* (Young, 1997) in soil.

Soils under *Carapa* were however significantly higher ($\alpha = 0.05$) in pH, available P and organic matter than both *Leucaena* and *Senna*. The pH values were, 4.53 for *Carapa* > 4.23 for *Leucaena* ≡ 4.13 for *Senna*. Available P values were 6.41 for *Carapa* > 3.13 for *Senna* ≡ 1.95 for *Leucaena* (Table 5.1). Leguminous species like *Leucaena* require large amounts of phosphorus for growth, nodulation and nitrogen fixation (Goma, 2003). Though, *Senna* is not leguminous, the uptake of P from the soil is often facilitated by heavy root infection by vesicular arbuscular mycorrhizae (VAM) making P more available (Habte, 1995) and recycled.

Table 5.1 Selected soil chemical properties (0 - 30cm) and mean comparisons as influenced by *Leucaena, Senna* and *Carapa* stands

Property	DF	F values	Pr-values	C V	[†]Mean comparison			Mean	Rank
					Leucaena	*Senna*	*Carapa*		
pH	2	26.7	0.001***	1.70	4.23^{b} (0.04)	4.13^{b} (0.04)	4.53^{a} (0.05)	4.30 (0.05)	Very Acidic
N (%)	2	23.4	0.002**	9.93	0.14^{a} (0.00)	0.16^{a} (0.01)	0.09^{b} (0.06)	0.13 (0.01)	Moderate
P (ppm)	2	3061	0.000***	1.89	1.95^{c} (0.01)	3.13^{b} (0.07)	6.41^{a} (0.004)	3.83 (0.06)	Low
K (me / 100g)	2	176	0.000***	6.87	0.15^{a} (0.01)	0.16^{a} (0.004)	0.05^{b} (0.004)	0.12 (0.003)	Low
Ca (me / 100g)	2	164	0.000***	6.93	3.30^{a} (0.01)	2.52^{b} (0.16)	1.00^{c} (0.004)	2.27 (0.13)	Low
Mg (me / 100g)	2	39.3	0.000***	6.92	1.34^{a} (0.01)	1.18^{a} (0.00)	0.80^{b} (0.08)	1.12 (0.06)	-
ECEC	2	46.6	0.000***	4.10	5.43^{a} (0.08)	4.57^{b} (0.17)	3.93^{c} (0.09)	4.64 (0.16)	Low
Organic Matter (%)	2	68.7	0.000***	5.50	2.37^{b} (0.02)	2.77^{b} (0.14)	3.90^{a} (0.09)	3.01 (0.14)	High

**, ***significant at 0.01 and 0.001probability levels

[†]Values with different alphabets differ significantly at α = 0.05 using Tukey's standardized range test

Numbers in parenthesis represent standard errors of means,

Rank as determined by Soil Research Institute, Kumasi Ghana, - Rank unavailable

Probably, there could be a high utilization of P under these stands and possibly accounted for the significantly ($\alpha = 0.05$) lower P levels under both *Leucaena* and *Senna* than *Carapa* where P was possibly under utilized.

As stands grow, accumulation of organic matter increases with litterfall increases and canopy closure. Thus, soil microclimate becomes less favourable for soil organic matter decomposition (Alriksson and Olsson, 1995). Such conditions under *Carapa* could have accounted for the significantly higher ($\alpha = 0.05$) organic matter (3.9%) than *Leucaena* (2.8%) and *Senna* (2.4%) respectively (Table 5.1).

Contrary to the above trend, Ca and ECEC differed significantly ($\alpha = 0.05$) among the three stands. This study reports soil Calcium of 3.30 for *Leucaena* > 2.52 for *Senna* > 1.00 for *Carapa*. Litter accumulation appeared to be responsible for the low soil Ca under *Carapa* as it remains fixed or immobilized in the plant tissues. Similarly, ECEC of 5.43 for *Leucaena* > 4.57 for *Senna* > 3.93 for *Carapa* were obtained (Table 5.1). The general soil fertility trend under the tree stands was *Leaucaena* > *Senna* > *Carapa*.

5.5 Effects of shade on *T. daniellii* growth

5.5.1 Survival

The survival of *T. daniellii* seedlings in response to the three shading levels over 40 weeks is presented in Figure 5.2.Shade significantly ($P < 0.001$) influenced survival of *T. daniellii* seedlings at week 40 (Table 5.2). This complements a study that reported that light significantly affected seedling survival of beech (*Fagus sylvatica* L.) seedlings (Minotta and Pinzauti, 1996).

Table 5.2 *T. daniellii* growth parameters in response to shade at week 40

Parameter	DF	F-values	Pr-values	Shade Levels (%) 73 (*Leucaena*)	 86 (*Senna*)	 98 (*Carapa*)	 Mean
Survival (%)	2	688.98	0.000***	70.93^{a} (3.80)	59.91^{b} (3.20)	20.02^{c} (1.87)	50.29 (1.44)
Lamina length (cm)	2	459.22	0.000***	27.1^{a} (0.13)	25.2^{b} (0.35)	18.0^{c} (0.65)	23.43 (0.32)
Lamina width (cm)	2	311.72	0.000***	17.6^{a} (0.13)	15.9^{b} (0.08)	11.4^{c} (0.76)	14.97 (0.26)
Petiole length (cm)	2	389.55	0.000***	43.6^{a} (0.90)	38.8^{b} (0.70)	20.4^{c} (1.39)	34.24 (0.88)
Number of tillers	2	694.24	0.000***	13^{a} (0.34)	10^{b} (0.33)	1^{c} (0.00)	8 (0.34)

*** significant at probability of 0.001

Values with different alphabets differ significantly at α = 0.05 using Tukey's standardized range test

Numbers in parenthesis represent the standard errors of means

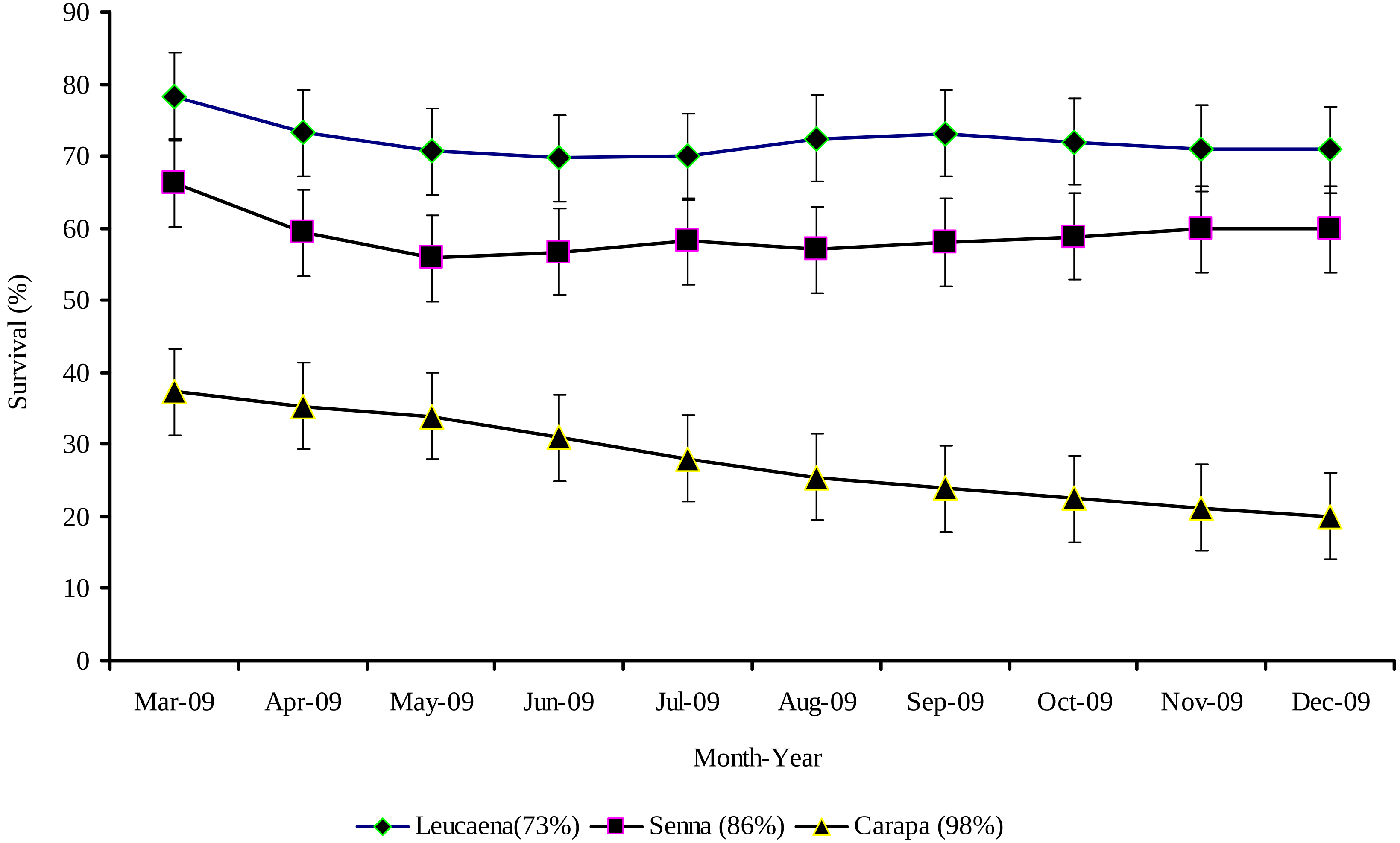

Figure 5.2 Survival of *T. daniellii* under three shade levels over 40 weeks

After initial decline in seedling survival after week 4, a fairly stable survival was maintained for 73% and 86% shade levels as compared to a continuous decline in survival under 98% shade over the 40 weeks (Figure 5.2). As shading reduced, *T. daniellii* survival increased. Hence, at week 40, survival was 71% for *Leucaena* > 60% for *Senna* > 20% for *Carapa* stands (Table 5.2).

Ninety eight percent (98%) shade under *Carapa* could have reduced the photosynthetic ability of *T. daniellii* seedlings which is often associated with low carbohydrate levels in plants. This, together with internal competition with elongation spike and stem sinks, could have accelerated tiller mortality as reported for wheat (Fraser *et al*., 1982). High shade under *Carapa* (98%) also reduced litter decomposition and led to a build up under the canopy (Appendix 3a). Slow litter decomposition influences the release of nutrients for plant growth. Litter cover affects tillering, seedling survival and growth by altering the physical and chemical environment. Abiotic conditions, such as light, temperature and moisture, are also affected by litter depth. With increasing litter depth, a larger concentration of nutrients or toxins may be leached from litter to soils (Jeffery, 1997) and possibly contributed to, high attrition among *T. daniellii* seedlings under *Carapa*.

Seedlings growing under dense litter mats often have high mortality rates due to expending all energy reserves in attempts to penetrate the litter. Surviving seedlings under such conditions are often severely etiolated or elongated, which can increase susceptibility to physical damage (Jeffery, 1997). Furthermore, higher light availability favour carbon-based defence compounds (e.g. tannins and phenols), whereas high shady conditions favour nitrogen-based defences (e.g. alkaloids). This is because fixed carbon is in less abundant supply under higher shade conditions (Middleton, 2001). These conditions possibly led to the development of weak leaves among *T. daniellii* seedlings under 98% shade making it susceptible to pest attacks or herbivory (Appendix 3b). Generally, herbivory reduces biomass production per plant and increases level of mortality (Bahmani, *et al*., 2000).

5.5.2 Lamina width and length

Shade significantly ($P < 0.001$) influenced lamina width and lamina length at week 40 (Table 5.2). It is clear that both parameters did not significantly increase over time under 98% shade. However, with the other shade levels such as 73%, lamina width and length increased over time from 9.2 – 17.6 cm and 15.8 – 27.1cm respectively. Similarly, lamina width and lamina length increased over time from 8.9 – 15.9 cm and 16.3 - 25.2 cm for 86% shade.

Seedlings responses to shade over 40 weeks depicted a gradual increase in both lamina width and lamina length for 73% and 86% shade levels respectively whiles no appreciable increases in lamina width and length were observed for 98% shade (Figures 5.3a and 5.3b). Survival in a shaded understorey demands maximization of light capture for photosynthesis (Middleton, 2001). Therefore, between weeks 4 and 16, increased lamina width were obtained for 98% shade as compared to 86% and 73% shade levels (Figure 5.3a). Similarly, between weeks 4 and 8, increased lamina length were obtained for 98% shade as compared to 86% and 73% shade levels (Figure 5.3b).

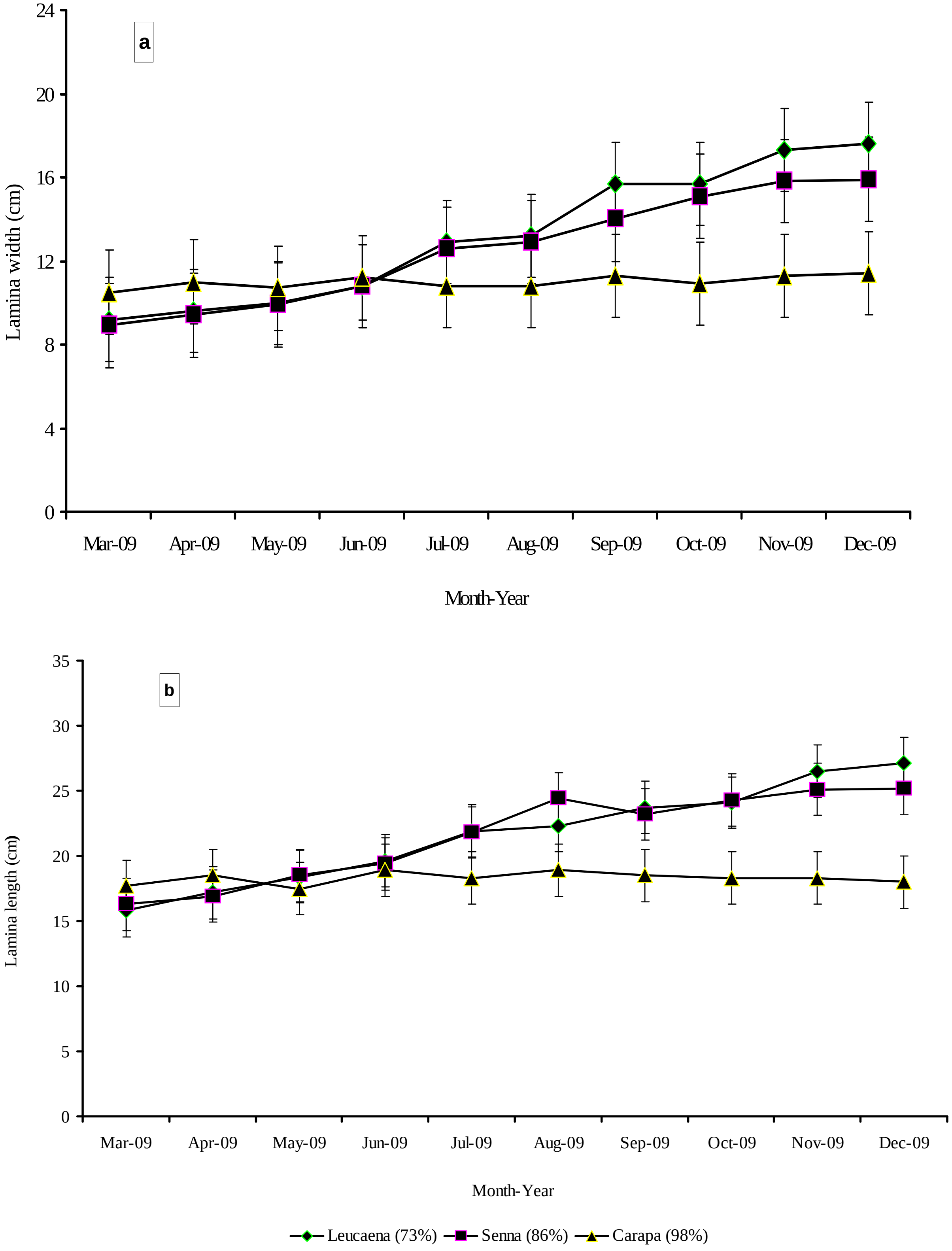

Figure 5.3 *T. daniellii* lamina width [a] and length [b] response to three shade levels over 40 weeks

5.5.3 Petiole length

Shade significantly ($P < 0.001$) influenced petiole length at week 40 (Table 5.2). Hence, higher illumination increased petiole length under low shade and decreased with increased shade. Consequently, petiole length values obtained were ranked as 43.6 cm > 38.8 cm > 20.4 cm for 73%, 86% and 98% shade levels respectively (Table 5.2). Petiole extension is responsive to light conditions (Dong, 1995) and plastic responses in lengths of petioles are important for the capture of light in a patchy environment (Hutchings and de Kroon, 1994). Petiole elongation may shift shaded leaf blades into higher light zones. However, this will not occur in shaded habitats where sunflecks are strongly variable in space and time and where there is hardly a vertical light gradient near the ground (Dong, 1995).

The pattern of petiole growth over 40 weeks in response to shade is illustrated in figure 5.4. There was a gradual increase in petiole length from week 4 – 40 for 73% and 95% shade respectively. However, no appreciable increase at 98% shade from week 4 – 24 was observed after which a decline and sturdy growth was observed from week 28 – 40. The decline could be attributed to the death and replacement of tillers with new but shorter ones as means of surviving under low illumination.

5.5.4 Number of tillers

Shade significantly ($P < 0.001$) influenced tiller production among *T. daniellii* seedlings (Table 5.2). The pattern of tiller production over 40 weeks is illustrated in Figure 5.5. Tiller production gradually increased from week 4 – 40 for 73% and 95% shade levels and no increase observed for 98% shade except at week 20 and 36 (Figure 5.5).

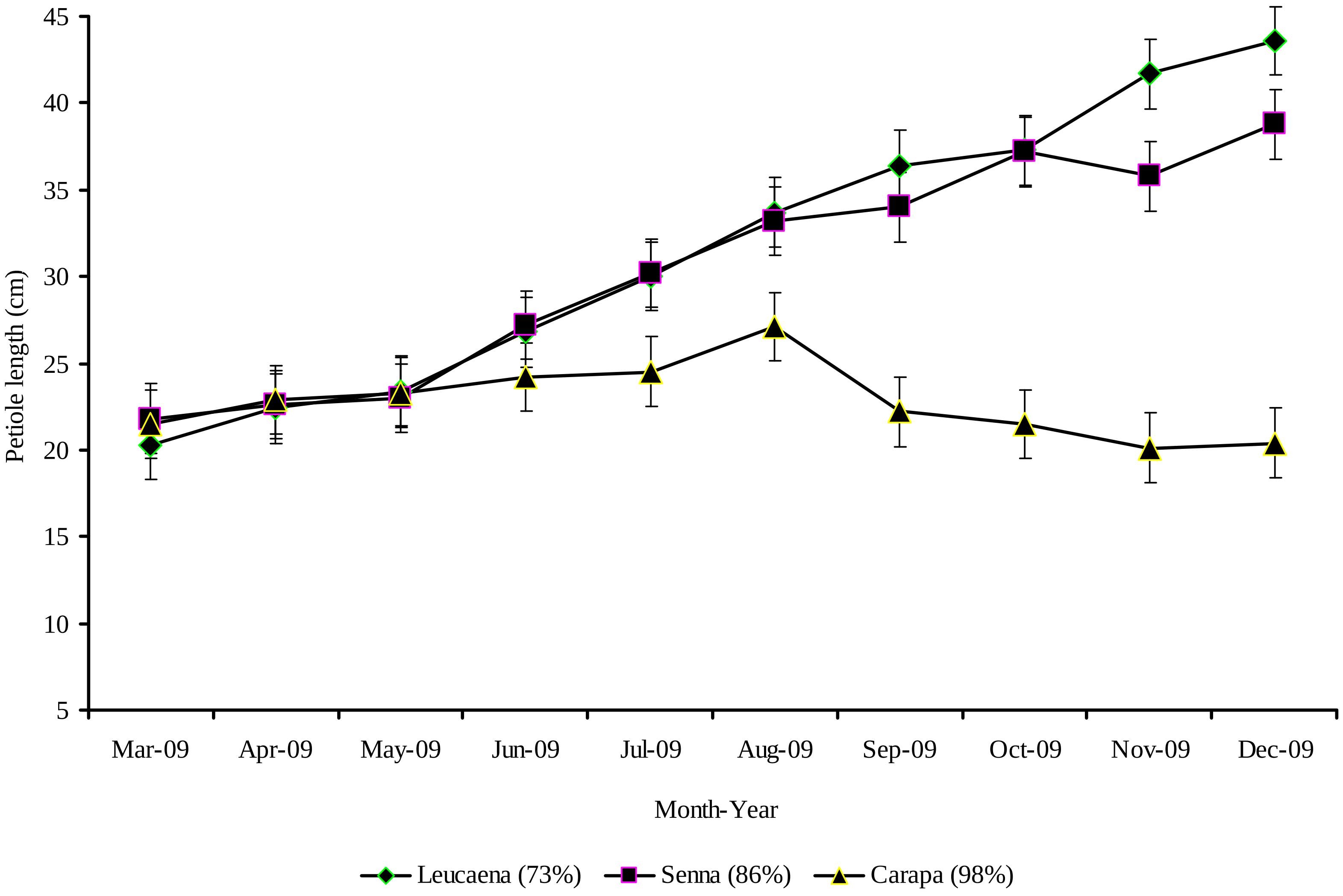

Figure 5.4 Response of *T. daniellii* petiole length to threee shade levels over 40 weeks

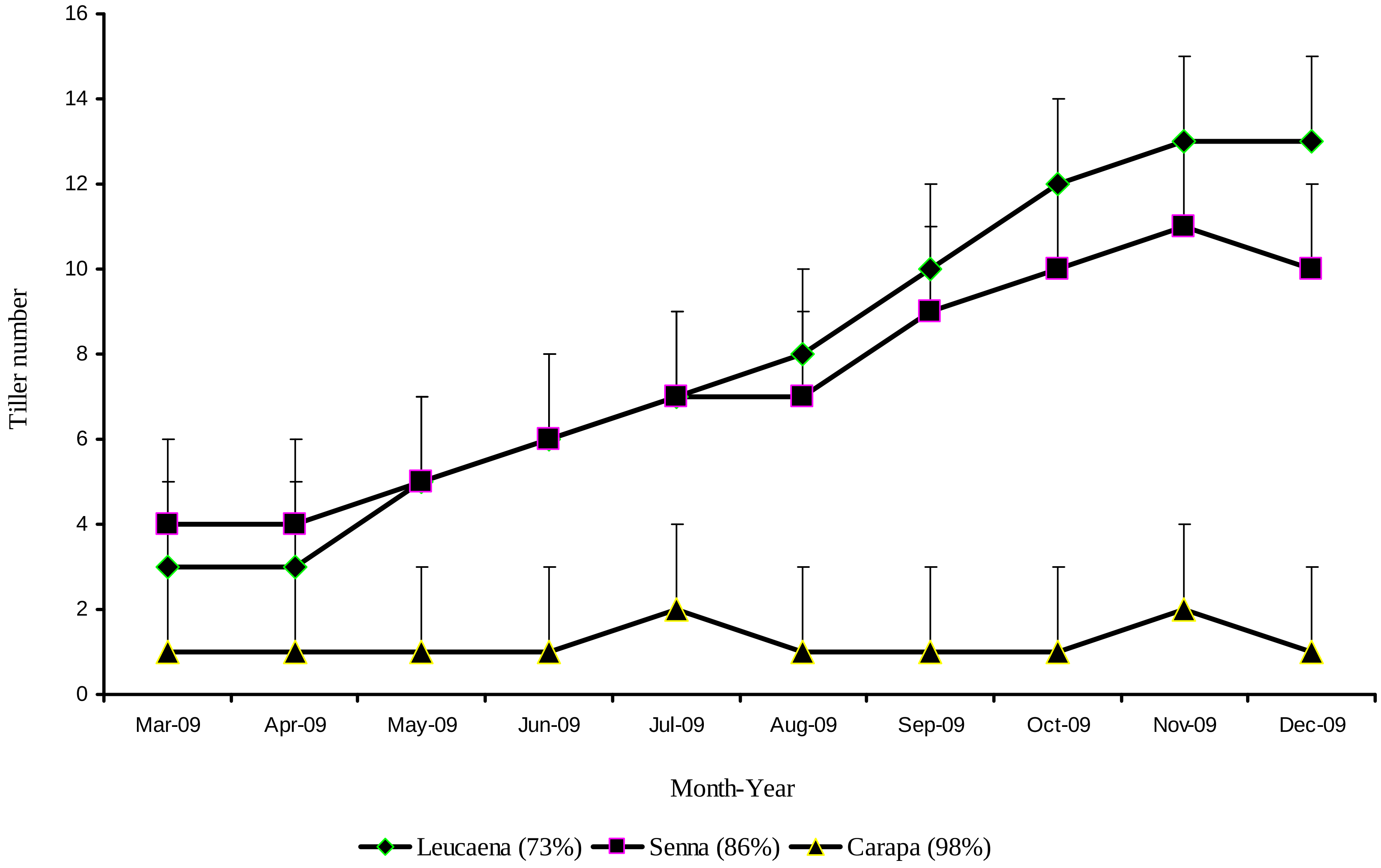

Figure 5.5 Tiller production of *T. daniellii* under three shade levels over 40 weeks

Herbage plants grown in areas with lower light levels have been reported to be smaller and had fewer numbers of tillers compared with plants under higher levels of radiation (Neel *et al*., 2008).

At week 40, tiller number under 73%, 95%, 98% shades were 13 > 10 > 1 respectively (Table 5.2). The development of more tillers under 73% and 95% shade might be a mechanism to increase the photosynthetic area of seedlings. Physiologically, light affects metabolism through photosynthesis, growth and development (Dai *et al*., 2009). Therefore, inability of *T. daniellii* seedlings to produce more tillers under 98 % shade could have contributed significantly to the poor survival. This is because each new tiller developed from the same rhizome possesses its own leaf which produces more photosynthate that is translocated into the underground stem for storage and other physiological activities. Therefore, the development and emergence of tillers could be a major mechanism for survival of *T. daniellii* seedlings.

5.6 Effects of spacing on *T. daniellii* growth

5.6.1 Survival

Spacing had no significant ($P < 0.001$) influence on the survival of *T. daniellii* seedlings at week 40. Survival response to spacing ranged between 48% and 52% (Table 5.3). This could suggest that survival largely depended on shade rather than spacing. Soils under *Leucaena* and *Senna* stands were generally more fertile than *Carapa* (Table 5.1). However, no differences in survival recorded for spacing also shows that, the utilization of nutrients for physiological activities to enhance survival of *T. daniellii* could be highly influenced by shade.

Table 5.3 *T. daniellii* growth parameters in response to spacing at week 40

				[†]Spacing (m × m)				
Parameter	DF	F-values	Pr-values	VHD	HD	MD	LD	Mean
Survival (%)	3	2.09	0.130^{ns}	50.3^{a}	50.7^{a}	48.0^{a}	52.1^{a}	50.29
				(9.89)	(8.79)	(6.67)	(8.14)	(1.67)
Lamina length (cm)	3	8.73	0.000***	23.2^{bc}	23.8^{ab}	22.5^{c}	24.3^{a}	23.45
				(1.19)	(1.61)	(1.87)	(0.98)	(0.37)
Lamina width (cm)	3	10.46	0.000***	15.5^{a}	14.9^{a}	14.0^{b}	15.4^{a}	14.97
				(0.52)	(1.06)	(1.58)	(0.77)	(0.30)
Petiole length (cm)	3	7.33	0.001***	37.1^{a}	33.4^{b}	32.8^{b}	33.7^{b}	34.25
				(0.95)	(3.38)	(4.33)	(1.38)	(1.01)
Number of tillers	3	1.81	0.174^{ns}	8^{a}	9^{a}	8^{a}	8^{a}	8
				(1.84)	(1.96)	(1.79)	(1.83)	(0.39)

*** significant at 0.001probability level, ^{ns} not significant at 0.05 probability level

[†]Different superscripted alphabets in a row indicates values significantly differ at α = 0.05 using Tukey’s mean separation technique

Numbers in parenthesis represent the standard errors of means

VHD-Very high density, HD-High density, MD-Medium density, LD-Low density

5.6.2 Lamina width and length

Spacing significantly ($P < 0.001$) influenced lamina width and lamina length at week 40 (Table 5.3). There was a general increase in lamina width with MD spacing recording the least values over the 40 weeks. At week 40 lamina widths for various spacing were 15.5 cm for VHD ≡ 15.4 cm for LD ≡ 14.9 cm for HD > 14.0 cm for MD (Figure 5.6a and Table 5.3). Lamina length also generally increased over the 40 weeks with the highest (24.3 cm) and lowest (22.5 cm) lamina lengths obtained for LD and MD respectively at week 40 (Figure 5.6b and Table 5.3).

Spacing determines plant population per unit area and variation in population could affect resource sharing and exploitation. Generally, leaves were large for LD seedlings due to less competition for resources by the fewer plants. Clearly, MD resulted in the least leaf (width-14.0 cm, length-22.5 cm) size. This suggests that extremes of spacing, that is VHD and LD, could enhance the growth of *T. daniellii* better than intermediary spacing. Therefore, the least lamina width and length obtained for medium density also suggest that plant population at 1.0 m × 1.0 m could neither be so high stimulate competition nor low enough enhance luxurious growth.

5.6.3 Petiole length

Spacing significantly ($P < 0.001$) influenced petiole length at week 40 (Table 5.3). Petiole lengths were 37.1 cm for VHD > 33.7 cm for LD ≡ 33.4 cm for MD ≡ 32.8 cm for HD spacing. The trend in petiole growth over 40 weeks is presented in Figure 5.7.

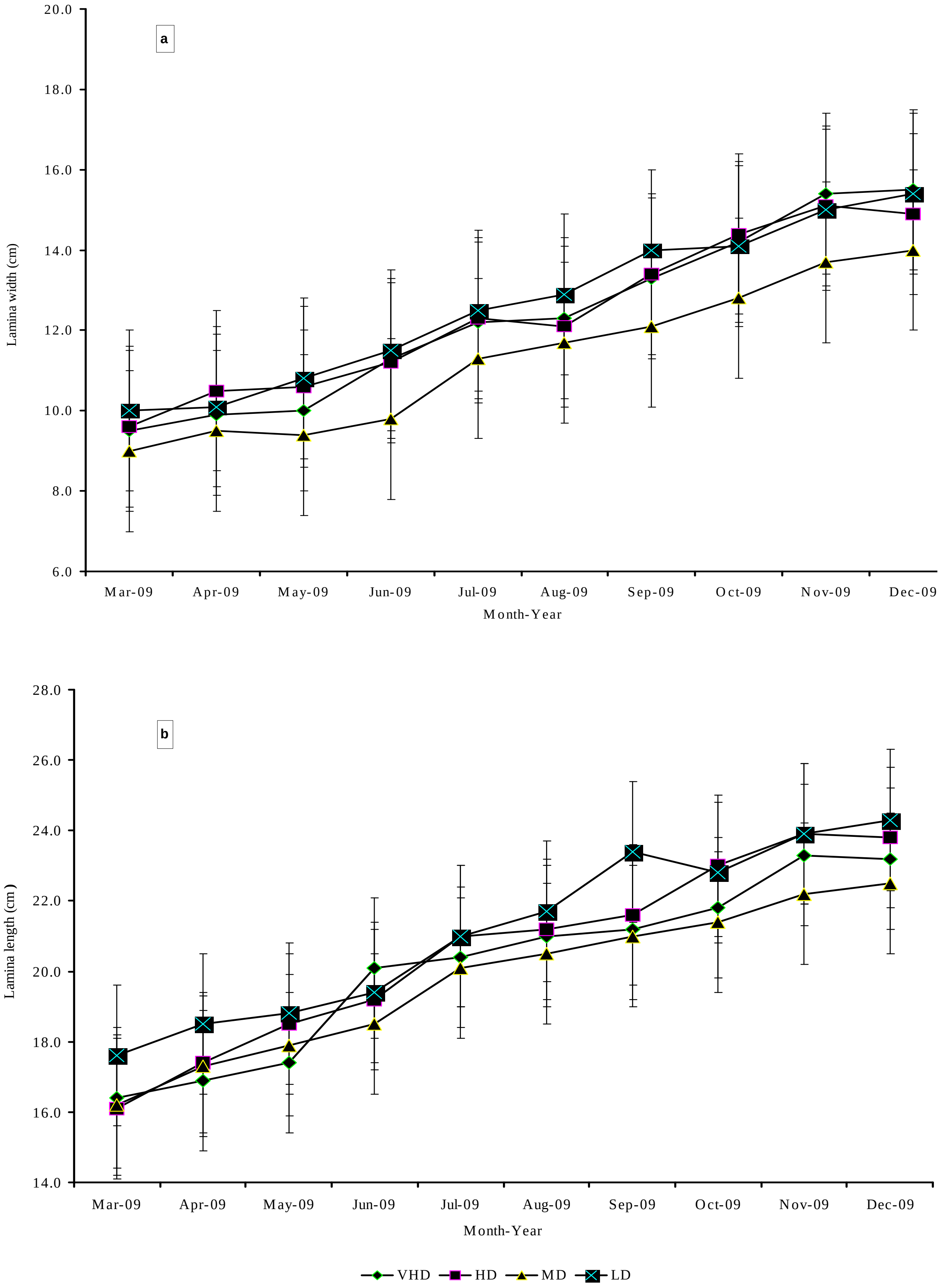

Figure 5.6 Pattern of *T. daniellii* lamina width [a] and length [b] growth in response to spacing over 40 weeks

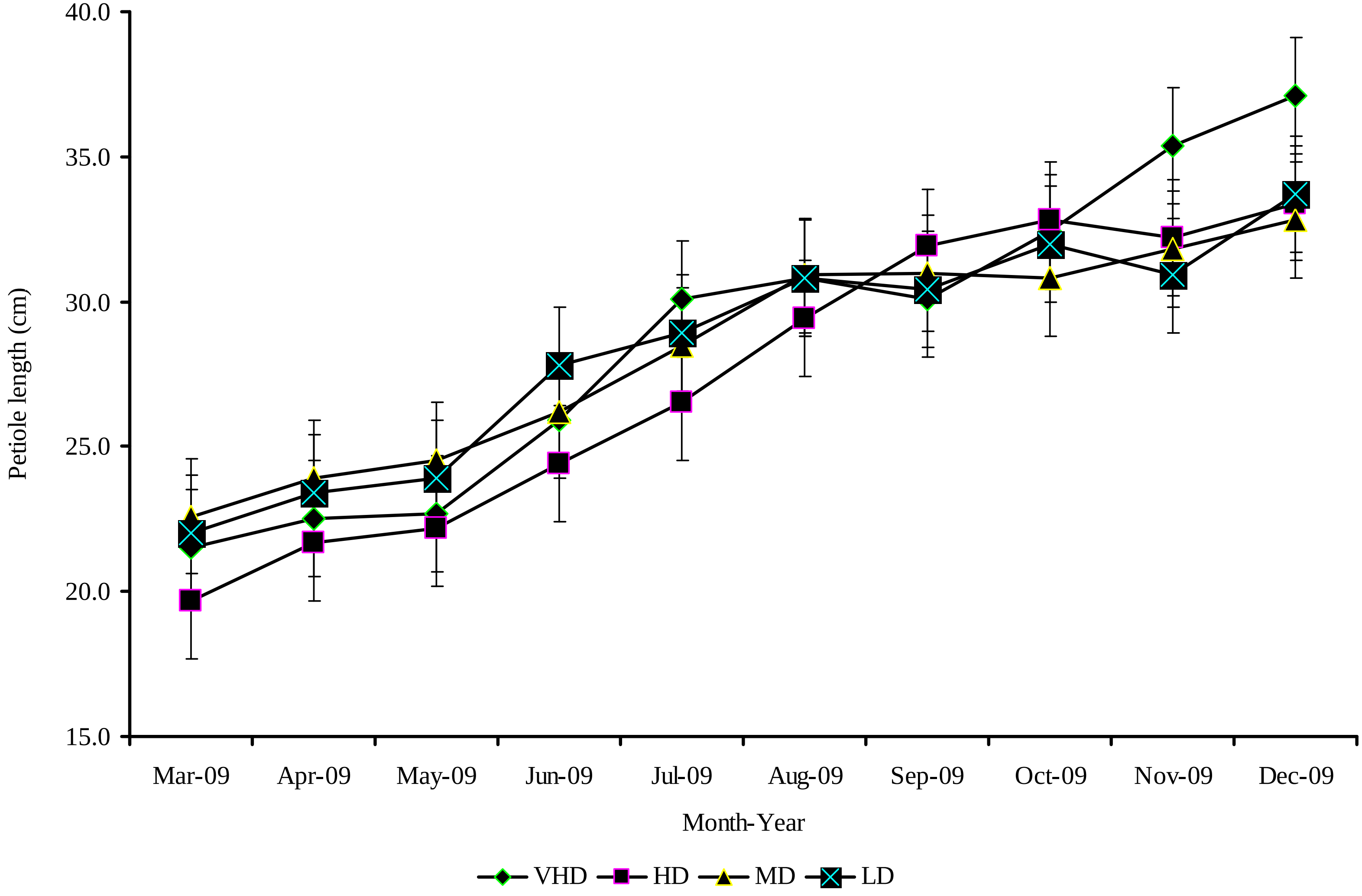

Figure 5.7 Pattern of *T. daniellii* petiole length growth in response to spacing over 40 weeks

In linseed (*Linum usitatissimum*), increased density (closer spacing) restricted the growth of individual plants, resulting in shorter stems with fewer smaller leaves (Leitch and Sahi, 1999). On the other hand, studies on peanut (*Arachis hypogaea* L.) indicated that as plant spacing increased, stem height generally decreased (Sconyers *et al*., 2005). With reference to *T. daniellii*, this study results indicated that closer spacing (VHD) significantly enhanced petiole elongation. With closer spacing, cumulative production of tillers over time could further reduce the spacing between individual petioles within *T. daniellii* stands. For instance, a study of spacing effects on safflower (*Carthamus tinctorius*) reported early development of a closed canopy among closely spaced stands (Blackshaw, 1993). Under such conditions, a possible competition for light could have facilitated investment of resources into petiole length over the 40 weeks.

5.6.4 Number of tillers

Spacing had no significant ($P < 0.001$) influence on tiller production of *T. daniellii* seedlings (Table 5.3). By inference, it could be said that no significant differences in tiller production may be obtained among *T. daniellii* seedlings with these spacing treatments. Generally, soils under *Leucaena* and *Senna* stands were fertile than *Carapa* (Table 5.1). Therefore, lack of differences in tillering among tree stands could imply that fertility may not influence the number tillers produced by *T. daniellii*. Hence, differences in light conditions within the stands could be the major factor that influences tillering.

5.7 Conclusions

The study ascertained the effects of shade and spacing as well as their interaction on *T. daniellii* growth with respect to survival, leaf parameters (lamina length and lamina width), petiole length and number of tillers over 40 weeks. There were three shade levels provided by *Leucaena* (73%), *Senna* (86%) and *Carapa* (98%) and four spacing treatments which were Very high density (VHD), High density (HD), Medium density (MD) and Low density (LD).

Shade significantly influenced survival, leaf sizes, petiole length and number of tillers. Recorded values for survival were 71% for *Leucaena* > 60% for *Senna* > 20% for *Carapa*. Leaf sizes were also larger for 73% (width-17.6 cm, length-27.1 cm) than 86% (width-15.9 cm, length-25.2 cm) and 98% (width-11.4 cm, length-18.0 cm) shade levels. Similarly, significantly longer petioles, 43.6 cm, were obtained for 73% shade compared to 38.8 cm for 86% and 20.4 cm for 98% shade levels. Tillering decreased with increased shade and were 13 for 73%, 10 for 86% and 1 for 98% shade levels. Therefore, the hypothesis that survival, lamina length, lamina width, petiole length and tiller production were not dependent on shade were not accepted.

Results suggest that high shading resulting in litter accumulation can be detrimental to the establishment of *T. daniellii* under tree stands and significantly reduce survival, tiller production and growth of planted seedlings regardless of these treatment spacing. Though shade seemed to be a dominant factor in the establishment of *T. daniellii* seedlings with spacing influencing some growth parameters, the extent to which these factors affect the successful cultivation of *T. daniellii* could be influenced by the prevailing soil conditions.

Spacing significantly influenced leaf sizes and petiole lengths but had no significant effect on survival and tiller production at week 40. Leaf sizes were (width-15.4 cm, length-24.3 cm) for LD, (width-15.5 cm, length-23.2 cm) for VHD, (width-14.9 cm, length-23.8 cm) for HD and (width-14.0 cm, length-22.5 cm) for MD. Petiole lengths were 37.1 cm for VHD > 33.7 cm for LD ≡ 33.4 cm for MD ≡ 32.8 cm for HD spacing. Therefore, the hypotheses that lamina length, lamina width, petiole length were not dependent on spacing were not accepted. On the contrary, the hypotheses that percentage survival and tiller production were not dependent on spacing were accepted.

5.8 Recommendation

A major limitation to this experiment is that only three shade levels were used and were not under controlled conditions since the study was carried out in an already established tree stands. This makes it difficult to make a clear cut inference for wider application of this study results with respect to the actual shade level that could promote the optimum growth of *T. daniellii*. Further studies is therefore recommended to be carried out on other shade levels under controlled conditions to determine suitable shade level that could promote the growth of *T. daniellii*.

Chapter 6

6.0 EARLY GROWTH RESPONSE OF THREE PROVENANCES OF *T. daniellii* TO NPK FERTILIZATION UNDER *Senna siamea* STAND

Summary

This experiment was conducted at the FRNR research farm (06º 41’N, 01º 37’W), Kumasi, Ghana. The objectives were to determine the effect of provenances and NPK fertilization on survival, lamina width and length, petiole length and diameter, and tiller production of *T. daniellii* over 24 weeks. A split plot in a completely randomized design with three replications and two factors was used. The main-plot factor was provenance (Western, Volta and Ashanti) and the sub-plot factor was fertilization (NPK 20:20:20 fertilization and a control). The study revealed significant variations in provenances for lamina length, lamina width, petiole length and petiole diameter. Lamina length of provenances were Western-23.7 cm ≡ Volta-21.1 cm > Ashanti-17.2 cm. Lamina width were Western-14.3 cm ≡ Volta-12.9 cm > Ashanti-9.0 cm. Also, petiole length were Western-37.7 cm ≡ Volta-36.1 cm > Ashanti-24.8 cm. Petiole diameter were Western-5.6 mm ≡ Volta-5.4 mm > Ashanti-3.8 mm. However survival and tiller production did not differ significantly among provenances at week 24. Fertilization also significantly enhanced the growth of lamina width, petiole diameter and tiller production. At week 24, lamina width were Fertilized-12.8 cm > Unfertilized-11.4 cm; petiole diameter were Fertilized-5.17 mm > Unfertilized-4.64 mm; and tiller numbers were Fertilized-5 > Unfertilized-4. However, fertilization had no significant effect on survival, lamina length and petiole length of *T. daniellii* provenances. The significantly higher lamina width, lamina length, petiole length and diameter values obtained for Western and Volta provenances suggests a greater potential for fast growth than the Ashanti provenance. Fertilization responses could also suggest that survival, lamina length and petiole length did not depend on nutrient supply.

6.1 Introduction

The successful cultivation and management of *T. daniellii* plantation requires the development and supply of superior seedlings. Such seedlings should be fast growing, early maturing and fruiting, have higher thaumatin content and easy to establish under varied environmental conditions. The improvement of quality characters in cultivated plants such as *T. daniellii* has great potential to alleviate problems caused by poverty. This can be achieved directly through enhanced fruit quality and quantity and indirectly through income stability that affect farmers' socioeconomic status. Many aspects of plant quality can be defined differently in terms of crop species, geographical region, and intended use of crop or crop product (Shu, 2004).

Currently, bulk supplies of fruits for export are mainly obtained from the Western and Volta Regions though reports also indicate that *T. daniellii* occur in the Ashanti, Eastern and Brong Ahafo Regions of Ghana. This suggests that *T. daniellii* can grow under different ecological factors. However, studies have shown that even subtle "micro-environmental" differences as for example water, light and temperature among maternal plants can significantly affect offspring phenotype (Schmid and Dolt, 1994). Hence, understanding the geographical distribution of ecologically relevant genetic variation and the environmental factors driving adaptive divergence within species will help to ensure appropriate sourcing of material for planting (O'Brien *et al*., 2007).

Therefore, integration of *T. daniellii* into farming systems require the assessment of growth performance to determine early maturing planting materials from various provenances. Plant growth can be enhanced by fertilization. Therefore, based on the need to nurture seedlings through early period of development and ensure vigour, the application of fertilizers in dry form has been recommended (Duryea and Landis, 1984). Identification of quality germplasm is vital to *T. daniellii* cultivation if farmers are certain about its success when planted. This study therefore compared the growth performance of *T. daniellii* provenances from the Western, Ashanti and Volta regions under the similar environmental conditions.

The hypotheses of the study were that provenances were not different and would respond similarly to NPK fertilization. The study objectives were to determine the effect of fertilization on *T. daniellii* survival, lamina width, lamina length, petiole length, petiole diameter and tiller production of the provenances.

6.2 Methodology

6.2.1 Site description

The research was conducted at the Faculty of Renewable Natural Resources research farm, KNUST, Kumasi, Ghana. The site conditions are as described in section 5.2.1.

6.2.3 Sources of plant materials

Uniform sized seedlings raised from rhizomes were used for this study. Rhizomes were obtained from *T. daniellii* stands in the Western, Volta and Ashanti Regions on 29/01/10, 6/02/10 and 13/02/10 respectively. Figure 7.1 illustrates areas where *T. daniellii* rhizomes were obtained. These were: Tano Nimre Forest Reserve, Near Damoakrom (N 05°32′, W 002°37□) in Western region; Bobiri Forest Reserve, Kubease (N 6° 41□, W 1° 21□) in Ashanti region, and the Afadjato-Agumatso Conservation Range, Gbledi-Chebi (N 07^{o}1.00', E 0^{o}34.00') in Volta region. Tano Nimre Forest Reserve, Bobiri Forest Reserve and Gbledi-Chebi fall within Moist evergreen, Moist semi-deciduous and Dry semi-deciduous vegetation/ecological zones of Ghana respectively (Danquah *et al.,* 2011). Obtained rhizomes were buried in the ground until new tillers emerged. Tillers with fully expanded leaves were detached plus about 3-inch rhizome from main rhizomes. The detached tillers were then nursed in poly bags filled with topsoil between 13 – 15th of February, 2010 and later field transplanted on 5th of May, 2010.

6.2.4 Experimental design

Plots were laid up within the alleys of three year old *Senna siamea* tress established in 2007. The alleys were spaced at 5 m apart and 1 m within row. Average tree height was 10.5 m and diameter was 8.7 cm. The experimental set up was a split plot in a completely randomized design (CRD) with three replications. The main and subplot treatments were provenance and fertilization respectively. The main plots had dimensions of 10 m × 5 m (50 m^2) and were spaced 3 m apart. Subplots had dimensions of 3 m × 3 m (9 m^2) and were spaced 2 m apart. Seedlings were planted at a spacing of 1 m × 1 m giving a total of 32 plants/main plot (35,556 plants/ha) and 16 plants/subplot (17,778 plants/ha). Main plot treatments comprised seedling provenances from Western, Volta and Ashanti Regions. Subplot treatments comprised NPK (20:20:20) fertilization and a control. Seedlings received a total amount of 20 g/plant (711.12 kg/ha for main plot and 355.56 kg/ha for subplot).

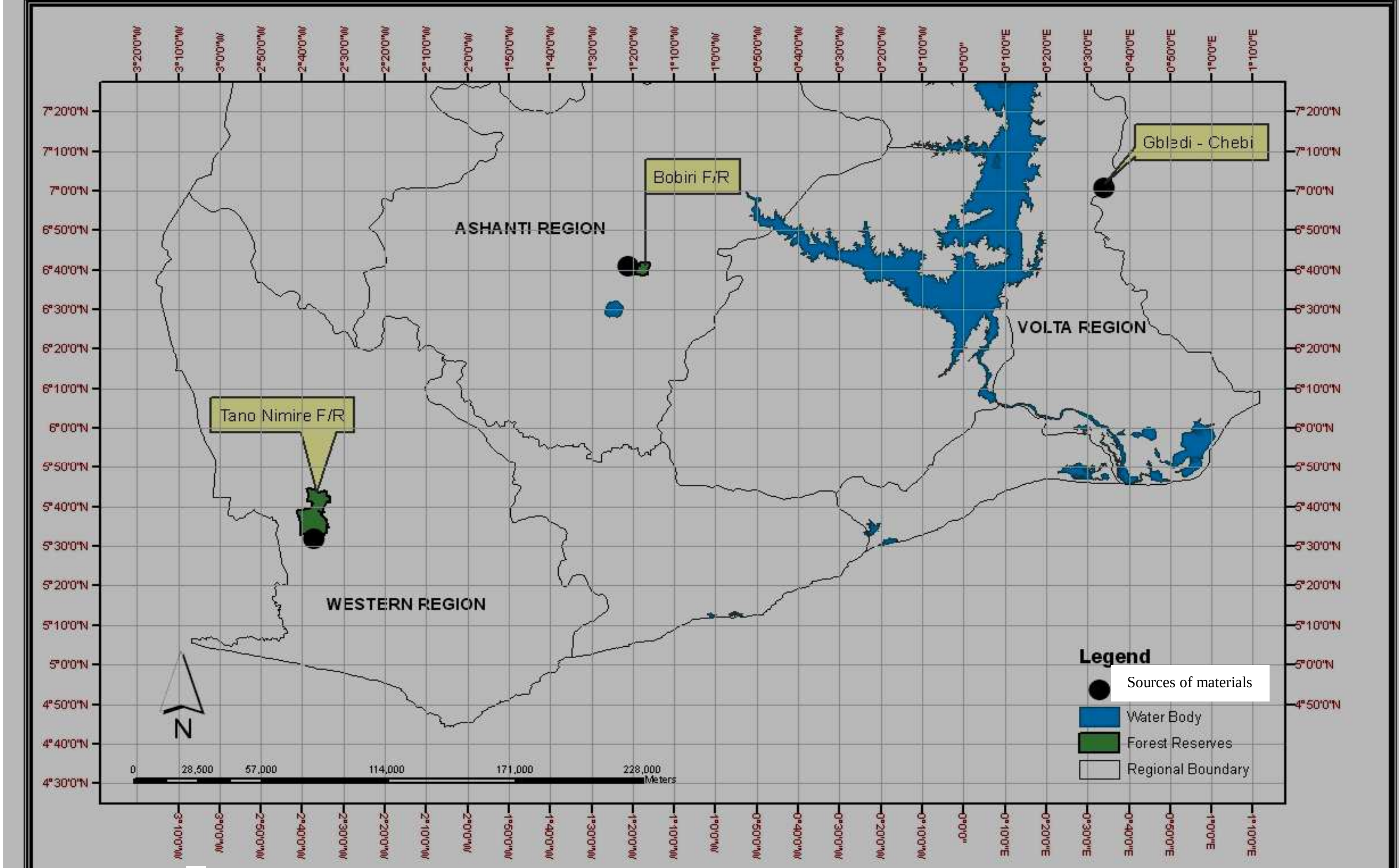

Figure 6.1 Sources of T. daniellii plant materials from the Western, Ashanti and Volta regions

Fertilization was done twice in a split application by ring method. The first and second applications were done on 18th June, 2010 and 18th September, 2010 respectively to coincide with the major and minor rainy seasons.

6.2.5 Data collection

Data were collected on survival, lamina length, lamina width, petiole diameter, number of tillers and petiole length at four weeks interval after the first fertilization for 24 weeks. Survival was determined through head count of seedlings on each plot and subsequently converted to percentage. Lamina length was measured from tip to the base of the leaf and lamina width was measured at the widest extent of leaf. Petiole length was measured from the base of the petiole to the lower pulvinus. Petiole basal diameter was measured with a caliper.

6.2.6 Data analysis

Analysis of variance (ANOVA) test of data and mean comparison was done using Tukey's separation techniques with the aid of statistical software, Statistix 8 (USDA/NACS, 2007).

Analysis of variance was based on a mixed – model below:

$$y_{ijk} = \mu + \alpha_i + \rho_k + \square_{ik} + \beta_j + (\alpha\beta)_{ij} + e_{ijk} \qquad \textit{Eqn. 6.1}$$

Where

y_{ijk} = estimated growth parameter

μ = general mean

α_i = effect of the ith level of provenance (main plot)

ρ_k = effect of the k^{th} replicate

$\square_{ik}$ = main plot random error

β_j = effect of the j^{th} level of fertilizer (subplot)

$(\alpha\beta)_{ij}$ = interaction effect between provenance and fertilizer

e_{ijk} = subplot random error

6.3 Results and Discussion

6.3.1 Survival

Survival did not differ significantly ($P > 0.05$) among *T. daniellii* provenances at week 24 (Table 6.3). Survivals were Western-98.0%, Volta-92.8% and Ashanti-87.5%. Similarly, survival of *Acacia nilotica* (Ræbild and Graudal, 2004) and *Polylepis australis* (Renison *et al*., 2005) were not influenced by provenances. On the other hand, among *Eucalyptus marginata* seedlings distributed in two provenances, significant differences in survival were reported (O'Brien *et al*., 2007).

Survival is regarded as a key variable when evaluating provenances since it indicates the adaptability of the provenance to the environment at the trial site (Ræbild and Graudal, 2004). The ability of provenances from Western and Volta to survive in Ashanti Region suggests that *T. daniellii* could survive under varied environmental conditions irrespective of the source of planting material. Since seedlings were raised from rhizomes, the presence of stored food (photosynthate) within rhizomes could have provided energy requirements needed for physiological activities during early growth. This could account for the lack of significant differences in survival for three provenances.

Table 6.3 Effect of provenance on the growth of *T. daniellii* provenance at week 24

Parameter	DF	F value	Pr-value	[†]Provenances			Mean
				Volta	Western	Ashanti	
Survival (%)	2	3.23	0.146 ^{ns}	92.8^{a}	98.0^{a}	87.5^{a}	92.8 (4.13)
Lamina length (cm)	2	30.03	0.004**	21.1^{a} (0.36)	23.7^{a} (0.34)	17.2^{b} (0.36)	20.6 (0.85)
Lamina width (cm)	2	54.45	0.001***	12.9^{a} (0.21)	14.3^{a} (0.22)	9.0^{b} (0.28)	12.1 (0.52)
Petiole length (cm)	2	20.73	0.008**	36.1^{a} (0.53)	37.7^{a} (0.81)	24.8^{b} (0.85)	32.8 (2.19)
Petiole diameter (mm)	2	17.42	0.011**	5.4^{a} (0.17)	5.6^{a} (0.12)	3.8^{b} (0.14)	4.9 (0.34)
Number of tiller	2	0.73	0.538 ^{ns}	5^{a} (0.10)	4^{a} (0.19)	4^{a} (0.15)	4 (0.32)

,* significant at 0.01 and 0.001 probability levels respectively, ^{ns} not significant at 0.05 probability level

[†]Values in a row with different superscripted alphabets significantly differ at $\alpha = 0.05$

Parenthesized values represent standard errors of means

6.3.2 Lamina length and width

Lamina length ($P < 0.01$) and lamina width ($P < 0.001$) growth differed significantly among provenances at week 24 (Table 6.3). Growth patterns for both lamina length (Figure 6.3 a) and lamina width (Figure 6.3 b) were similar. Gradual increases were observed for Western and Volta provenances but no appreciable increase was observed for Ashanti provenance from week 4 – 24. At week 24, lamina length of the provenances were Western-23.7 cm ≡ Volta-21.1 cm > Ashanti-17.2 cm. Similarly, lamina width of the provenances were Western-14.3 cm ≡ Volta-12.9 cm > Ashanti-9.0 cm (Table 6.3).

Leaf size determined by lamina length and width influences important physiological processes, including photosynthesis, transpiration and thermoregulation, and varies with environmental factors (Yates *et al*., 2010). Significant differences in leaf size between provenances for field grown foliage of *Fuchsia excorticata* have been reported (Sweetapple and Nugent, 1999). Additionally, there were significant differences between provenances in leaf length, leaf width and leaf area of *Leucochrysum albicans*. These variations, in part were related to edaphic and climatic conditions of the source of planting material (Gilfedder and Kirkpatrick, 1994). Conversely, a study on two provenances of *Fagus orientalis* and *Fagus sylvatica* revealed significant differences for leaf length and leaf area, but no significant differences in leaf width (von Wuehlisch and Gailing, 2004). Among *Solidago altissima* plants, there were no significant phenotypic variations in leaf length and leaf width (Schmid and Dolt, 1994).

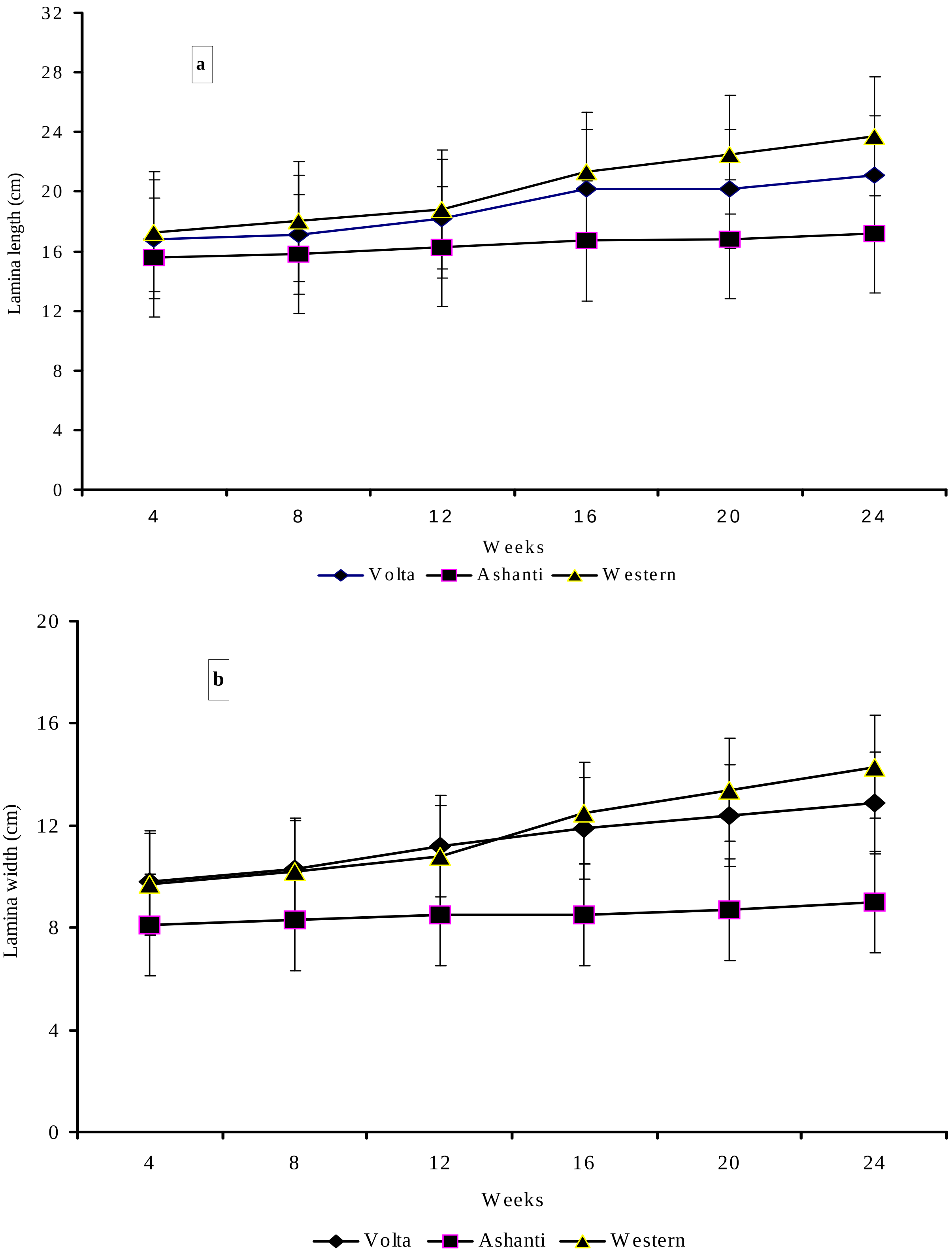

Figure 6.2 Patterns of lamina length [a] and lamina width [b] growth of three provenances of *T. daniellii* from week 4 - 24

Based on results obtained in the present study, it could be inferred that the leaves of seedlings from Western and Volta were larger than Ashanti. In a related study, significant differences in mean leaf size of *Eucalyptus microtheca* seedlings from six provenances were reported. Seedlings from the semi-arid sites had the smallest mean leaf sizes, while those from seasonally dry sites had larger mean leaf sizes (Tuomela *et al*., 2000). Generally, larger leaves posses large leaf area which could facilitate the capture of light for photosynthesis under shade conditions for Western and Volta provenances of *T. daniellii*. In line with this, greater biomass in leaves of *E. microtheca* populations was attributed to higher total plant photosynthesis due to greater leaf area.

6.3.3 Petiole length and diameter

Petiole length differed significantly (P < 0.01) among the provenances at week 24 (Table 6.3). Two provenances of *Fagus orientalis* and *Fagus sylvatica* similarly revealed significant differences in petiole length among provenances (von Wuehlisch and Gailing, 2004). A gradual increase in petiole length was observed for Volta and Western provenances but no appreciable increase was realized for Ashanti provenance from week 4 – 24 (Fig. 6.3a). At week 24, petiole length of the provenances were Western-37.7 cm ≡ Volta-36.1 cm > Ashanti-24.8 cm.

Similarly diameter (P = 0.01) growth differed significantly among the provenances at week 24 (Table 6.3). No appreciable increase in petiole diameter was obtained for Ashanti provenance compared to Volta and Western provenances that recorded consistent increase over the 24 weeks (Fig. 6.3b).

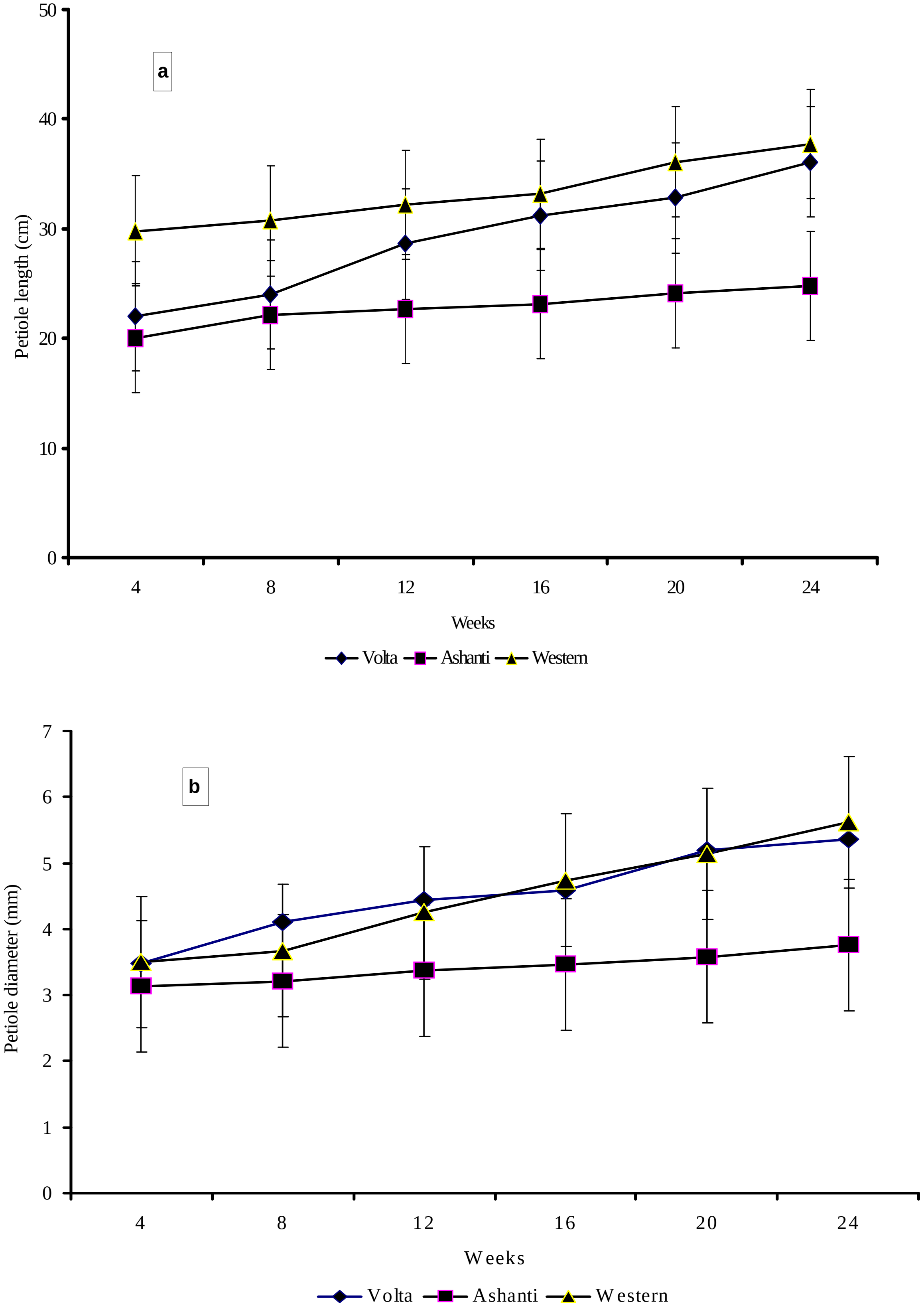

Figure 6.3 Pattern of petiole length [a] and petiole diameter [b] growth of three provenances of *T. daniellii* from week 4 - 24

Petiole diameter for the provenances were Western-5.6 mm ≡ Volta-5.4 mm > Ashanti-3.8 mm at week 24. Petioles of *T. daniellii* serve as aboveground pseudo-stems that support and position leaves for light interception.

Studies on stem diameters revealed significant differences among provenances in *Pongamia pinnata* from 10 agro-climatic zones (Ramesh, 2007). Similarly, significant ($P < 0.05$) variations in diameter were observed among 3 year old *Albizia lebbek* trees from 12 provenances (Toky *et al.*, 1996). In contrast, there were no significant differences between stem diameters of *Quercus robur* seedlings from two sources (Harmer, 2000).

Longer petiole lengths for Western and Volta provenances could indicate better growth since longer petioles could place leaves in advantageous positions for light interception. Larger leaves allow the plants to gain height more rapidly and require longer petioles to avoid self-shading. Also, increases in leaf size are often bound to enhanced biomass investment in petiole (Niinemets *et al.*, 2007). From this study, lamina length and lamina width (Section 6.3.2) of leaves of Western and Volta provenances were larger than Ashanti. Probably, larger leaves require stronger petioles for support. This possibly explains why Western and Volta provenances had larger petiole diameters than Ashanti provenance.

6.3.4 Tiller

Provenance did not significantly ($P < 0.05$) influence tiller production (Table 6.3) at week 24. Tiller number obtained for the provenances were Volta-5, Ashanti-4 and Western-4.

This could imply that under similar growth conditions, *T. daniellii* from different provenances may not significantly vary in their ability to produce tillers. Also, it could be an indication that other environmental factors influence tillering rather than the maternal source of *T. daniellii* seedlings.

6.4 Fertilization

6.4.1 Survival

Fertilization had no significant ($P > 0.05$) effect on survival of *T. daniellii* provenances at week 24 (Table 6.4). Survival was 94.6% for fertilized and 91.0% for unfertilized seedlings. This could imply that the initial survival of *T. daniellii* provenances may not depend on fertilization but on food/nutrient reserves within rhizomes attached to seedlings at the time of transplant.

6.4.2 Lamina length and width

Fertilization had no significant ($P > 0.05$) effect on lamina length of provenances at week 24. Lamina lengths were 21.2 cm for fertilized and 20.8 cm for unfertilized seedlings (Table 6.4). Similarly, the results could suggest that lamina length growth of *T. daniellii* provenances may not be dependent on fertilization.

Conversely, NPK fertilization significantly ($P < 0.05$) influenced lamina width of provenances at week 24. Lamina width of 12.8 cm > 11.4 cm were obtained for fertilized and unfertilized seedlings respectively (Table 6.4). Gradual and continuous increases in lamina width were observed among both fertilized and unfertilized seedlings from week 4 – 24. However, distinctive increases in lamina width were observed for fertilized than unfertilized seedlings after week 12 (Fig. 6.6). In a similar study, NPK (19:19:19) fertilization of *Hippeastrum vittatum* for two seasons revealed a significant increment in leaf length and width in both seasons. The rate of 5 g fertilizer per plant gave the highest values of leaf length (40.36 and 40.35 cm) and width (2.83 and 2.87 cm) compared to the untreated plants in both seasons respectively (El-Naggar and El-Nasharty, 2009).

There were no differences in lamina length; however differences in lamina width could cause variation in leaf sizes. Hence, fertilized seedlings could have larger leaves than unfertilized seedlings. This could increase photosynthetic leaf area of fertilized seedlings and ensure fast growth than unfertilized seedlings.

6.4.3 Petiole length and diameter

Fertilization had no significant ($P > 0.05$) effect on petiole length of provenances at week 24 (Table 6.4). Petiole lengths were 34.5 cm for fertilized and 31.6 cm for unfertilized seedlings. This indicates that petiole lengths of provenances were not enhanced by fertilization at the rates applied.

Table 6.4 Effect of fertilization on the growth of *T. daniellii* provenances at week 24

Parameter	DF	F value	Pr-value	Mean comparison		Mean
				Fertilized	Unfertilized	
Survival (%)	1	1.61	0.252 ^{ns}	94.6 ^{a}	91.0 ^{a}	92.8
				(2.72)	(3.72)	(2.81)
Lamina length (cm)	1	3.11	0.129 ^{ns}	21.2 ^{a}	20.1^{a}	20.64
				(0.39)	(0.56)	(0.64)
Lamina width (cm)	1	12.81	0.012**	12.8 ^{a}	11.4 ^{b}	12.07
				(0.23)	(0.39)	(0.39)
Petiole length (cm)	1	7.93	0.085 ^{ns}	34.5 ^{a}	31.1 ^{a}	32.82
				(1.17)	(1.43)	(1.64)
Petiole diameter (mm)	1	4.24	0.031*	5.17 ^{a}	4.64 ^{b}	4.9
				(0.29)	(0.07)	(0.19)
Number of tiller	1	6.00	0.050*	5 ^{a}	4 ^{b}	4
				(0.14)	(0.20)	(0.27)

*,** significant at 0.05 and 0.01 probability levels respectively, ^{ns} not significant at 0.05 probability level
Values in columns with different superscripted alphabets significantly differ at $\alpha = 0.05$
Parenthesised numbers represent standard errors of means

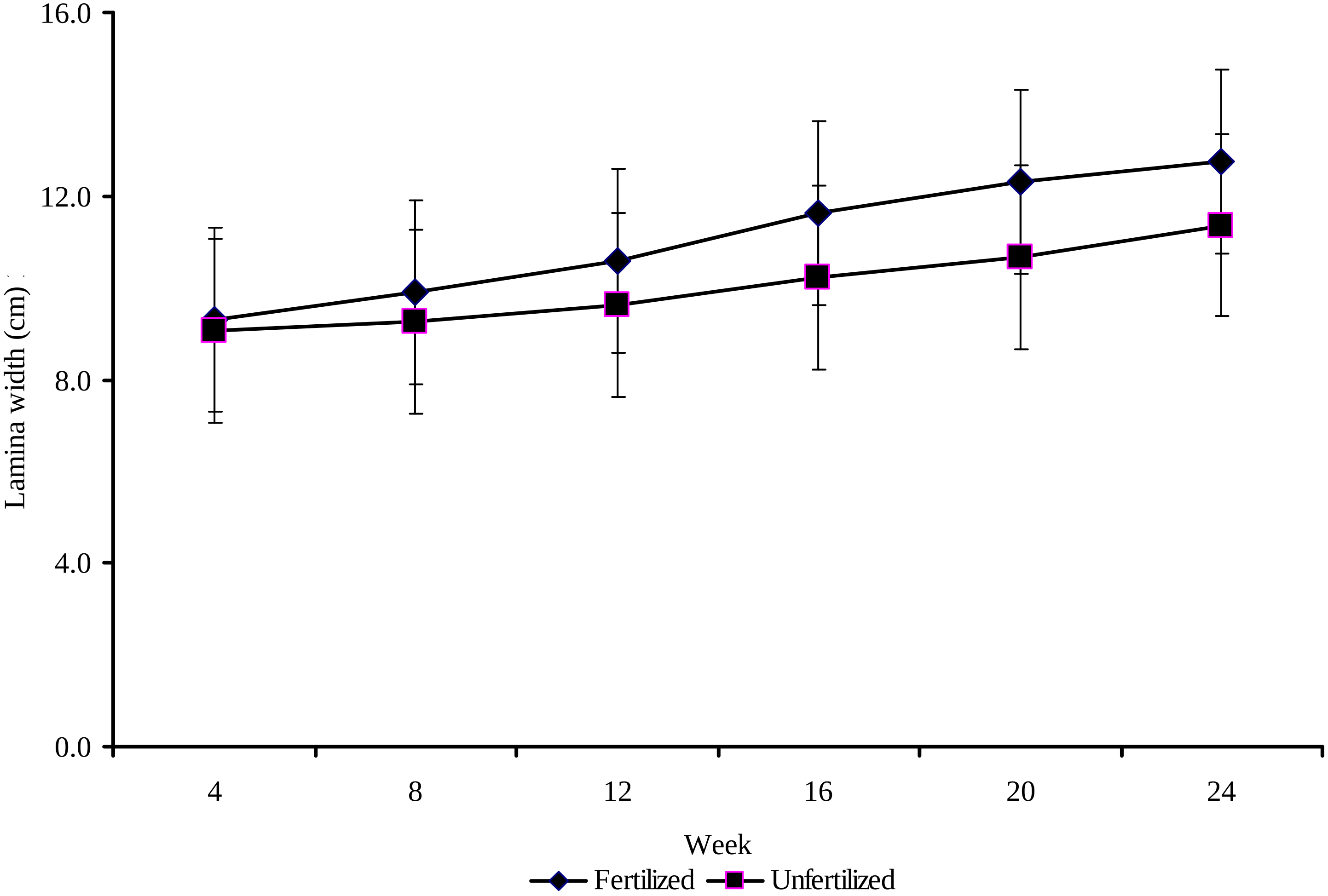

Figure 6.4 Effect of fertilization on *T. daniellii* lamina width from week 4 - 24

On the other hand, fertilization significantly ($P < 0.05$) influenced petiole diameter of provenances at week 24 (Table 6.4). Petiole diameters were 5.17 mm for fertilized and 4.64 mm for unfertilized seedlings. Pattern of petiole diameter growth over the 24 weeks is illustrated in Figure 6.5. As leaves adapt to a light gradient inside a canopy, the inclination angles, morphology, anatomy, size and mass of their petioles and laminas could be modified. The results of this study suggest that fertilization increased leaf size. This would require the development of stronger petioles that could hold up or position *T. daniellii* leaves for light interception. Therefore, increased petiole diameter in response to fertilization could result from the need to hold larger leaves that were produced under favourable nutrient supplies.

6.4.4 Tiller

Tiller production was significantly ($P = 0.05$) influenced by fertilization after 24 weeks. Tiller numbers were 5 for fertilized and 4 for unfertilized seedlings at week 24 (Table 6.4). Similarly, studies on *Eriophorum vaginatum* and wheat reported that tillering was significantly influenced by NPK fertilization (Shaver and Chapin III, 1995; Rehman *et al*., 2010) Therefore, NPK fertilization enhanced *T. daniellii* growth through the production of more tillers than unfertilized seedlings. Pattern of tiller production showed no variation in tiller production for both fertilized and unfertilized seedlings over the 24 weeks (Fig. 6.6).

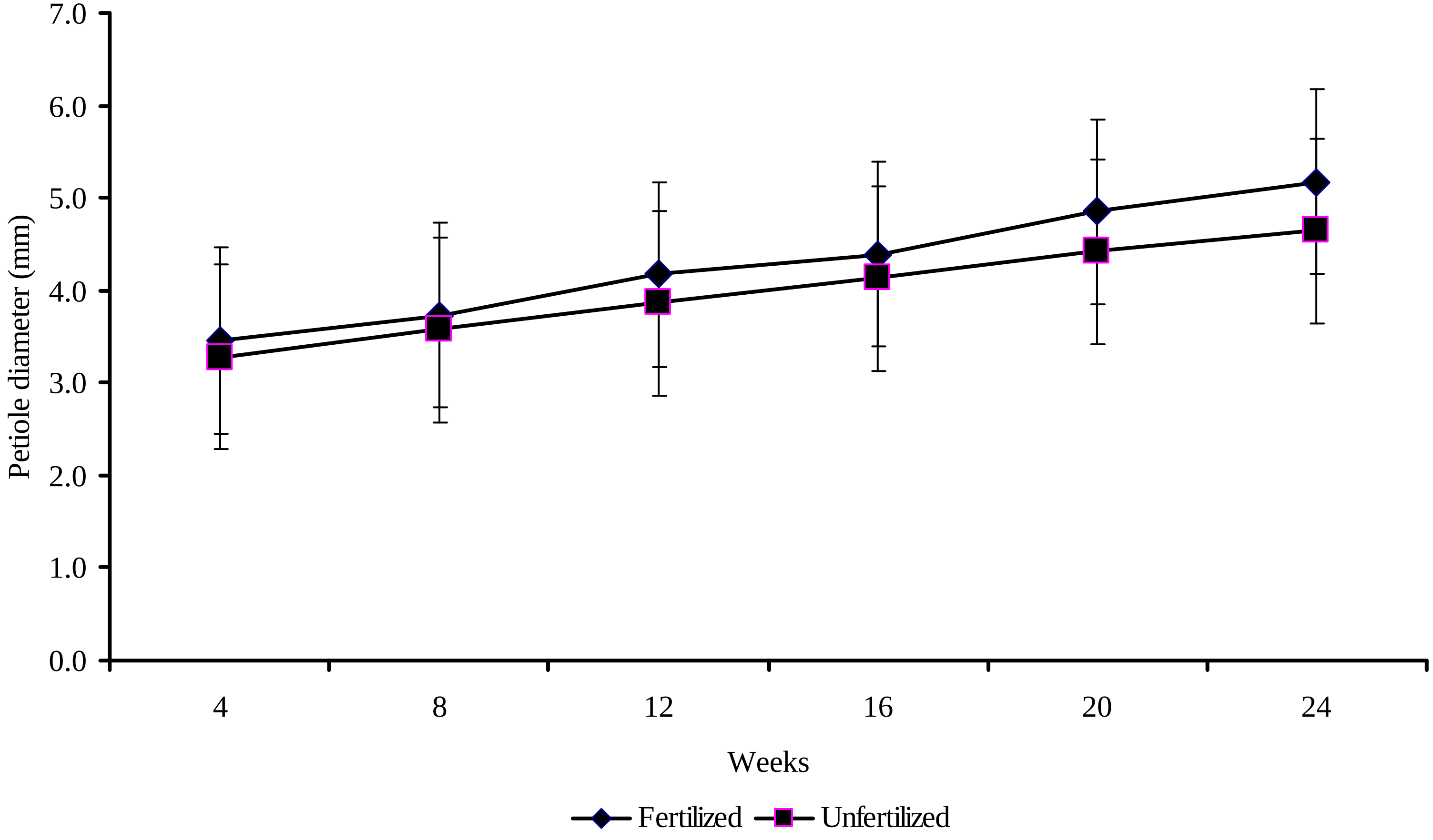

Figure 6.5 Effect of fertilization on *T. daniellii* petiole diameter from week 4 - 24

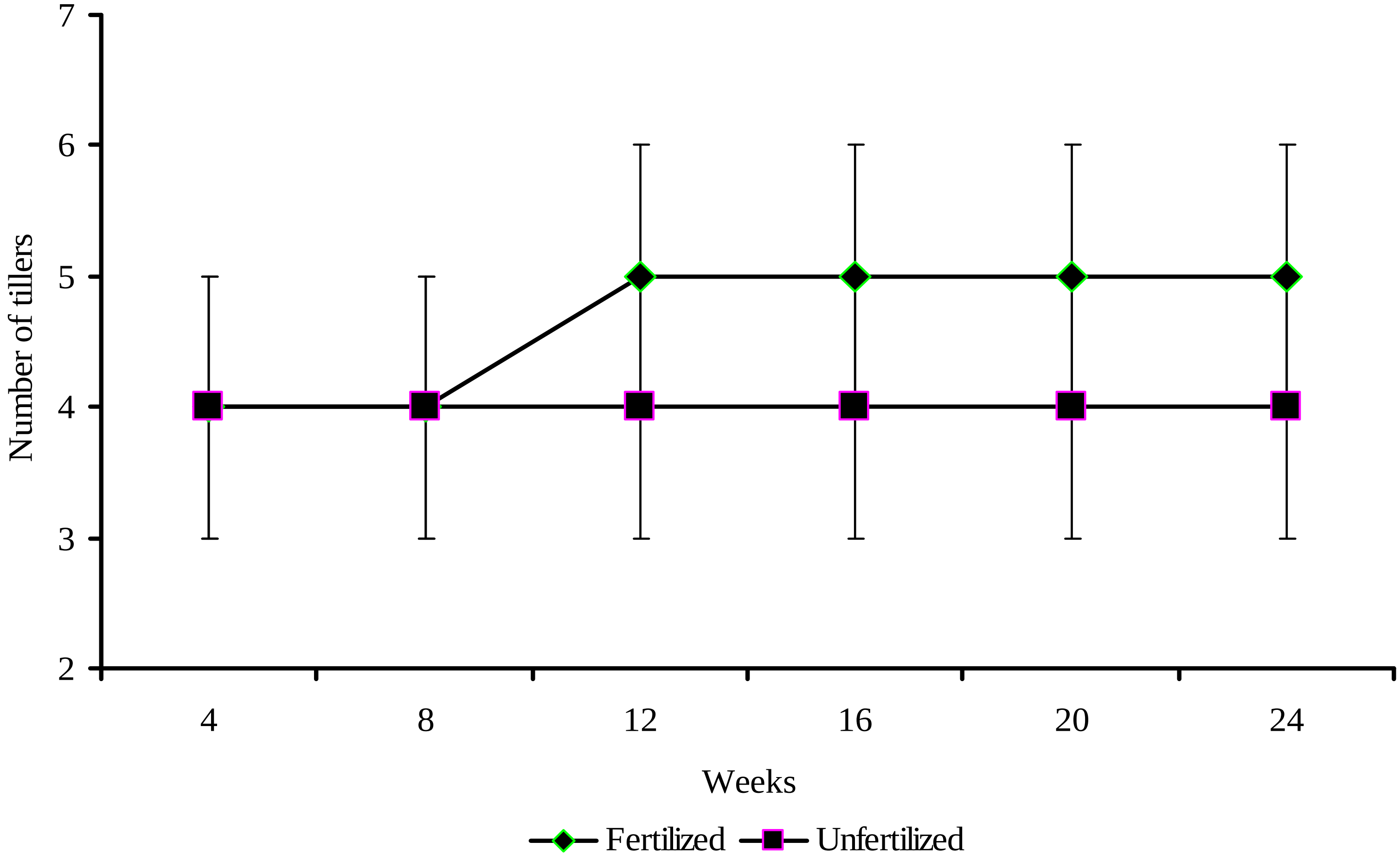

Figure 6.6 Fertilization effectd on *T. daniellii* tiller production from week 4 - 24

6.6 Conclusions

The research was conducted over 24 weeks to determine the growth response of *T. daniellii* provenances from Ashanti, Western and Volta regions to NPK fertilization. Growth parameters studied were survival, lamina width, lamina length, petiole length, petiole diameter and number of tiller.

At week 24, there were significant differences in the *T. daniellii* provenances with respect to lamina width, lamina length, petiole length and petiole diameter. Leaf sizes of provenances were Western (length-23.7 cm, width-14.3 cm) ≡ Volta (length-21.1 cm, width-12.9 cm > Ashanti (length-17.2 cm, width-9.0 cm). Larger leaf sizes required longer and larger petioles for support. Ranking of petiole sizes were similar to that for leaf; and were in the order Western (length-37.7 cm, diameter-5.6 mm ≡ Volta (length-36.1 cm, diameter-5.4 mm > Ashanti (length-24.8 cm, diameter-3.8 mm). The hypotheses that lamina width, lamina length, petiole length and petiole diameter of were not different among the *T. daniellii* provenances were therefore rejected.

Survival and tiller production were however similar for the provenances. The hypotheses that survival and tiller production were not different among the *T. daniellii* provenances were therefore accepted.

Over the 24 week study period, NPK (20:20:20) fertilization significantly influenced provenances of *T. daniellii* with respect to lamina width, petiole diameter and tiller production compared to unfertilized seedlings. At week 24, lamina width ranked as

Fertilized-12.8 cm > Unfertilized-11.4 cm. The trend was the same for petiole diameter: Fertilized-5.17 mm > Unfertilized-4.64 mm; and tiller numbers: Fertilized-5 > Unfertilized-4. The hypotheses that survival, lamina length and petiole length responded similarly to fertilization were therefore accepted.

However, fertilization had no significant influence on survival, lamina length and petiole length. Therefore, the hypotheses that lamina width, petiole diameter and tiller production responded similarly to fertilization were rejected.

In conclusion, significantly higher lamina width, lamina length, petiole length and diameter values obtained for Western and Volta provenances possibly suggest a greater potential for fast growth than the Ashanti provenance. Fertilization responses could also suggest that survival, lamina length and petiole length did not depend on nutrient supply.

6.7 Recommendations

This study considered the growth performance of only three provenances of *T. daniellii* and their response to only two levels of fertilization. Considering the wide distribution range of *T. daniellii* in other parts of Ghana as well as West Africa, it is recommended that the collection base of the provenances should be widened in a further study to determine *T. daniellii* plants with desirable growth characteristics. With respect to determining suitable fertilizer levels for optimum growth of *T. daniellii*, varied levels of fertilization is recommended in future studies.

Chapter 7

7.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

In line with the general goal of conducting research that could facilitate the integration and management of *T. daniellii* in agroforestry systems as well as its commercial cultivation through diverse studies, the following conclusions and recommendations were made.

7.1 Study conclusions

Study one (chapter 3) revealed that fruits were predominantly supplied from Benda, Benda Nkwanta, Kokoase, Amoaku, Hiamatu, Samreboi and Aggreyso within Aowin-Suaman and Wassa Amenfi West districts of the Western region of Ghana. This study further highlighted the potential and major roles played by *T. daniellii* in supplementing household incomes in these communities who obtained GH¢ 3 – 15 per week. However, there was no conservation, cultivation or integration of *T. daniellii* into farming systems in all the communities previously or currently involved in fruits supply. The lack of conservation, cultivation and continuous decline in natural stands could be an indication of unsustainable future fruit supplies with continuous dependence on collection from the wild. Soil chemical (pH, N, P, K, Ca, Mg, TBS, ECEC, organic matter) and physical properties (texture) of natural stands differed significantly among sites except for Na and bulk density. The soils of stands studied were mainly silt loam or sandy loam with bulk density values within the reported range for most soils of 1.0 – 2.0 gcm^{-3}. Significant variation in most selected soil chemical and physical properties of natural stands predicts the adaptability and capability of growing *T. daniellii* at different sites. This makes it amenable to diverse soils.

Study two (chapter 4) revealed that foliage harvest significantly influenced number of flowers and fruits supplied. No harvest stands produced significantly higher number of flowers and fruits than all other harvest stands. However, total fruit weight was not influenced by foliage harvest and ranged from 59.7 - 127.9 kg/ha. Foliage harvesting could therefore be said to cause a significant reduction in fruit number but may not necessarily cause significant reduction in fruit biomass. By the end of week 64, there were no significant differences in specific leaf area between treatments and ranged between 143.9 cm ^{2}g $^{-1}$ and 148.9 cm ^{2}g $^{-1}$. Stimulatory growth response to foliage harvest exhibited by *T. daniellii* cast a doubt about calls for its sole management for fruits as no significant differences in specific leaf area were found. For both fruit and leaf collection, the highest total income over 64 weeks per hectare was GH ¢ 24411.36 for 50% followed by GH ¢ 17480.40 for 75% and GH ¢ 15640.33 for 25% harvest stands. The lowest total income, GH ¢ 153.48, was obtained for the control due to lack of supplementary income from leaf harvesting. This suggests that, with appropriate management, *T. daniellii* stands could be exploited for both foliage and fruits.

Study 3 (chapter 5) revealed that shade significantly influenced survival, leaf sizes (lamina length and width), petiole length and number of tillers. Seedlings with 73% shade significantly recorded the highest survival, were larger and produced more tillers than 86% and 98% shade levels. Survival was 71% for Leucaena (73%) > 60% for *Senna*

(86%) > 20% for *Carapa* (98%). Leaf sizes were 73% (width-17.6 cm, length-27.1 cm) > 86% (width-15.9 cm, length-25.2 cm) > 98% (width-11.4 cm, length-18.0 cm) shade levels. Petiole lengths were 43.6 for 73%, 38.8 cm for 86% and 20.4 cm for 98% shade levels while tillering was 13 for 73% > 10 for 86% > 1 for 98% shade levels.

Shade appears to be a dominant factor that affects the growth of *T. daniellii* and significantly influenced survival, lamina width, lamina length and width, petiole length and tiller production. Though, shade tolerant, this study shows that higher light availability could significantly enhance the growth of *T. daniellii*. Furthermore, spacing significantly influenced leaf sizes and petiole lengths but had no significant effect on survival and tiller production at week 40. Leaf sizes were (width-15.4 cm, length-24.3 cm) for low density, (width-15.5 cm, length-23.2 cm) for very high density, (width-14.9 cm, length-23.8 cm) for high density and (width-14.0 cm, length-22.5 cm) for medium density. Petiole lengths were 37.1 cm for very high density > 33.7 cm for low density ≡ 33.4 cm for medium density ≡ 32.8 cm for high density spacing.

Study 4 (chapter 6) revealed significant differences in the *T. daniellii* provenances with respect to lamina width, lamina length, petiole length and petiole diameter. Leaf sizes of provenances were Western (length-23.7 cm, width-14.3 cm) ≡ Volta (length-21.1 cm, width-12.9 cm > Ashanti (length-17.2 cm, width-9.0 cm). Ranking of petiole sizes were similar to that for leaf; and were Western (length-37.7 cm, diameter-5.6 mm ≡ Volta (length-36.1 cm, diameter-5.4 mm > Ashanti (length-24.8 cm, diameter-3.8 mm). However, survival and tiller production were similar for the provenances. Significant differences in provenances from Ashanti, Western and Volta potentially shows a wide variability in growth characteristics of *T. daniellii* populations. In the quest to develop superior propagules for large scale planting, this study has shown that Western and Volta provenances are better candidates compared to the Ashanti provenance.

Also, NPK (20:20:20) fertilization significantly influenced provenances of *T. daniellii* with respect to lamina width, petiole diameter and tiller production than unfertilized seedlings. Lamina width were Fertilized-12.8 cm > Unfertilized-11.4 cm. Similarly, petiole diameter was ranked: Fertilized-5.17 mm > Unfertilized-4.64 mm; and tiller numbers were Fertilized-5 > Unfertilized-4. However, fertilization had no significant influence on survival, lamina length and petiole length. In conclusion, significantly higher lamina width, lamina length, petiole length and diameter values obtained for Western and Volta provenances possibly suggest a greater potential for fast growth than the Ashanti provenance. Fertilization responses could also suggest that survival, lamina length and petiole length did not depend on nutrient supply.

7.2 Study recommendations

(i) It is recommended that further studies be carried out on other sites supporting the growth of *T. daniellii* to assist in obtaining comprehensive information on site specific conditions that support optimum growth and fruit yields of *T. daniellii*.

(ii) Currently, information on other foliage harvest levels and their effects on *T. daniellii* growth and fruit yield are unavailable. Further studies is therefore required using different harvesting levels at different sites to determine sustainable foliage harvest levels with minimum effects on growth and fruit production of *T. daniellii*.

(iii) The study on income projections of foliage and fruit harvest are based on the assumption of a ready market for harvested products. It does not take into consideration losses incurred through rejection of rotten fruit by buyers, drying of foliage as well as transportation and other costs. These, among other economic factors, when duly considered in a study can help ascertain the actual potential incomes that could be obtained from the harvests of *T. daniellii* fruits and leaves.

(iv) With respect to shading effects on the growth of *T. daniellii*, three shade levels were used under uncontrolled conditions since the study was carried out in an already established tree stands. Further studies is therefore recommended to be carried out on other shade levels under controlled conditions including no shade to determine effects that could promote the optimum growth and production of *T. daniellii*.

(v) Considering the wide distribution range of *T. daniellii* plants in Ghana, it is recommended that the collection base of the provenances should be widened in a further study to determine *T. daniellii* plants with desirable growth characteristics.

(vi) With respect to determining adequate fertilizer levels for optimum growth of *T. daniellii*, varied levels of fertilization is recommended in future studies. Such studies should focus on plant nutrient demands in relation to soil nutrient levels.

(vii) These studies demonstrates the adaptability and capability of growing *T. daniellii* at different sites and therefore recommend its integration into agroforestry systems under low shade and managed sustainably for both foliage and fruits through 50% harvesting of foliage. Also, the Western and Volta provenances showed superior growth characteristics and are recommended for integration into agroforestry systems compared to the Ashanti provenance.

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APPENDICE 1


a

b

c

d

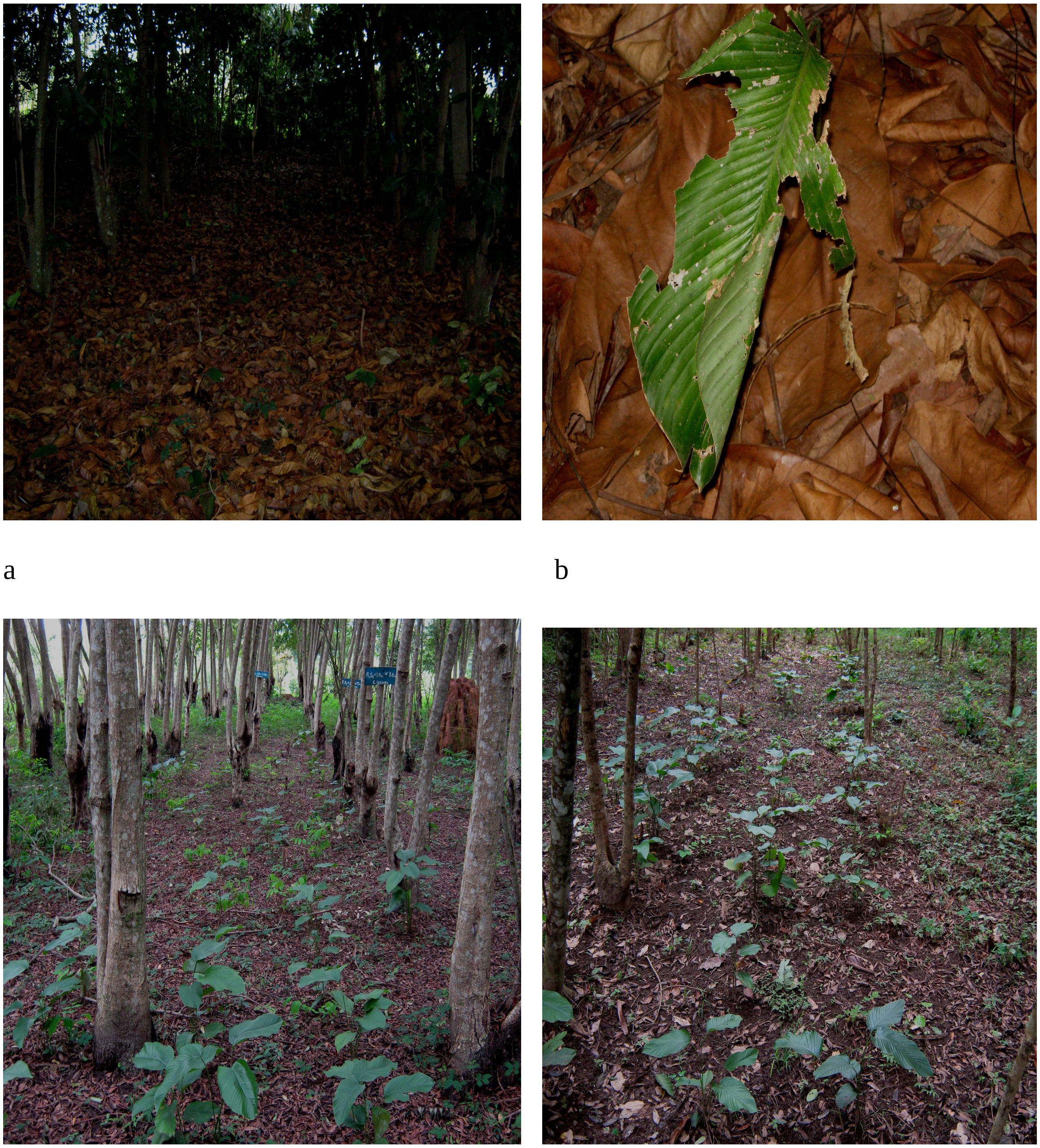
Plates (a) Participants involved in a focus group discussion with researcher; (b) Soil sampling by researcher within a natural stand of *T. daniellii*; (c) Fruit collectors at the receiving station at Samartex; (d) Fruit collected from natural stands

APPENDIX 2

a b c d

Plates (a) Natural stand of *T. daniellii* on a fallow land plus *Alchornea spp*; (b) Farmer indicating cleared stands of naturally occurring *T. daniellii* on cocoa farm; (c) Remaining biomass (leaf and petiole) of cleared *T. daniellii* stand in a cocoa farm; (d) Regenerating stands of *T. daniellii* few weeks after clearance

APPENDIX 3



a b

c d

Seedlings of *T. daniellii* growing under (a) *Carapa procera* with litter accumulation (b) Pest attacked leaf under *Carapa* (d) *Leucaena leucocephala* (c) *Sena siamea*